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HOW DO NOVICE AND EXPERT LEARNERS REPRESENT, UNDERSTAND, AND DISCUSS GEOLOGIC TIME?

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Abstract

This dissertation examined the representations novice and expert learners constructed for the geologic timescale. Learners engaged in a three-part activity. The purpose was to compare novice learners' representations to those of expert learners. This provided insight into the similarities and differences between their strategies for event ordering, assigning values and scale to the geologic timescale model, as well as their language and practices to complete the model. With a qualitative approach to data analysis informed by an expert-novice theoretical framework grounded in phenomenography, learner responses comprised the data analyzed. These data highlighted learners' metacognitive thoughts that might not otherwise be shared through lectures or laboratory activities. Learners' responses were analyzed using a discourse framework that positioned learners as *knowers*. Novice and expert learners both excelled at ordering and discussing events before the Phanerozoic, but were challenged with events during the Phanerozoic. Novice learners had difficulty assigning values to events and establishing a scale for their models. Expert learners expressed difficulty with determining a scale because of the size of the model, yet eventually used anchor points and unitized the model to establish a scale. Despite challenges constructing their models, novice learners spoke confidently using claims and few hedging phrases indicating their confidence in statements made. Experts used more hedges than novices, however the hedging comments were made about more complex conceptions. Using both phenomenographic and discourse analysis approaches for analysis foregrounded learners' discussions of how they perceived geologic time and their ways of knowing and doing. This research is intended to enhance the geoscience community's understanding of the ways novice and expert learners think and discuss conceptions of geologic time, including the events and values of time, and the strategies used to determine accuracy of

scale. This knowledge will provide a base from which to support geoscience curriculum development at the university level, specifically to design activities that will not only engage and express learners' metacognitive scientific practices, but to encourage their construction of scientific identities and membership in the geoscience community.

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by

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Dissertation

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Chapter 1

Introduction

Geologic time has been taught for many years in geoscience classes and is fundamental to the discipline. In order to study and understand geological processes and how they occur, we must also understand the time over which these processes occur. Humans encounter time on a daily basis. We can easily understand its breakdown into years, months, hours and seconds. How does this understanding extend to thousands, millions and billions of years? Most people have difficulty understanding because the scales are so massive (Dodick & Orion, 2006). It can be very difficult to think in terms of millions of years because it appears abstract and unrelatable.

The purpose of this study was to investigate the understanding, discourse, and representations learners construct about the geologic timescale upon enrolling in their first geoscience course and how they compare to those of geoscience graduate students (experts). In this chapter, I will introduce the difficulties associated with learning geologic time, the significance of this study for learners and educators, and the methods used to gain an understanding of learners' conceptions of geologic time. First, novice learners' model construction, event ordering, assigning values, and scale card use, was examined. After that, novice learners' strategies and discourses, language and practices, to complete the activity were analyzed. The novice learners' model construction, strategies, and discourses were compared to those of expert learners. Similarities and differences between novices and experts was documented. By examining the similarities and differences between novice and experts' conceptions, patterns were established in experts' ability to discuss and understand the scale and events in geologic time. Additionally, understanding the patterns in experts' strategies and ability to represent and discuss geologic time provided insight into how understanding is made and geoscience skills are developed. These patterns can then be used for curriculum development, activities, and assessments to support learning in the geosciences.

Statement of the Problem

There are few concepts in "geology more important than geologic or deep time" (Dodick & Orion, 2003c, p. 708). Geologic time is a system that chronologically relates stratigraphy, order and position of layers of rock, to time. It is used to describe the timing and relationship of events throughout Earth's history. Geologic time spans 4.6 billion years of Earth's history and is the basis for understanding the principles of geology, cosmology and evolutionary biology. Understanding geologic time is also instrumental in solving problems such as climate change, handling endangered species, disposal of nuclear waste and the use of fossil fuels (Zhu, Rehrey, Treadwell, & Johnson, 2012). To a novice, it may not be clear how geologic time is relevant to these problems. Many of the Earth's surface processes occur over an extremely long time; most of which take place outside of a human's lifespan. Therefore, it can be difficult to understand how an event such as climate change will affect the earth today and in the future, without being able to understand what has happened to the Earth in the past and over long periods of time. Thus, it is important for the public to understand geologic time in order become scientifically literate for decision-making regarding their daily lives.

In the geosciences, experts use and understand various scales of magnitude. Thus, in order for any of these topics to make sense, the learner has to be able to understand the temporal and spatial ordering of events in geologic time, as well as its immense scale. Furthermore, for the learner to be successful in understanding the large scale of time, the instructor has to be able to identify and work with learners' preexisting ideas of the geologic time. Thus, this dissertation examined representations, discourse, and conceptions novice learners' hold entering a university-level geoscience classroom compared to those of expert learners at the graduate level in the university. This will not only allow educators to address these conceptions to make learning geologic time more accessible by identifying any conceptions of events, values, and scale but also how to build on learners' scientific practices and language.

Many studies that examined learners' conceptions of time focused on K-12 learners (Ault, 1982; Dodick & Orion, 2003a; Libarkin et al., 2007; Trend, 1998, 2000, 2001), with few studies focusing on university-level learners (Dodick & Orion, 2003a; Libarkin, Kurdziel & Anderson, 2007). This dissertation will add to research on learners' understanding of geologic time by examining university-level learners' representations and understanding of geologic time. This study specifically examined how non-major undergraduate learners and geoscience graduate students represent geologic time in terms of temporal order, duration of events, their conceptions of its scale, and how the events related to one another in time. As there are a number of factors that can affect learners' conceptions of geologic time, working with a range of learners from novice to expert provided insight as to how learners developed their models, the strategies they used, and how they discussed their representations of the scale of geologic time.

Purpose of the Study

The purpose of this study was to gain insight into novice and expert learners' understanding, representations, and discourse regarding geologic time. This study examined how novice and expert learners constructed a geologic timescale model; this includes the events and their ordering, relationships between events, event duration, and scale of geologic time. Examining how both novice learners' representations compared with expert learners provided insight into how understanding is made and geoscience skills are developed. This study was qualitative in nature. Data were gathered using task-based interviews. Learners engaged in a geologic timescale model-eliciting activity designed to examine how learners temporally ordered events and how they decided on the scale of their models.

Research Questions

1. How do learners understand and represent the placement of events and their relationships on a blank geologic timescale?

2. How do learners represent and understand the scale of geologic time?

3. How do learners discuss their conceptions about geologic time? What do these conceptions about geologic time reveal about their prior knowledge?

Overview of Methodology

This study was designed to be a cross-sectional qualitative examination using an expert-novice framework. The study was conducted at a university in New York State and involved seven participants; five undergraduate students from an introductory earth science course in the fall of 2015, as well as two Earth Science graduate students. Both novice and expert learners completed a model-eliciting geologic timescale activity. During the activity, the researcher asked interview questions to illicit learners' understanding of the events, duration and scale of geologic time. Learners' responses to the interview questions were transcribed verbatim. Field notes documented participants' movements within the activity, including gestures, body language, and hesitations. Participants completed a survey that asked about their science and mathematics backgrounds (high school and college). Data analysis was guided by phenomenography, which was used to interpret learners' ideas in relation to their background and history, and how these shaped the learners' knowledge and decision-making during the geologic time task. Phenomenography was chosen to analyze the data collected, as this research investigated learners' ideas regarding geologic time through talk, as well as how the learners transformed and constructed the activity.

Data was then further organized and analyzed according to discourse analysis methods used by Elizabeth Moje (2008), Rebecca Rogers (2013), and James Paul Gee (2001, 2000). Moje's work was used to focus on where participants' knowledge comes from, whether it be their prior knowledge or informal educational knowledge (e.g., museums, zoos, etc.), institutional, K-12 or university experiences, or societal, such as knowledge from religious, cultural or familial experiences. These sources are referred to as *funds of knowledge*. Rogers' work guided analysis of learners' *ways of representing.* Specifically, the ways of representing focuses on learners' *ways of knowing and ways of doing*. Ways of knowing were the words and phrases learners used throughout the activity, while ways of doing were the practices and strategies they employed to complete the activity. The ways of representing were the ideas that were foregrounded in learners' selection of words and their repetition, and themes that were presented during the activity (Rogers, 2013, p. 32). Gee and Moje's work on identities was used to examine learners' identities associated with the geoscience affinity group. Learners' identities constructed in relation to the geoscience community can be reflected through their discourses. Discourse included are funds of knowledge, ways of knowing, and ways of doing (Moje, 2008).

Rationale

Although formulation of a usable geologic time system started back as far as the eighteenth century with James Hutton, it was in 1911 that Professor Arthur Holmes, a British geologist, first established a time period for Devonian rock from Norway. A timescale for geologic processes had not been devised until Holmes' published his work in 1911, making Holmes the pioneer of the modern geologic time scale. Since 1911, the geologic time scale is used in every discipline in geology, as well as chemistry, physics, and biological science classes: structural geology, sedimentology, paleontology, mineralogy, petrology, geomorphology, biology, evolutionary biology, biogeography, geography, and more. Each class mentioned relies on a context of time. For example, physical geology classes discuss the solid state of the earth, the rocks it is composed of and the processes by which these rocks change. The geologic time scale is used to put each of these processes into a context of when that particular rock unit formed or was altered in the context of Earth's long history.

Without the geologic time scale, a teacher would not be able to explain why studying rocks and their age is important. They also would not be able to explain the ties that physical geology has to evolutionary biology. For instance, plate tectonics is one of the primary topics discussed in a physical geology class. What many students may not realize is how plate tectonics affected many plants and animals over time. It's easy to understand how moving continents would disable animal migration. However, it might be difficult to think about the long-term effects of plate tectonics on events such as climate change and large-scale mass extinctions. For example, one of the largest mass extinctions for marine life occurred at the end of the Paleozoic era into the early Mesozoic era with the formation of Pangaea. The formation of the supercontinent Pangaea resulted in the closure of a large seaway. Not only did it make the continent cold and dry, the organisms living between continents went extinct. Approximately 96% of marine species and 70% of terrestrial vertebrates went extinct. Without a context of time, geologists and biologists would not have been able to conclude that the closure of the seaway and mass extinction were linked.

As described in the examples given, geologic time is significant and provides a background for many disciplines. Therefore, lacking an understanding of geologic time may result in difficulty understanding the mechanisms behind physical changes on the planet. Examining learners' understanding and representations of geologic time would not only assist in developing students' ability to think spatially and to develop skills required for abstract thinking, but it would also increase science literacy as it offers relevant perspectives on cultural, political, economic and environmental issues pertinent to all citizens, not just scientists (Cervato & Frodeman, 2012) and can represent larger culturally-significant, relevant or topics of interest to the students.

As understanding events in time, their temporal ordering, duration and scale is fundamental to geologic time, it is therefore logical to examine the prior knowledge and skill set of novice learners entering the university setting and how this compares to experts in the geosciences. In this research, *expert* refers to graduate students majoring in a geoscience field. *Novice* refers to any student that does not have a geoscience background but is enrolled in an introductory geoscience course; students entering as freshmen that do not have a background in geosciences or upper class students taking an entry-level geoscience course for a requirement but majoring in a different field. Examining learners' prior knowledge and skill development is important for a few reasons. First, learners enter a geoscience course with existing conceptions about geologic time. These conceptions may or may not align with those of the course being taught. It would benefit both the instructor of the course and the student to identify these conceptions to use them while teaching. Second, professors, instructors and graduate teaching assistants (GTAs) have expectations of the skills and knowledge of a student entering a university-level course. There have been discussions at conferences, most recently at the Summit on the future of Undergraduate Geoscience Education, at the University of Texas at Austin, where many geoscientists expressed concern about learners entering college and not possessing the skills necessary to succeed in the geosciences.

Role of the researcher

The researcher was responsible for recruiting participants and conducting the task-based interviews during the geologic timescale activity. In addition, the researcher transcribed the interviews verbatim using video and audio recordings taken during the task-based interview, in conjunction with her field notes documenting gestures and event card placement and movement. The researcher took on this role for two reasons. First, the researcher knows the activity and goal of the study. As questions in the task-based activity varied based on participant answers, the interviewer needed to be well-versed in geology content and how to conduct an interview. Second, the researcher did not want to be at a distance from the project as she might miss some of the gestures, body language, or the way participants talk about events in time. Gestures and body language can reveal participants "connections between cognition and perception, and convey subtle meanings that would be awkward or impossible to explain with language alone" (Kastens, Agrawal & Liben, 2008). For example, a learner might move their arms in a specific manner depicting an angle or shape of an object to accompany or replace speech. Learners body language can change with their comfort level. For example, learners that become anxious might stand up straight, their bodies become rigid, or their hands may shake (Waxer, 1977). Although there was a video recording the task-based interview, the researcher wanted to be present to capture these moments in their field notes to add into interview transcripts.

Subjectivities statement

My previous assistantship as a graduate teaching assistant (GTA) in a geoscience department, along with prior knowledge of the geoscience programs, staff and relationships with

GTAs of the department to be studied, could skew what was observed. My connections to the department were a useful base for the study, as I was able to draw participants from the department to participate in the study.

After conducting research and teaching in the geosciences, I decided to obtain my PhD in Science Teaching to focus my interests toward research about teaching and learning in the geosciences. Since my positionality is focused on revealing student learning and position learners as knowers, my perceptions are focused ways of knowing and doing. My awareness of my positionality with the geosciences as an educator and student was documented in a subjectivities journal throughout the semester.

Definitions and Terms

1. *Anchor points* are pivotal points for the learner based on their background or experiments that help them to develop the scales of their geologic timescales (Tretter et al., 2006b).
2. *Change* is the shift or transformation of events in time.
3. *Concept Inventory* (CI) is an evaluation instrument designed to qualitatively and/or quantitatively examine learners' conceptual understanding and to evaluate learning.
4. *Duration* is the temporal extent of an interval or event.
5. *Geoscience concept inventory* (GCI) is an evaluation instrument designed to qualitatively examine learners' conceptual understanding of geological phenomena, processes and alternative conceptions. The GCI was originally developed for evaluation of learning in entry-level geoscience courses.
6. *Information focus* refers to "themes that are represented in the first part of the clause and are generally the known information" (Rogers, 2013, p. 32).

7. *Lexical relations* refer to the “relation and classification of experiences through an unfolding series of activities” (Rogers, 2013, p. 32).
8. *Lexicalization* refers to the selection of wordings.
9. *Representations (of geologic time)* refers to the image(s) of geologic time that the learner has in their mind; this includes the events, the ordering of the events, relationships between events, event duration and scale of geologic time.
10. *Model-eliciting activity* (MEA) is typically an open-ended question or activity designed to reveal student thinking (Lesh, Hoover, Hole, Kelly, & Post, 2000).
11. *Relexicalization* refers to the renaming or re-voicing of words (e.g., words that are repeatedly used) (Rogers, 2013).
12. *Scale* in this activity is a ratio between the linear dimensions of the learner’s created model against the dimensions of geologic timescale. For example, the ratio would be representative of the placement of an event on the learner’s timescale compared to the placement of the event in geologic time.
13. *Simultaneity* refers to events occurring at the same time.
14. *Stratigraphy* refers to the order and position of layers of rock and their relationship to time (specifically geologic time)
15. *Succession* is a temporal arrangement of events in Earth’s history. For example, a series of rock units occur in a chronological order.
16. *Task-based interviews* are interviews that are used to examine students’ thinking during an activity (Goldin, 2000). This type of interviewing looks at what the participant is doing, what the participant is thinking while completing the task and how they rationalize their reasoning for completing the task a specific way.

17. *Temporal Order* is the arrangement or organization of events in a sequential time order.
18. *Temporal relationship* the relationship of these events in time to one another, how they are separate or how they overlap with one another.

Organization of the Dissertation

Chapter two is a literature review focused on learners' conceptions of geologic time and factors that affect learners' understanding of geologic time, such as learners' understanding of large numbers and event temporal ordering. Additionally, chapter two includes a review of literature about strategies other researchers previously employed to examine learners' conceptions of geologic time. This literature provides justification for the methods used during this dissertation. At the end of the chapter, I present theoretical frameworks used as the basis of this study.

Chapter three describes the methodology for this study and provides a rationale for the methodological approach chosen. Chapter three also includes a description of the research setting and sample, as well a data collection and analysis methods. Finally, it includes detailed descriptions of all aspects of the design and procedures of the study, including examples and reasoning for underlying choices made as a result of the pilot study.

Chapters four and five present the findings of the study. Chapter four presents findings from Activity I: event ordering. Chapter five presents findings from Activity II and III: learners' assigned values for the events, as well as scale and duration. These findings discuss the correct and incorrect ordering of the learners' timescales, logical reasoning for event placement, and strategies for event placement.

Chapter six presents findings from discourse analysis that focused on funds of knowledge, and the lexicalization and relexicalization of learners' speech throughout the course of the activity, the *ways of knowing and doing*. Funds of knowledge are the various sources learners draw on to construct their models. Learners were not consciously drawing from these funds during model construction. Instead they were identified through analysis when learners attributed knowledge to a particular source. Lexicalization and relexicalization refers to the words and phrases experts and novices used and repeated throughout the activity, which reflected learners' ways of knowing. Ways of knowing include the language, content knowledge, ability to establish research studies, and further one's knowledge specific to the geosciences. Learners ways of doing include being able to share the content knowledge of the geoscience community in conversation, conferences, conducting research, teaching, and going into the field. Findings on learners' ways of knowing and doing combined with their funds of knowledge, provide insight into how learners relate and engage with the geoscience community, known as *identities*.

Chapter seven presents the discussion and conclusion of the dissertation. This chapter includes a summary and discussion of the findings presented in chapters four through six, and presents the limitations, implications, and future research. The findings in chapters five and six, specifically patterns learners' strategies and their relationship to the literature discussed in chapter two are presented. The implications were constructed based on the similarities and differences between novice and expert learners' strategies, their geoscience identities, discourses, and funds of knowledge. Finally, future research is grounded in addressing the limitations presented, including the model itself and the addition of an intermediary group between the novices and experts. The development of activities and models that focus on revealing learners' discourses, specifically their identities and funds of knowledge, is also discussed.

Chapter 2

Theoretical Framework and Literature Review

What, then, is time? If no one asks me, I know what it is; but if I wish to explain to him who asks, I do not know.

— *St. Augustine*

Theoretical Framework

This study was designed to gain insight into how novice learners understand, represent, and discuss geologic time, and how that compares to expert learners. Insight into similarities and differences in the way experts and novices represent, discuss, and process information has implications for the role of knowledge and expertise development in regard to geologic time. The theoretical framework, expert-novice theory, is used to guide this research in regard to alternate conceptions learners' hold, their representations and strategies for timescale construction, as well as the way learners discuss geologic time.

This research not only examines cognitive topics such as the content knowledge and metacognitive practices of expert and novice learners, but also strategies and discourse used to construct the geologic timescale models. The theoretical framework is used to provide a general representation of the relationships between the findings for experts and novices throughout the activity, as well as how the research problem was explored.

Expert-novice theory. Experts tend to "notice features and meaningful patterns, can apply knowledge, and have an expansive and deep understanding of content knowledge" and provide insight into "their nature of thinking and problem solving" (Bransford, Brown, & Cocking, 2000, p. 31) (also see: Chi, 1978; Chi, Feltovich, & Glaser, 1981; Chi, Glaser, & Rees, 1982; Glaser & Chi, 1988; Tretter, Jones, & Minogue, 2006b). Experts and novices tend to "organize, present, discuss and interpret knowledge differently" (Bransford, Brown, & Cocking, 2000, p. 31). Thus, this study was designed to gain an understanding of the representations learners have about the geologic timescale. This was achieved by examining how novice learners discussed and constructed geologic time on a model and compared to how experts strategized, discussed, and constructed their models.

Experts have extensive knowledge that is useful for thinking and problem solving, not just extensive knowledge of facts in their respective fields. Research conducted on “experts in the areas of mathematics, science and chess found that experts’ ability to problem solve was based on an expansive and deep knowledge of the subject matter” (Bransford, Brown, & Cocking, 2000, p. 9). However, these were not lists of disconnected facts, but organized and usable knowledge, to “specify the contexts in which it is applicable; these concepts support understanding and transfer to other contexts” (Bransford, Brown, & Cocking, 2000, p. 9). Therefore, in order for novice learners to eventually become experts in a particular field, they must meet these three criteria:

(1) Have a deep foundation of factual knowledge
(2) Understand facts and ideas in the context of a conceptual framework
(3) Organize knowledge in way that facilitate retrieval and application (Bransford, Brown, & Cocking (2000, p. 16).

Being able to combine those particular factors allows an expert to be able to notice patterns, relationships, discrepancies, as well as generating reasonable arguments and explanations (Bransford, Brown, & Cocking, 2000). Moreover, experts are able to generate arguments relatively quickly as they are able to identify relevant information because of their fluency in the subject matter. Experts’ “enhanced ability to recognize meaningful patterns is the ability to chunk information into useful bundles to reduce the cognitive load” (Tretter et al., 2006b, p. 1063).

Using an expert-novice theoretical framework relies on examining how learners are thinking and conceptualizing various phenomena. As the literature suggests, continued research needs to be conducted into the effectiveness of interventions designed to provide novice learners with experiences to specifically enhance their abilities to recognize meaningful patterns of information (e.g., Simon, 1980; Bransford et al., 2000; Uttal & Cohen, 2012) as well as providing more activities or examples of scale that will make the extreme scales more relatable (Tretter et al., 2006b). In order to do this, we must first determine how experts in different fields think about concepts differently than novices, not simply in terms of the amount of information but how they build, understand and represent their knowledge. An expert-novice framework is ideal for this research, which utilizes model-eliciting activities in conjunction with task-based interviews. Model-eliciting activities are designed to reveal learners' thinking and task-based interviews examine learners' thinking during the activity. As the activity and task-based interview require both types of learners to reveal their strategies, patterns, content knowledge, and reference points as they complete the activity, researchers gain insight into novice and experts' representations, understanding and discussions of geologic time, in terms of the events, duration and scale.

As representations allow the learner to visualize information they might not have experienced, we can think of the geologic timescale model constructed in this study as a cognitive map of the learners' representations. Cognitive maps are a type of representation that serves as ‘‘a process composed of a series of psychological transformations by which an individual acquires, stores, recalls, and decodes information about the relative locations and attributes of the phenomena in their everyday spatial environment’’ (Tretter, Jones, Andre, Negishi, & Minogue, 2006a, p. 284). As a result, a cognitive map, or a model of the way in which we live, is produced (Tretter et al., 2006a). Therefore, construction of the geologic timescale model affords the researcher the opportunity to gain insight into how the learner visualizes and understands geologic time.

Theoretical framework conclusion. In conclusion, this research was based primarily in expert-novice theoretical concepts but will also utilize cognitive and constructivist theory to examine learners' representations and construction of time. First, expert-novice theoretical concepts are grounded in constructivist theory focused on meaningful patterns, knowledge application and construction, and content knowledge and problem solving skills expressed by both novice and experts. As the purpose of this study was to gain an understanding of the representations novice learners have upon enrolling in their first geoscience course, it is important to first examine learners' representations, and discussions regarding geologic time as they enter the university. In order to understand how geoscience skills are developed, it is important to compare novice and expert learners' conceptions about events and their relative and absolute positons in time, representations, and discussions.

This comparison serves two purposes: 1) to assist novice learners with skill building in the geosciences, and 2) to inform instructors how novice learners think about geologic time, by providing information as to which events they know well or hold alternate conceptions about, the variation learners have regarding when they think events occurred in time, and their conceptions about scale. Second, in order to understand learners' conceptions as the basis of their representations, it was necessary to understand their prior knowledge and where they constructed this knowledge, whether it was from their K-12 experiences, personal beliefs, or from informal education sources (e.g., museums, zoos, etc.,). The source of knowledge assists in understanding where conceptions, alternate and correct, may arise from, as well as how to support or adapt the novice learners' conceptions novice.

Finally, phenomenography guided the collection and identification of learners' models, or cognitive maps, expressed through the geologic timescale activity. Phenomenography emphasizes learners' individual experiences and focuses on their conceptions and their representations of time. Phenomenography was used in conjunction with discourse analysis. The discourse analysis conducted in this study focused on understanding the sources of knowledge each individual used to create their models and how they made meaning from these sources. Analysis of learners' language provided awareness into how each participant thought and engaged with geologic time. As phenomenography is focused on "ways of experiencing" (Säljö, 1997, p. 173), which includes practices and "ways of talking and reasoning" (p. 173), it overlaps with Rogers' discourse work (2013) focusing on ways of knowing and doing, known as "ways of representing". Furthermore, the task-based interviews focused on capturing rich variations and similarities of experiences and conceptions, while emphasizing the different voices within the sample group (Kinnunen & Simon, 2012). The different voices about the phenomena of geologic time were then "discerned and described in a nuanced picture of relevant experiences" within the two groups, novices and experts (p. 201).

The following literature review will present the challenges learners have faced when studying geologic time. Previous research primarily focused on novice learners in the K-12 setting, but includes a few studies that contain geoscience majors or experts. Additionally, the research focuses primarily on the difficulties learners have when thinking about geologic time, rather than their successes with geological knowledge. As this study is to gain an understanding of the representations of novice and expert learners, specifically in regard to geologic time, it was important that the research conducted not only identify challenges learners face when thinking about geologic time, but also the background knowledge regarding geologic time that learners know and bring to the university classroom.

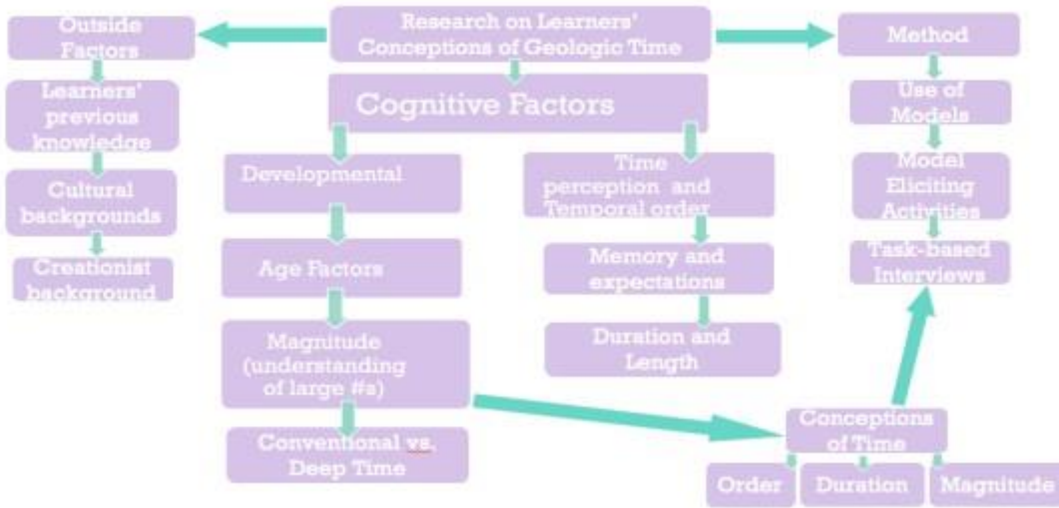
Literature Review

Introduction. Many people have asked about the origins of the Earth. Their curiosities have led to questions such as "when and how did the earth form?" or "when did life first appear on earth?" Many scientists are still working answer these questions. However, learning about the time over which these events occurred is difficult for many people. The abstract idea of a very different earth with extinct species, coupled with the large scale of time, presents a challenge for learners.

The geologic time scale is a chronological measurement that relates the order and position of strata to time, as well as relating the timing and relationship of events, and is constructed on the order of billions of years. For example, the evolution of small mammals was dated to around 225 million years ago, as the earliest known mammal fossil was found in strata dated 225 million years old. In fact, the age of the earth is currently estimated at 4.6 billion years. In order for events in geologic time, such plate movement, landmass changes, evolutionary connections and development of modern day organisms, climate change and duration of events, to make sense, learners must understand the scale of time these phenomena represent and their temporal order. In addition, for learners to understand large scales of time, the instructor has to build from learners' preexisting ideas of the geologic timescale. For example, if a person thinks the earth is only 100,000 years old, how do they make sense of scientists' claims about organisms that lived 350 million years ago? Or if they have difficulty understanding large numbers, how can they work with time in large numbers? Researching how learners think about time might help answer these questions.

The following is a literature review focused on learners' conceptions of geologic time, time perception and order, understanding of large numbers, and strategies employed to examine learners' understanding of deep geologic time. The literature review excludes research prior to the year 2000 with the exception of research on time perception and order, which includes special cases as early as 1969 to present. Literature from as early as 1969 was included as it provides perspectives on learners' conceptions about time, including temporal ordering and scale. Additionally, prior to the 1990s, research on geologic time was situated in cognitive learning frameworks and transitioned to include constructivist frameworks in the late 1990s. The literature presents the limitations of previous work.

The literature review begins with research on learners' conceptions of geologic time, such as developmental factors, and then time perception and temporal order. Discussions of conceptions of time, such as temporal ordering, duration, and magnitude, in conjunction with outside factors, such as learners' previous knowledge, cultural and creationist backgrounds will be included. A review of methods used in geologic time literature will follow. The diagram below represents the relationships of these bodies of literature and the order of presentation in the paper.



Research on learners' conceptions of time

Learners' conceptions of time. Research about learners' conceptions of geologic time was conducted in an array of settings from elementary school to high school (Libarkin et al., 2007) and recently extended to colleges and universities, with the majority of work being done in the K-12 setting.

Early research on science education was led by Ault's work with children's conceptions of geologic time. In 1982, Ault conducted a study on elementary-aged children using a relational definition, looking at events in terms of *before* and *after*, as a cognitive framework based on Zwart's research in 1976 and Piaget's research methodology on time conception (1969). A relational view assumes that the "succession of events is fundamental to understanding reality" (Ault, 1982, p. 305). Thus, Ault (1981, 1982) worked under Zwart's relational idea that the "simplest relation for an observer to grasp is the successional relationship, known as the before and after event relationship" (Dodick & Orion, 2003a, p. 416). Ault studied children five to 11 years of age to examine their understanding of time conception and geology (Dodick & Orion, 2003a). Although Ault concluded that a child's concept of conventional time did not impede their understanding of geologic events in the classroom, when brought into the field, children could not relate what they learned in school to what they saw in the geological settings.

Additionally, "most of geology builds its knowledge of time through static, visual entities (formation, fossils and landforms)" so depicting geological events in terms of motion would result in difficulties for children to apply time taught statically to questions referring to motion (Dodick & Orion, 2003a, p. 417). Finally, Ault made a claim that conventional time would not interfere with a child's understanding of geologic time (Ault, 1981, 1982). However, geologic time possesses components that are not seen in conventional time. For example, the large scale of geologic time, spatial and visual thinking, content knowledge regarding evolutionary rates and relationships, and the ability to think of time past a human life span, (Dodick & Orion, 2003a), can interfere with understanding geologic time. Harner's (1982) studies of 14-year olds' use of time vocabulary found they were just beginning to include century, generation, and forefather (Dodick & Orion, 2003a) in their language. Thus, the children in Ault's studies in 1981 and 1982 would not have been able to comprehend the expansive scale of geologic time (Dodick & Orion, 2003a).

Conventional time versus deep time: understanding large numbers. Difficulty with large numbers is seen across all ages from children, beginning at age six, and up to college students. Young children, ages six to 14, do not have a temporal awareness past one year and are just becoming aware of ideas concerning the magnitude of conventional time. Therefore, the components of geologic time, such as the magnitude or units of time, would interfere with the understanding of geologic time (Friedman, 1982). Learners that had sufficient knowledge of large numbers still have difficulty with the time span of thousands and millions of years (Dodick

& Orion, 2003a; Cheek, 2014, 2011). Thus, understanding the magnitude and large numbers associated with deep time likely presents additional challenges.

Recent studies (Cheek, 2014, 2011; Libarkin et al., 2007; Dodick & Orion, 2003a, 2003b) investigated learners' relative and absolute temporal ordering of geologic events. Findings indicated that learners were generally able to place geologic events in correct temporal order on a relative scale, but are unclear about where those same events fit on an absolute scale (Cheek, 2011; Catley & Novick, 2009; Hidalgo & Otero, 2004; Libarkin et al., 2007; Trend, 1998, 2000, 2001). The majority of studies on learners' conceptions and understanding of temporal and spatial scales of geologic time has been confined to K-12 science learners. Few studies investigated temporal tasks and spatial reasoning with college students. Cheek (2011) suggested that even many educated adults would have trouble with numbers of extreme scale, on both micro and macro time scales. Cheek conducted task-based interviews with 35 students ages 13-24 (12 eighth graders, 11 eleventh graders and 12 university students) to examine their understanding of the size of numbers in the thousands or greater and their relationships among periods of various magnitudes using number lines. Cheek concluded that "less than half of the participants performed well enough to suggest they had sufficient knowledge of numbers up to 100 million" and only four of the twelve university students had insufficient knowledge to deal with large numbers (Cheek, 2011, p. 1057). Even the only geology major of the study had difficulty with making a scale for the study as he indicated in his interview:

> I'm just thinking of how big these numbers are compared to each other. I'm not quite sure 'cause we don't deal with numbers this big normally in our average day. So I really don't know how long one million years is compared to a

> thousand. I really don't know how long a thousand years is (David, interview in Cheek, 2011).

Students displayed difficulty with relationships between time periods up to 100 years, even though previous research by Siegler and Opfer suggested otherwise (2003). Additionally, students were not able to linearly map times on the scales to the extent that the researcher expected based on previous research conducted (Cheek, 2011). Students considered to have sufficient knowledge to deal with large numbers in deep time were able to construct timelines and then referenced their timelines according to the largest number of the scale. In other words, these students were able to look at the whole timescale and consider multiple relationships, whereas the students that lacked knowledge of large numbers used themselves or 1 year as a reference to construct their timelines.

In order to gain a better understanding of the learners' perceptions of large numbers and geologic time, consider previous "work on time cognition, which comes from the field of psychology and is primarily concerned with the perception of time" (Dodick and Orion, 2003a, p. 417). Knowledge about how all learners perceive and relate time to their lives will allow for an understanding of how learners comprehend geologic time.

Cognition: time perception and temporal order. When referring how long or short something is in time, how often do we refer to our own experiences? According to Ault (1982), our understanding of time is proportional to our expectations and memories (p. 304). In other words, we make psychological meaning of time based on our own personal experiences. For example, an interview with an eighty-five-year-old woman about the quickest and longest happenings she could recall, resulted in a comparison to her lived experiences. The woman cited "lightning striking a barn and killing a horse" as the quickest amount of time and compared to a "kettle left out in a field rusting" as the longest (p. 304).

The interview reflected how "memory and the expectation of events within the human experience control the limits to the psychological meaning, reality" and our perception of time (Ault, 1982, p. 304). Therefore, our perception of time is grounded in our own experiences and ideas, which learners are asked to think about during this study. To gain an understanding of the learners' conceptions of time, researchers identified temporal order, duration, and successiveness and simultaneity as important for understanding conventional time (Brown & Smith-Petersen, 2014; Cheek, 2010; Libarkin et al., 2007, 2005; Dodick & Orion, 2003a, 2003b; Harner, 1982; Ault, 1982, 1981; Friedman, 1982, 1978).

A person's understanding of duration is linked to their perception of duration (Casasanto & Boroditsky, 2008). In 1969, Piaget found that "children (age nine), when tested about space and time, based their judgments of duration on their experience of distance" (Casasanto & Boroditsky, 2008, p. 588). For example, when asked to "judge the relative duration of two trains traveling along parallel tracks, children often reported (erroneously) that the train that traveled the longer distance took the longer time. Piaget concluded that children could not reliably distinguish the spatial and temporal components of events until about age nine" (Casasanto & Boroditsky, 2008, p. 588). Another explanation would be that children in the study may not have been introduced to the topic of rate. Without an understanding of rate, children would lack an understanding of how to compare one quantity to another, making duration a difficult concept.

Additionally, when speaking, people often use metaphors about time in terms of space, but less often discuss space in terms of time (Casasanto & Boroditsky, 2008). In a study of nine college-aged participants at MIT, when prompted with lines of various lengths to examine distance and duration, spatial displacement affected how participants estimated duration, but duration did not affect their estimates of spatial displacement (Casasanto & Boroditsky, 2008). However, participants included irrelevant spatial information when making their temporal estimates but not vice versa. In other words, they saw that "for stimuli of the same average duration, lines that traveled a shorter distance were judged to take a shorter time, and lines that traveled a longer distance were judged to take a longer time" (p. 582). Thus, the "findings suggest that Piaget was right about the phenomenon he observed, but that this was not just seen in nine year olds", but also "undergraduates could not reliably distinguish the spatial and temporal components of their experience, either were judged to take a longer time" (Casasanto & Boroditsky, 2008, p. 588).

In conclusion, pure psychological studies have shed light on our understanding and perception of time, which conveys the difficulty of understanding time outside of a human life span, and our judgments of scale and duration are proportional to our expectations and memories (Dodick & Orion, 2003a). Additionally, most studies regarding time perception, specifically geologic time, have focused on children no older than 11 years of age, while few studies exist on high school and college-aged learners. These studies restricted the time frame used for examination to no more than years, which was problematic for learners studying geologic time (Dodick & Orion, 2003a).

Factors affecting learners' understanding of time. As mentioned previously, large numbers and time perception make learning about geologic time difficult. Additionally, temporal organization (*order*) of events on the timescale, temporal extent of an interval (*duration*), the temporal relationship between the events (*successiveness and simultaneity*), and shift or transformation of events in time (*change*) (Brown & Smith-Petersen, 2014; Dodick & Orion, 2003), as well as cultural and religious backgrounds of learners (Ault, 1982; Libarkin et al., 2007) further complicate learning about geologic time.

Research about students' conceptions of geologic time primarily focused on conceptions of successional events and duration of geological events (Cheek, 2011). These studies are useful for understanding how students' piece together facts about time in a relative order, but do not examine their first initial thoughts about events in geologic time unless done at the absolute beginning of the course, otherwise maturation of material during a course could affect their conceptions about events. In addition, studying succession provides the researcher with the learner's ideas about what it means to have order or concurrent events.

Examining the duration of events is extremely important. Students often equated size with duration (Dodick & Orion, 2003a). For example, if we were to examine two layers of deposited sandstone that were both half a meter deep, they do not necessarily represent the same speed of deposition or the same amount of time to deposit a half a meter of sediment. One layer may have been deposited rapidly during a catastrophic event, while the other was deposited consistently over thousands of years. The concept that the same width of a layer, even of the same materials, will not represent the same amount of time can be difficult for some learners.

Understanding our human existence and the relationship to events in deep time is another difficulty. As humans, we have only been on earth for 2.5 million years and in our present-day lives, we have only seen the oldest person living for 100-110 years as an extreme. Understanding that the earth formed thousands of millions of years prior to our existence continues to be a difficult concept to grasp. Life on earth began approximately 2.3 billion years ago with cyanobacteria and multicellular life 1.77 billion years later. Additionally, the extent of a learner's knowledge and experience in geoscience content is another potential factor in understanding geologic time. For example, if a student has not heard of Pangaea, it would be difficult for them to place Pangea on a timeline, as they lack the background knowledge of Pangaea and its relationship to other events in time. However, this would provide great insight into how a learner thinks about these events without having any content knowledge to guide them. Additionally, just because a student has the content knowledge about a topic, such as Pangea, does not necessarily mean that they fully understand the event.

Understanding duration and order of events is problematic for learners. Humans have a difficulty believing the instability of the earth (Kusnick, 2002). They might be able to see the relative order of events, but the language, lack of clear specimen knowledge (e.g. fossils and their living relatives) and length of time represented can still result in shying away from geologic time (Kusnick, 2002). Additionally, cultural and religious backgrounds, such as the young Earth creationists or familial beliefs, can result in difficulty understanding the scale of geologic time, ordering of events and mechanisms of events and their temporal relationships.

Methods: strategies to understand geologic time

According to Catley and Novick (2008), a temporal framework to understand deep time should include a key number of macroevolutionary events that span the entirety of Earth's history to understand changes in the Earth and evolution of life. In order to gain a deeper understanding of learners' conceptions regarding deep, geologic time, various strategies have been developed to help transform the large scale of time into human-relatable metrics including model scaling projects, task-based interviews, and Geoscience Concept Inventory (GCI) exams. Task-based interviewing and scaling projects have been used in geology and are prominent in astronomy and mathematics education research.

It is important to note two types of research have been conducted to gain insight into learners' conceptions of geologic time: event-based studies and logic-based studies. Event-based studies focus on learners' understanding of the "entirety of geologic time, starting from the formation of the Earth or the Universe and work through to present day" (Dodick & Orion, 2006, p. 78). Event-based studies are typically biological-geological events, studied using card-sorting tasks or listing of events, and are typically conducted discussing relative time, although few studies have been conducted including absolute time (Dodick & Orion, 2006). The studies that discuss time include timelines or number lines in which participants are asked about their "proposed temporal order to present their knowledge or misconceptions of relative and absolute time" using questionnaires or interviews (Dodick & Orion, 2006, p. 78). Questionnaires and interviews are administered post-activity to gain insight into learners' conceptions of time and the ordering of events. Event-based studies were conducted on "middle school children (ages 10-11), high-school students (age 17), primary teacher trainees, teachers and college students" (Dodick & Orion, 2006, p. 78).

Logic-based studies examine "logical decisions that learners' make that apply to the ordering of biological-geological of events" (Dodick & Orion, 2006, p. 78). Typically, logic-based studies use puzzles and questionnaires with "visual components for relative dating of stratigraphic layers or to rebuild a depositional environment" (Dodick & Orion, 2006, p.78) to assess learners' conceptions.

To summarize, logic-based studies differ from event-based studies as they focus on the strategies employed by learners in order to construct a task. Although logic-based studies have primarily focused on reconstruction of depositional environments, they are used to gain an understanding of the microscale of relative time. Event-based studies focus on the macroscale of geologic time, focusing on large events in Earth's history (Dodick & Orion, 2006).

Therefore, the strategies described to examine learners' understanding and representations of time in the next few sections are separated into two categories of event-based strategies and logic-based strategies. Models and model-eliciting activities are generally strategies used to examine learners' ordering skills by focusing on learners' understanding of the entirety of time expressed through models, such as card-sorting tasks on timelines. Task-based interviews and concept exams are discussed under logic-based strategies, as they are used to examine the methods learners' employ during the event-based tasks.

Event-based Strategies. ***Concrete scaling models*****.** One of the most important abilities a geoscientist has is the ability to think spatially. As research has continued to expand, technological development has also expanded and allowed us to extend our human senses into otherwise inaccessible domains of the micro and macro worlds of science (Tretter, Jones, & Minogue, 2006b). Devices such as microscopes and telescopes are examples of instruments that work in both large and small spatial scales (Tretter et al., 2006b). In order to have a fundamental understanding of various scientific phenomena, learners must be able to "mentally maneuver across many orders of spatial magnitude" (Tretter et al., 2006b, p. 1062).

Geoscientists continuously think about how to represent processes or phenomena, as well as manipulate objects (Kastens et al., 2009). Representations of geological phenomena, or models, can assist geoscientists to think spatially. Models allow geoscientists to take their data and make predictions or assemble their own thoughts into a visual or tangible representation. Models come in an array of forms from maps and cross-sections (Kastens et al., 2009), to plate tectonic block models. In addition to scientists, instructors and learners can use models for science instruction.

Using models in the classroom allows instructors to introduce geological concepts as a source of science communication (Gilbert & Ireton, 2003). Science instructors and researchers can also benefit from students working with models because it provides a visual representation of student understanding, for example, how the students consider scientific ‘facts’, and their understanding of how a particular phenomenon works. Models can be used to help learners take what they have studied thus far and piece together the facts presented to them. Therefore, models assist in taking this “fragmented knowledge about concepts and relationships into much larger, more clearly understood constructs” (Gilbert & Ireton, 2003, p. vii). Thus, models are useful for “unifying the various branches of science by enhancing coherence in science instruction” (Tretter et al., 2006b).

Building or using models allows the learner to think about the relationships between the individual components of geology and makes a clearer picture of the phenomenon. Additionally, models can institute creativity, intuition, as well as both the qualitative and quantitative aspects of geology (Gilbert & Ireton, 2003). It is important for the instructor to know and point out the characteristics distinctive to the model and the actual phenomena the model represents. Not knowing the “strengths and weaknesses of the model” or “how the model and the phenomena compare and contrast” will only result in confusion for the student (Gilbert & Ireton, 2003, p. viii). Thus, it is important to know and note the limitations of the model. The goal of using models is to reveal learners’ innovation, logic, spatial awareness and understanding of conceptual knowledge (Gilbert & Ireton, 2003), which is especially useful for examining geologic time as it allows researchers to gain an understanding of learners’ cognitive representation of the timescale.

"Concrete models can be physically manipulated" (Gilbert & Ireton, 2003, p. 37). Concrete scale models are deliberately designed to look like their targets. The term 'target', refers to "some part of the model in which the objects or symbols are intended to represent" (p. 1). For example, the target of a solar system model may be to show the arrangement of the planets in relation to one another, scale, or both. The geologic timescale in and of itself is both a model and target. Geoscientists created the timescale to show a relationship between events, time, and lithographic (rock) units that are symbolic of an event in time. Therefore, it is a model as it is used to "facilitate recognition and identify features of the targets that are of particular interest" (Gilbert & Ireton, 2003, p. 11), but also a target because it displays a portion of time with symbolic features.

Geologic time scale models are considered concrete models as they can be physically manipulated by the learner. In addition, there is a mathematical component to the geologic time scale as well. The geologic timescale requires the learner to think about the proportion of time covered by events and the relationships between the events, as well as physical measurements of the timescale. For example, events are associated with a particular value or range of values in time. Placement of an event on the timescale model refers to a specific point in time, which can be measured. Therefore, on a timescale model, the difference between the placement of an event on the model by the learner and the timing of the event according to geologic time may be calculated (Libarkin, Kurdziel, & Anderson, 2007). Therefore, learning associated with models involves revealing and building the learners' conceptual model and can allow for a better understanding of the limits of learning or a learner's prior knowledge.

Model-eliciting activities. After designing or choosing a model to be used, a unique strategy can be used to design a model-eliciting activity to reveal student thinking. Model-eliciting activities (MEAs) are open-ended activities or questions designed to engage the learner in thinking about particular aspects of the model, thereby making the learner's thinking more transparent (Lesh, Hoover, Hole, Kelly, & Post, 2000). MEAs differ from a typical in-class, open-ended questions in that they do not simply examine the answer the learner supplies, but examines the process in which the learner used to get to that answer (Diefes-Dux, Bowman, Zawojewski, & Hjalmarson, 2006). Thus, it should assist in examining learners' high-order thinking and reasoning skills, as well as their verbal skills, for providing an explanation to a researcher, instructor or group member, depending on the activity (Diefes-Dux et al., 2006).

According to Tretter et al., (2006a), "early work in spatial decision-making behavior emphasized the centrality of personal experience, arguing that spatial behavior was most frequently based on what was perceived to exist and what had been already experienced more than being based on the objective reality of a problem situation" (p. 284). Both visual and verbal information can be used for representing and recalling information. In other words, when asked to remember a particular event or object, a participant can retrieve either the word or the image individually, or both simultaneously. As the scale of geologic time is quite abstract, individualized cognitive mapping would be a method to obtain temporal and spatial information from participants. In addition, geologic time can be represented by a variety of images that could evoke both visual and verbal information from participants.

Kinesthetic activities may be particularly useful for understanding ideas regarding both temporal but more importantly spatial size (Tretter et al., 2006a). According to Tretter et al., (2006a) imagery is particularly useful for assisting people new skills.

> Kinesthetic experiences may play a central role in developing useful cognitive maps related to spatial size. Imagery can help one learn new skills, as shown by cognition

> experiments suggesting that metric information is stored in the parietal lobe in a form useful for the new task. When a person imagines moving in various ways, the subsystems that are used to produce the actions are affected (Kosslyn, 1992). This may mean that spatial size relationships are better stored and recalled if there are kinesthetic experiences stored in the brain related to such sizes. (p. 284)

Therefore, the use of kinesthetic experiences, such as model-eliciting activities, which require learning through physical activities rather than learning through a lecture, would work to reduce the limitation by providing visual imagery. The learner would be able to relate to these images, such as pictures of familiar, everyday objects, for scale comparison.

Although MEAs have been used extensively in K-12 mathematics education, they are applicable to all disciplines and education levels ranging from elementary school to university. For example, Diefes-Dux et al. (2006) used MEAs in an engineering program intended for first-year students. MEAs were used to introduce students to the principles of engineering in order to "place them on the trajectory to attain the skills to graduate in engineering, but also as a tool to retain students for success in the field of engineering" (p. 55). Diefes-Dux et al. used MEAs for instructional practice and skill development, as they were able to gain an understanding of student thinking, reasoning and verbal skills of students in introductory engineering courses.

MEAs have been used in geoscience education research (Dodick & Orion, 2003a), but take the form of event-based or logic-based tasks. Event-based activities ask learners to articulate their temporal understanding of events in Earth's history, including the origin of Earth's formation. Examples of these activities include card-sorting tasks (arranging events temporally in geologic time) (Libarkin et al., 2005, 2007; Noonan-Pulling & Good, 1999; Marques & Thompson, 1997) or chronologically ordering time on a number line while responding to interview questions or questionnaires within the task (Cheek, 2010; Dodick & Orion, 2003a; Trend 1997, 1998, 2001).

While event-based activities focus on learners' understanding of temporal ordering, logic-based activities focus on "cognitive processes undergone by the learner while trying to solve problems that involve geologic time" (Dodick & Orion, 2003a, p. 416). Logic-based activities can take the form of "solving puzzles involving skills that are necessary to understanding geologic time, such as superposition and correlation" (p. 416). Logic-based studies in geoscience education have typically been theorized by combining geology with developmental psychology to understand learners' temporal awareness from conventional to deep time with age progression. Classic examples of logic-based research would be by Ault (1981, 1982), Freidman (1978, 1982) and Harner (1982). Although modeling activities allow researchers and instructors insight into a learner's thought processes, the ability to interview while the learner completes the task would be more beneficial to exploring learners' ideas, strategies, and movements while completing the task. This particular method is known as a task-based interview and will be discussed in the next section.

Logic-based Strategies. ***Task-based interviews***. Task-based interviewing is a qualitative research method that examines a participant's strategy for solving a task, revealing their thinking through their actions and explanations (Goldin, 2000). Task-based interviews are research instruments used to gain understanding of student thinking or as assessment tools to "describe the subject's knowledge and/or improving the practice of a specific discipline's education, such as improving geoscience education" (Goldin, 2000, p. 520). Although task-based interviews have been primarily used in mathematics education research (Goldin, 2000, 2003; Koichu & Harel, 2007), they can be adapted for research and assessment in any discipline.

Task-based interview questions are typically structured to easily compare learners' responses; however, questions can be semi-structured depending upon the task design. For example, in this study, the general questions regarding strategies for completing a timescale will be the same for each participant, however the follow-up questions will vary based on the participant's explanations. Task-based interviews allow for the combination of using model-eliciting activities in conjunction with interview.

Combining event and logic-based strategies through a model-eliciting activity, task-based interview, and concrete scale, is especially useful for examining geologic time. It allows researchers to gain an understanding of learners' representations of the timescale, including their logic for ordering events, their expression of conceptual knowledge of events, event relationships, and spatial representations of events and deep time, while communicating how they constructed their representations. They provide the opportunity to obtain information on student achievement and understanding, cognitive development and representation, construction of information, as well as learners' beliefs and attitudes toward the subject (Goldin, 2000). Thus, as Goldin stated, task-based interviews have "great potential for indicating whether we are succeeding" (p. 524) in our educational goals in the classroom and can be a tool of assessing educational reform, curriculum or teaching methods.

Literature Review Conclusion

Geologic time is "one of the most culturally relevant topics within our history of thought" (Cervato & Frodeman, 2012, p. 20), as all places around the world are affected by different geologic events now and throughout time. While temporal spans of geologic time are difficult to understand, as represented by the literature review in the previous section, it offers relevant perspectives on cultural, political, economic and environmental issues pertinent to all citizens, not just scientists (Cervato & Frodeman, 2012). All learners should be provided necessary information to understand geologic time, and how that knowledge can assist in understanding issues such as climate change, energy crises and geohazard issues (such as landslides and earthquakes). “Improving our understanding of how humans think and learn about the earth can help geoscientists and geoscience educators, such as professors and graduate teaching assistants, do our jobs better, and can highlight the strengths that geoscience expertise brings to interdisciplinary problem solving” (Kastens et al., 2009). Not only would teaching geologic time assist in developing students’ ability to think spatially and to develop skills required for abstract thinking, but it would also allow teachers to better represent larger culturally-significant, relevant or topics of interest to the students.

As educational studies in the geosciences are extremely limited compared to those in chemistry, biology and physics (Cheek, 2010; Libarkin et al., 2005; Dodick & Orion, 2003a), it is important to research and understand learners’ conceptions about geological phenomena. A scientifically literate public is important for the future populations and the well-being of the planet (Catley & Novick, 2008; Zhu et al., 2012). In order to comprehend geologic time and its application, one must be able to understand the temporal ordering and relationships between past events, their duration and the spatial nature of the timescale.

As “learning geoscience requires a high-level of spatial thinking” (Kastens & Ishikawa, 2006, p. 51), it is important for learners to have developed the ability to conceptualize scientific phenomena at very different scales (Tretter et al., 2006b). The “importance of scaling concepts for the development of science literacy has been highlighted as an important unifying curricular theme in science education by the *Benchmarks for Science Literacy*” (Tretter et al., 2006b, p. 1062). Additionally, the Next Generation Science Standards (2012) stress that “it is critical to recognize what is relevant at different measures of size, time, and energy and to recognize how changes in scale, proportion, or quantity affect a system's structure or performance" in order to enrich a learner's understanding and application of scientific practice (NGSS Appendix G, 2013, p. 1). Thus, emphasizing spatial concepts across disciplines is a strategy to maximize curricular coherence in science curricula (Tretter et al., 2006b).

Studies on spatial scale, temporal ordering, and duration not only have implications for student learning but also for the structure of course curriculum in K-12 and undergraduate education. Although courses such as biology, chemistry and physics are offered in high school, they are not all mandatory. Moreover, earth science is typically an elective course, if it is offered. In addition, exposure to scientific topics can vary among schools, districts and states. For example, evolution has been banned from being taught in schools in many southern schools in the United States, such as Tennessee in law House Bill 368 (HB 368/SB 893) (Strauss, Washington Post, 2012; http://ncse.com).

With the lack of clear establishment of course requirements, students enter colleges and universities with varying degrees of science backgrounds and conceptual understanding. As there is still a debate ongoing in the United States as to which science classes, topics, and how much of each learner needs to know to graduate high school (DeBoer, 1991, 2000), learners are left to piece together facts presented in each of their science courses to try to understand where the events presented in their primary science courses (biology, chemistry and physics) fit in time and how they relate. The NGSS, established in 2013, was designed to address this issue, however, they are not being adopted in every state in the U.S. Therefore, learners have difficulty making connections between topics presented in each of their science classes, even though these classes support one another. This in turn increases the gap between knowledge expectations professors have regarding novice learners' geoscience skills and those they possess entering the university.

Over the course of this literature review, I have discussed the importance of understanding learners' conceptions of geologic time and the importance of having a scientifically literate public. How do the two relate? If learners have a lack of understanding of geologic time, they may have difficulty understanding the mechanisms behind physical changes on the planet. For example, climate change is a highly-debated topic. The mechanisms behind climate change and it effects can be explained through various courses such as political science, biology, chemistry, physics and earth science. Inability to understand climate change or flat out rejection of the topic, reflects on the learners' conceptions about Earth's climate and its changes over time, chemical cycling, as well as how climate impacts Earth's fauna and flora. The public will be expected to vote on issues regarding sustainability of the Earth that require an understanding of various scientific phenomena, including climate change. As educators, we want to make sure that the public is able to make knowledgeable decisions based on the information provided to them. Although geologic time may not be the basis of every decision they make, the pieces that make up geologic time will (i.e. understanding of large numbers, spatial awareness, relationships between events in the past, their order and duration).

Therefore, examining how both novice and expert learners' representations, understandings, and discussions regarding geologic time compare, it provides insight into how understandings are made and geoscience skills are developed and improved. Examining how both novice learners' representations compare with learners with more experience provides insight into how understanding is made and geoscience skills are developed, specifically in regard to geologic time. Therefore, educators can work on developing students' ability to think spatially and build the skills required for abstract thinking.

In conclusion, it is important to have activities, curricula and research that can examine and expand learners' knowledge of spatial scale, temporal ordering and duration to support their explorations in science classes. Leaners as young as preschoolers, already have conceptions about scientific phenomena, their occurrence and scale (Tretter et al., 2006b). Therefore, it is our job as researchers and educators to explore these conceptions as way to enrich learners' understandings of science.

Chapter 3

Methodology and Procedure

At a recent summit on the future of undergraduate geoscience education (2014), various geoscientists expressed that learners entering college “lacked the skills necessary to become geologists” (Summit on the future of Undergraduate Geoscience Education, University of Texas at Austin). In order to understand what skills or practices are necessary to succeed in the geosciences, it is important to understand what topics are incorporated in the geosciences. According to the Framework for K-12 Science Education, the foundation of the Next Generation Science Standards (NGSS),

> Earth consists of a set of systems—atmosphere, hydrosphere, geosphere, and biosphere—that are intricately interconnected. These systems have differing sources of energy, and matter cycles within and among them in multiple ways and on various time scales. Small changes in one part of one system can have large and sudden consequences in parts of other systems, or they can have no effect at all. Understanding the different processes that cause Earth to change over time (in a sense, how it “works”) therefore requires knowledge of the multiple systems’ interconnections and feedbacks. In addition, Earth is part of a broader system—the solar system—which is itself a small part of one of the many galaxies in the universe. (National Research Council, 2012, p. 169)

Consequently, the skills learners need to succeed in a university-level geoscience course require the ability to first understand the universe and Earth “as a whole and addresses its grand scale in both space and time (National Research Council, 2012, p. 170). This idea includes the overall structure, composition, and history of the universe, the forces and processes by which the solar system operates, and Earth’s planetary history” (National Research Council, 2012, p. 170). After learners understand the large scale of time of Earth's history, learners can build toward understanding processes that "drive Earth's conditions and its continual evolution (i.e., changes over time)", "large-scale structure and composition", individual systems and their relationships, and how these systems and our society interact (National Research Council, 2012, p. 170). These ideas require learners to be able to work from large-scale to small-scale changes in time. Further, the underlying skills that learners need to understand these large-to-small scale changes are the abilities to understand and apply geological terminology, spatial thinking, knowing the events, relationships between events, and duration of geologic time.

The skills or practices expected of undergraduate learners is not uniform among universities. The Framework and NGSS standards discussed above, are designed to address the skills and content knowledge learners should possess by the time they graduate high school. One goal of which is to address the skill development required to "learn science outside of school" and to "have the skills to enter careers of their choice" (National Science Council, 2012, p. 1). However, the standards have not been adopted by every state and were implemented in 2013. Therefore, it should be noted that learners participating in this study were not be affected by the standards. Even if learners were affected by the NGSS, the standards' impacts on student learning would not show up yet, and this study was not designed to examine that impact.

Given this discussion about skill development in the geosciences, it is important to note that undergraduate learners enter the university with conceptions about events, the relationships between events, and scale of geologic time from their previous courses. This means that learners have ideas and skills, but they might not know how and when to put them into practice. As disciplines such as biology, chemistry and physics, are often taught separately (Quinn et al, 2012), it can be challenging for learners to understand the temporal relationships between events and organisms, connected through these courses. Moreover, learners may be confused about geologic time itself, specifically understanding the units in which time is to be discussed. For example, units, such as millions or billions of years, may appear interchangeable when thinking about deep time. In the pilot study for this dissertation, three out of five learners incorporated B.C. and A.D. into their timescale model, but expressed uncertainty about their relationship to large values of time. These examples display some of the challenges associated with learning time, specifically understanding units associated with large numbers and deep time. Most university-level learners had a history course prior to entering the university. Many history courses reference points in time using B.C. (or B.C.E) and A.D. However, history courses are not expected to explain where B.C. and A.D. fit into the geologic timescale, nor is it expected that geoscience courses would explain where B.C. and A.D. specifically fit into the geologic timescale. Therefore, it is easy to see how disconnects can form between two disciplines that are both discussing time.

This research is useful for identifying areas where connections and disconnections, or gaps, exist between learners' knowledge prior to entering the university and when they begin to develop expertise. The goal of this study is to gain insight into novice and expert learners' understanding, representations, and discourse regarding geologic time. As described in the theoretical framework in chapter two, this study examines the variation between novice and expert learners' understanding, representation, and discussion of geologic time. This chapter begins by describing the methodology supporting the study, followed by the rationale and methods used for data collection and analysis, as well as the reasoning for use of these methods. In addition, the participants and context of the research study are described in detail.

Methodology

This research was inspired by Chuck Fidler's work (2009a, 2009b) and Thomas Tretter, Gail Jones, and James Minogue's (2006) work on spatial scale conceptions of scientific phenomena. Fidler's work focused on preservice elementary teacher's conceptions of scale associated with astronomy. Fidler provided teachers with cards that had images of objects of varying spatial scales. Teachers were asked to sort the cards in order of smallest to largest units to understand their ideas regarding the conceptualization of cosmic dimensions and identify alternate conceptions about astronomy. Tretter et al. (2006a and 2006b) provided expert and novice learners names of objects of varying scales and required participants to order them in a relative and absolute size order from smallest to largest. Tretter et al.'s work not only focused on how learners' attempts at accuracy leveraged their proportional reasoning skills, but also focused on the differences between expert and novice leaners' methods to maneuver various spatial scales. The card sorting tasks for order and size, combined with the focus on strategies to mentally maneuver spatial scales is the foundation of this research.

Rationale for the study. To support the expert-novice theoretical framework, a phenomenographic approach was used to support the study. As "identification of the variation in conceptions that exists within a group of learners (novices) can play a vital role in curriculum development by helping instructors (experts) to develop their teaching practices, and to design learning activities aimed at helping students to construct knowledge and gain understanding of specific concepts" (Stokes, 2011, p. 24), it was key to develop a research study that not only provided insight into learners' conceptions, but the sources of evidence they draw meaning from and how the learner conceptualizes the phenomenon.

Phenomenography is “aimed at understanding and improving learning” (Maybee, 2007, p. 159). Specifically, phenomenography can be used to reveal different patterns of meaning through experiences, perceptions, and conceptions of various phenomena (Bruce, 1997; Limberg, 1999; Lupton, 2004; Reed, 2006). Phenomenography is a “research approach that takes a non-dualist, second-order perspective describing the key aspects of the variation of individuals’ experience of a phenomenon” (Reed, 2006, p. 1; Maybee, 2007). A non-dualist stance is one in which the internal (thought process), is not separated from the external (world or phenomenon) (Reed, 2006; Säljö, 1994). A second-order perspective describes conceptions from the learners’ point-of-view and explores the relationship between the learner and the phenomenon. This is an “objectivist approach where emphasis is placed on what the researcher(s) observe” and the meaning derived through interpretation and interaction of how an individual constructs their view and ideas regarding a phenomenon, rather than making claims about the phenomenon itself (Reed, 2006, p. 1).

Phenomenography in this particular dissertation focuses on interpretations of meaning behind learners’ experiences and thoughts regarding geologic time as learners’ thinking is the phenomenon being examined. In order to understand learners’ thinking and understanding about geologic time, it was essential to have a theoretical “approach that had *understanding* as a research outcome” (p. 1). The results of a phenomenographic analysis are a “set of categories of description describing the variation in the way a phenomenon is experienced” (p. 1). The categories contain more complex groupings or examples, to describe the way the phenomenon is experienced by an individual. The categories are the result of emergent coding as predetermined coding would not align with a second-order view necessary for phenomenographic research. The categories and groupings are based on the following four assumptions from Stokes (2011):

1. Individuals can experience or understand the same phenomenon or aspect of reality in different ways, and thus hold different conceptions of it.
2. An individual's conceptions can be accessed, e.g., verbally or in writing.
3. A limited number of conceptions exists about a phenomenon.
4. These conceptions are logically related, typically by way of a hierarchy ranging from simple to complex. (p. 25)

As phenomenography is "based on the constructivist principle that meaning is constructed from social and personal experience", with "its value to education in exposing the different ways learners understand a particular aspect of their subject" (p. 25), interview questions were designed to focus on learners' perspectives and experiences, as well as to discern ways of thinking and sources of knowledge. Specifically, learners were asked to reflect on their experience and their strategies to represent geologic time (Maybee, 2007; Reed, 2007). For example, learners were asked to describe their strategies and what sources of knowledge they drew on to complete the model. After interviews were transcribed and coded they could be analyzed using discourse analysis as the focus was on learners' conceptions of geologic time, their thought process, including both content and sources of knowledge, and how they represented these ideas on a model.

A typical phenomenographic approach has participants engage in an activity or perform a task and answer questions after the activity through an interview in open-ended or structured form or responses written by the learner in response to a question (Reed, 2007). As a phenomenographic approach is designed for learners to reflect on their experience with a phenomenon, a task-based interview was used to provide in the moment discussion to clarify and gather responses that were fresh in the learners' mind. A "typical phenomenographic interview is also semi-structured in nature with only a few key questions predetermined" (p. 5).

> The object of study (as described earlier) is held central to the interviewer's focus at all times and guides the interview situation. The majority of the interview is thus centered around following up and exploring different aspects of the interviewee's experience as thoroughly as possible. The process of continuous probing and directed following up of comments makes the phenomenographic interview by nature more intimidating than a traditional qualitative interview (p. 5).

As phenomenography "aims to describe the key aspects of the variation of the experience of a phenomenon rather than focus on the richness of individual experiences" (p. 2), the findings were written to align with a phenomenographic approach. Therefore, novice and expert learners' understanding, representations, and discourses regarding geologic time were summarized together within each category to emphasize collective as well as individual meaning, instead of only separate, individual experiences with no overlap.

Finally, phenomenographic analysis focuses on the conceptions learners have about the phenomenon and the relationships between the conceptions. As this work focuses on learners understanding of events in time, their relationships to one another, along with their ideas of scale and proportional reasoning, phenomenography was used in the development of the activity and data analysis to understand how geologic time is understood and experienced by each learner. Understanding and experience is expressed through learners' representations of events and scale on a model and discussions of the strategies and reasoning throughout construction of the model. Phenomenography further supports this work and the theoretical framework as it looks at two different groups, expert and novice learners, understanding of the geologic time, as well as their backgrounds and beliefs.

To summarize, data collection and analysis in this dissertation was grounded in phenomenography, as the study was a qualitative, model-eliciting activity that employed semi-structured, task-based interviewing. Learners reflected their understanding, representation, and discourses about geologic time, and on the process of their learning by discussing the strategies used to complete the modeling activity. After data collection and transcription, findings were determined through emergent coding rather than predetermined coding to align closely with learners' experiences and discourses. The phenomenon examined was learners' thinking about geologic time, and was represented the variation between two groups of learners, novices and experts. A phenomenographic approach was used in conjunction with discourse analysis in particular, as a "phenomenographic analysis does not have the same focus on linguistic elements" (Collier-Reed & Ingerman, 2014, p. 6). Therefore, to make up for the short-comings of phenomenography, discourse analysis was used to best capture learners' experiences and identities reflected through their language, practices, and sources of knowledge. The data, which includes learners' utterances or verbal language, gestures, body language, reasoning during model construction, used to communicate their experiences with geologic time, are understood to be indicative of learners' ideas, knowledge, and geologic practices from the learner's perspective, as the questions focus on learners' "ways of talking and reasoning" (Säljö, 1997). Therefore, a phenomenographic approach was used to examine the phenomenon of learners' understanding of geologic time, while discourse analysis was used to gain insight into the meaning embedded in their thinking, representations, and discourses.

An understanding of geologic time is fundamental to all geoscience courses. Learners must comprehend temporal ordering, duration, and scale to use geologic time. Therefore, it is logical to examine the prior knowledge and practices of novice learners entering the university and how they compare to the knowledge and practices of experts in the geosciences. In this research, *expert* refers to graduate students majoring in a geoscience field. *Novice* refers to any student that does not have a geoscience background but is enrolled in an introductory geoscience course. Examining learners' prior knowledge and skill development is important for two reasons: 1) Students with socially, ethnically, and academically diverse backgrounds bring a range of knowledge that shapes their conceptions and beliefs about geologic phenomena based on their prior experiences (Stokes, 2011). Learners enter a geoscience course with existing conceptions about geologic time, but because these conceptions may or may not align with those of the course being taught, it would benefit both the instructor and the student to identify these conceptions and address students' understanding. Therefore, with the increasing diversity of the student population, an emphasis on "student success has become more prevalent" and "must be addressed for all students to have a fair chance of succeeding academically" (Stokes, 2011, p. 23); 2) Deficit language has been used to discuss novice learners' abilities entering introductory Earth Science courses, specifically the lack of knowledge and skills to be successful (Bianchi, Whitney, Breton, & Hilton-Brown, 2002; Valencia & Solórzano, 1997) in the Earth Sciences.

Research Design

Research was conducted using a cross-sectional qualitative design. "In a cross-sectional study, the researcher compares two different groups within the same parameters" (Williams, 2011, p. 67). A cross-sectional study can be conducted at one point or over a short period of time (Levin, 2006). As the study did not include an examination of change in learning over a period of time, each learner participated in the activity once with the researcher. Novice learners met with the researcher at the beginning of the semester before geologic time was discussed in their geoscience course. This was to ensure that the researcher gained knowledge of the conceptions about geologic time that novice learners had entering the university classroom. As the experts have already learned about geologic time, they were not restricted to participating at the beginning of the semester. Expert learners' activity and task-based interview was conducted throughout the semester.

Although there is great value in quantitative research methods, they were not chosen to support this study. Quantitative research methods are highly valuable in distinguishing the role that various factors have in students' conceptions of geologic time, however this research is not intended to determine which variables are statistically significant in learners' conceptions of geologic time. Significant research exists on the factors that affect learners' conceptions of time, as discussed in chapter two. This research was designed to explore the variations and similarities in novice geoscience and expert learners' representations and discussions of geologic time and what those conceptions can tell us about how they understand and learn geologic time. "Reliance on quantification implies that only certain questions can be asked", specifically those that can be represented statistically (Cheek, 2010b, p. 146). A key strength of qualitative research is the richness and volume of data that is created (Cheek, 2010b). As the questions in a task-based interview are generated based on learners' responses and movements during an activity, each question cannot be represented numerically or analyzed statistically. Finally, quantitative research samples are typically large and are chosen to represent a large population. As this research was designed to employ interviewing to gain in-depth knowledge, a large sample size could have taken years to transcribe, code, and analyze. Although this limits generalizability of results, a small sample size was chosen to support the goals of the research to gain insights into learners' understanding, representation, and discussions of geologic time. Regardless of how this translates to an entire population, the insights into novice and expert learners' strategies, discourse, and representations is still useful.

Finally, there was a limitation to using a cross-sectional design. Cross-sectional designs generally represent an entire population. Random sampling is the best way to guarantee the sample used is representative of the entire population. However, this research required participants to volunteer, which is not random sampling. At the time of recruitment, it was not possible to identify the motivations of the volunteers for participating in this study. The backgrounds of the learners are discussed later in this chapter, under *samples*.

Activity Design. The geologic timescale activity is a three-part activity, adapting prior work with scale (Fidler, 2009a, 2009b; Tretter et al., 2006a and 2006b) to geologic time. Part I, *event ordering*, focuses learners' conceptions of events, their relationships, and how these events are ordered. Learners were presented a blank geologic timescale to examine how they represented the order and relationships between events in time, as well as their spatial relationship which is not explicitly discussed in the interview until part III. This is done intentionally to see how learners are thinking about spatial and proportional reasoning throughout the activity. Part II, *assigned values*, focuses on values of time, establishing the numbers participants assigned to these events or duration of time between events in their mind. This was done in two parts. Learners were asked to assign values without having any other numbers on the timescale. This was done to gain an understanding of the values they had in their minds without providing any scale that may alter their conceptions. Learners were then provided values for *present day* and *Earth's formation*. These two "events" were on the timescale model from the beginning of activity. Learners were then able to adjust their model if they choose to. Part III, *scale*, focuses on learners' conceptions of event scale and duration using scale cards. Learners were provided another card sorting task to gain an understanding of learners' conceptions about the scale of geologic time. Findings from a pilot study resulted in adaptations to the activity, which will be discussed at the end of this section.

Task-based interviews and model-eliciting activity. As previously discussed in chapter two, task-based interviewing is a method to examine a learner's strategy for solving a task, revealing their thinking through their actions and explanations (Goldin, 2000). Task-based interview questions are typically structured to easily compare learners' responses; however, questions can be semi-structured depending upon the task design. For example, in geologic time research, general questions regarding strategies for completing a timescale were the same for each participant, however the follow-up questions varied based on the participant's explanations (see Table 3.1).

Table 3.1
Examples of task-based interview questions and intended answers

Question	Intended answer: what should be described by the learner
What was your strategy for placing the event cards in this particular order? (This is the initial question after every participant has completed ordering the event cards)	1. A description of how the learner choose to order the events 2. A card-by-card description of why the learner choose to group cards 3. A card-by-card description of the relationship between event cards 4. What the event card meant to them (not all participants begin describing 2 and 3, therefore, follow-up questions are asked)
What made you place these cards together? (If learners grouped cards together)	1. A card-by-card description of the relationship between event cards 2. A description of why event cards were not put with other event cards
You placed x card here, what prompted you to place it here? (For clarification or to address specific event cards)	1. A description of how the learner choose to order the events 2. A card-by-card description of why the learner choose to group cards, if they did or why they kept a card by itself

Task-based interviews were conducted while the learners participated in a model-eliciting activity (MEA) since the model-eliciting activity reveals student thinking through the talk or actions the participant makes while completing the activity. This design was important for two reasons: 1) it allowed the participant to discuss and think through model construction during the activity. Explaining their thinking also gives the participant an opportunity to evaluate it. For example, during the pilot study, all five participants placed their event cards on the timescale. As learners discussed their reasoning, they found connections between other event cards or they remembered something about the particular event that resulted in them moving the event cards. 2) Conducting a task-based interview during the MEA allowed the researcher access to the participants' thought process as they completed the task versus waiting until after it has been fully completed or days later. This meant the information was fresh in the participants' minds and would not be forgotten.

Learners conducted the MEA one-on-one with the researcher. The pilot study was conducted with a group of students and with students one-on-one to see which method would provide the most in-depth information into learners' understanding and discussions of geologic time. With a small group of students, one person dominated ordering the event cards and explaining the reasoning for arrangement of the cards. Having more than one participant perform the task at a time did not allow the researcher to gain an understanding of each individual's representation of time. Thus, it was decided that only one participant would be examined at a time.

Geologic Timescale Activity Part I. After the learner read and discussed the IRB consent form with the researcher, the learner was given a survey about their educational background. The initial survey only included their name, major and science background. The revised survey includes their reasons for participation, mathematics background, and previous experiences with geologic timescale (see Appendix A). After completion of the survey, participants were given instructions on Part I of the timescale activity.

In Part I, learners were given a blank geologic timescale 4.6 meters long and approximately 0.3 meters wide. For the sake of clarity throughout the dissertation, the blank geologic timescale learners worked on throughout the activity will be referred to as the *model*. The term *geologic timescale* refers to the timescale established by geologists. The model was scaled to 4.6 meters to represent 4.6 billion years of time. Learners could place the event cards in any order, essentially providing their cognitive map of geologic time. The only indications of *time* on the model in Part I were the phrases *present day* and *Earth's Formation*; the rest of the model was left blank to observe where learners would place the events given only those two key phrases.

In addition to the scaled model, learners were provided geologic event cards to place on the model. Eighteen events were chosen based on conversations with geosciences faculty and staff during the pilot study. Event cards represented key points on the geologic timescale that these professors and staff members expected learners to know prior to the onset of the geoscience course. These event cards, their description, and the value in time they represent are presented in Table 3.2. For clarity, event card titles were italicized to separate them from the text. The first learner to participate in the activity was an expert learner who immediately noticed a card for *amphibians first appear on Earth* was not provided. At the end of the activity, each subsequent learner was asked where they would have placed an amphibians card if they were provided one, and prompted for their reasoning of the placement of the event. The question was asked at the end of Part I in case the learner brought it up conceptions of amphibians on their own. This was done for consistency among each learners’ questioning and discussions.

Table 3.2
Geologic Timescale Event Cards and Dates

Date (value of time)	**Name/Description of the Event**
0 years	*Present Day*
2.5 Ma	*Humans first appear on Earth*
45 Ma	*Large mammals first appear on Earth*
65 Ma	*Dinosaurs go extinct*
65 Ma	*Asteroid hits the Earth*
130 Ma	*Flowering plants first appear on Earth*
150 Ma	*Birds first appear on Earth*
200 Ma	*Pangea begins to break apart*
225 Ma	*Small mammals first appear on Earth*
230 Ma	*Dinosaurs first appear on Earth*
270 Ma	*Pangea forms*
320 Ma	*Reptiles first appear on Earth*
360 Ma	*Trees first appear on Earth*
370 Ma	*Amphibians first appear on Earth***
425 Ma	*Vascular (Land) Plants first appear on Earth*
530 Ma	*Fish first appear on Earth*
2.3 Ga	*Enough oxygen to sustain life*
3.5 Ga	*First evidence of life on Earth (cyanobacteria)*
3.5 Ga	*Photosynthesis begins on Earth*
4.1 Ga	*Earth's atmosphere forms*
4.6 Ga	*Earth's formation*

*Ma refers to million years and Ga refers to billion years
***Amphibians first appear on Earth* was not a card presented to learners for the task.

Learners were provided *event cards*: pictures of events in time, glued to a piece of cardboard for stability, with a straw taped to the back. Event cards were approximately 10.2 centimeters (4 inches) long and 7.6 centimeters (3 inches) high. The size of the event cards might have prevented learners from overlapping and showing the exact place the learner wanted the event to be represented. For example, if the learner placed an event card that is 10.2 centimeters long on the model, that represents 10 million years (Table 3.2). If the learner wanted to place two events as occurring within 5 million years of one another, placing event cards that next to one another would take up 20.4 centimeters or 20 million years, which would result in a 15-million-year discrepancy. To avoid this confusion, a straw was added to the back of each event card to use as a marker indicating where the area on the timescale indicating the event card's placement. Below is an image of the event card, *dinosaurs go extinct*, with the stick attached to the back (Figure 3.1).

Figure 3.1: Image of the event card *dinosaurs go extinct*

Please note that the term *first appeared on Earth* was used instead of *evolved* for event card descriptions that contain organisms. This was not to take away from the scientific description or value placed on the event. Some learners might not believe in evolution or may struggle with those concepts. However, it was important to ensure that all learners would feel comfortable completing the activity and hopefully, would open the door to a discussion about their beliefs, how they came to be, and most importantly, how they thought about geologic time.

A picture of the geologic timescale model, including all of the event cards in the correct temporal ordering and spatial representation, has been provided below (Figure 2). The picture displays the basic setup of the activity with the blank timescale (white, paper background), the post-its at each end marking *present day* on the left side of the timescale and *Earth's formation* on the right side of the timescale.

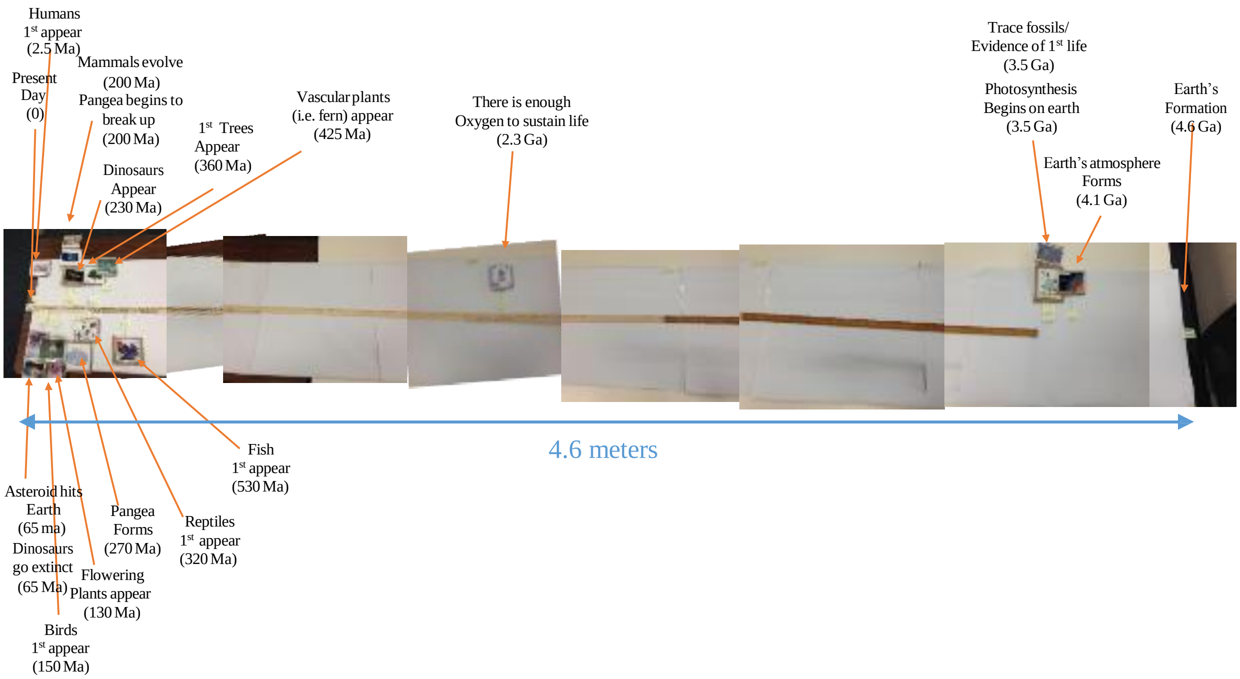


Figure 3.2: Composite image of the geologic timescale activity setup

Part I sought to gain an understanding of 1) how learners picture the connections between events in geologic time and 2) it served as a reflection of their ideas of event duration (e.g., how long the event lasted or time between events). With the scaling of the timescale to 4.6 meters, 1 millimeter represented 1 million years (Table 3.2). Therefore, the straw used to mark a more precise placement of the event represented 1 million years of time.

Table 3.3
Geologic timescale activity: scale of the model

Meters	Years
100 centimeters (1 meter)	1 billion years
50 centimeters	500 million years
10 centimeters	100 million years
1 centimeter	10 million years
1 millimeter	1 million years

Geologic Timescale Activity Part II. Part two focused on the learners' perceptions of duration and scale of geologic time. In order to understand the magnitude of geologic time, it was necessary to understand how learners think about large numbers, which also reflected their understanding of the relationships between conventional and deep time. After completing Part I, learners were given post-it notes and a pencil to write down the value of time they thought the events occurred and place them on the timescale. Post-it notes allowed learners to easily move their values around on the timescale as they thought through the activity.

Learners were not given any tick marks or indications of how large the timescale was until after they were provided with values of time for *present day* and *Earth's formation.* This was done intentionally to gain as much understanding of their ability to depict the order and duration of events in time as possible. After learners assigned their initial values of time, called *original assigned values*, they were provided with values of time for *present day* and *Earth's formation*, 0 years and 4.6 billion years, respectively. Learners were then able to keep their original values or change their values if they chose to. If values were changed, they were referred to as *secondary assigned values*. The values for *present day* and *Earth's* formation were provided for a few reasons. The first was to see if learners would change their assigned values based on the new values provided. Second, if they did change their values, the goal shifted to identifying the learners' reasoning for this change. Finally, this allowed for further opportunity to identify how experts and novices differed with their strategies and reasoning to scale the event cards.

Geologic Timescale Activity Part III. In Part III, learners were given a second card-sorting task. Learners were given a second set of cards. Each card had a picture with a scale, as shown in Table 3.4. The scale related a distance to a particular amount of time. For example, a football field is roughly 100 meters long. The image of the football field on the card represented 100 meters equal to 100 million years on the timescale, which was stated on the card (Figure 2). Therefore, the learner could place the football field card on the timescale where they imagined it representing 100 million years as an increment of time, where they thought a duration of 100 million years was between events, or use it to add up to another value. The equivalent of the amount time in years to spatial scale were provided for two reasons, 1) learners would not be able to forget to use units of time or chose random units of time at this point in the activity, and 2) to keep the units consist and easily compare between novice and expert learners. Iconic statues, animals, buildings or objects were used that a novice learner might recognize to try to help the learner conceptualize a relative scale. It was expected that learners would use multiple scaling cards to create their scales. Therefore, multiple scaling cards were provided for learners to combine cards and values. Additionally, values were provided in meters to be consistent with the scale of the model, as it was 4.6 meters in length.

Table 3.4
Geologic Timescale Scaling Cards

Scale	Distance	Name/Description of the Scaling Card
2.5 million years	2.5 meters	Average door to a house
5 million years	5 meters	Length of Hummer H1
20 million years	20 meters	Length of a sperm whale
40 million years	40 meters	Distance from A to B
45 million years*	45 meters	Statue of Liberty (not including base)
50 million years	50 meters	Height of the Arc de Triomphe
65 million years	65 meters	Boeing 767 400 ER Jet
100 million years*	100 meters	Length of the average football field
150 million years	150 meters	Great Pyramid (Giza)
200 million years	200 meters	Small airport runway
300 million years	300 meters	Height of the Eiffel Tower (Paris, France)
400 million years	400 meters	Quarter mile
500 million years	500 meters	CN Tower in Toronto, Canada
1200 million years	1200 meters	Faneuil Hall to New England Aquarium (Massachusetts)
1600 million years	1600 meters	Golden Gate Bridge
1700 million years	1700 meters	Average airport runway
1900 million years*	1900 meters	Akashi-Kaikyo Bridge
2700 million years	2700 meters	Golden Gate Bridge

*Notes that a time was rounded up for ease of finding a matching distance
A to B refer to specific locations on a university campus. To protect learners in this research, the names of the specific locations have been removed and placed with the letters A and B.

Development of the geologic timescale activity: The role of the pilot study

A pilot study, containing a series of preliminary task-based interviews based upon the literature examined in chapter two, preceded the main study. The pilot study was designed to develop and test the interview protocol and design, in order to give future participants better tools for sharing their ideas throughout the activity. Finally, small changes were made based on the pilot study, summarized in Table 3.5.

Table 3.5
Activity design: changes made based on the pilot study

Pilot Study Design	Final Design
Group of learners complete activity	Individual learners complete activity
Individual learners complete activity	Survey of students' backgrounds
Consisted of 17 event cards	Consisted of 18 event cards
Event card: *mammals appear on Earth*	*Mammals* event card was split into two separate cards: *small mammals* and *large mammals appear on Earth*
No scale cards were provided; Parts I and II only (event ordering and assigning values)	Scale cards were added to ease learners' mathematical anxiety associated with assigning values and thinking about scale

Samples and data collection

Samples. This study examined learners in introductory geosciences courses, as well as geoscience graduate students, to understand how learners at the graduate level think about geologic time versus undergraduate students whose focus is not in the geological sciences. The sample consisted of seven learners: five undergraduate learners and two geoscience graduate students of varying geoscience majors. All volunteers were from the same university in New York State. Learners ranged in age from 18-31. Demographic information from the survey can be found in Table 3.6.

All learners were given gender-neutral pseudonyms. Five females and two males participated in the study. However, the gender will not be listed with the associated pseudonym. Although social constructs such as gender, race, and class are typically included in discourse analysis and are used heavily in STEM education research, these constructs were left out of this study's results. First, gender was irrelevant in terms of answering the research questions. The study was designed to look at learners' representations, understanding, and discourse between novices and experts, first and foremost. Therefore, gender was not meant to be the focus of the study.

Second, upon reading the transcripts, the content knowledge and conceptions did not vary significantly between males and females. Therefore, there were no conclusions or strong evidence to justify summarizing a comparison between males and females. Due to this finding, I felt discomfort assigning gender labels to the learners. Third, as the research study included only seven participants it would be difficult to summarize and generalize similarities and differences in male and female thinking about geologic time, especially when there were only two male participants.

Finally, race and class were not asked for in the survey questions, and therefore could not be identified. The study was intended to gain insight into overall understanding of geologic time, based on learners' conceptions including event ordering, assigning values, and scale determination by novice and expert learners. While social constructs are useful for gaining insight into individual learning and strategies to understand ways to make geologic time more accessible for all learners, the themes and codes that emerged in the data did not reveal any significant insight based on examination with these constructs in mind.

Additionally, as audio and video recordings were collected to analyze data, these are considered identifiable data. Audio and video recordings were kept in a password protected excel spreadsheet on a laptop used only by the researcher and her advisor. The original names and pseudonyms were kept in a separate locked file box.

Table 3.6
Learners' Demographic Information

Learner	**Age**	**Major(s)**	**High School: Science Courses**	**College Science courses**	**Mathematics Courses**	**Experience with geologic timescale**	**Reason for participation**
Cameron, Novice	18	Political science (pre-law track)	Honors biology, Honors chemistry, AP Biology, AP Environmental Research	Introductory Earth Science	Algebra I & II, Pre-calculus, Honors calculus	Middle school earth science (while reading the textbook only)	Interested to see how you research on geologic time; extra credit
Frankie, Novice	19	Environmental Engineering	Earth Science, Biology, Chemistry, Physics	General Chemistry I & II, Physics I, Intro. Earth Science	Algebra I & II, Geometry, Pre-calculus, calculus III	Learned the "idea" of the age of the earth and how little humans have been a part of it	Never been the "subject" in a study and thought it would be interesting; enjoys learning about earth science and thought it would benefit learning the subject
Harper, Novice	18	Sport Management	Earth science, biology, chemistry, physics and environmental science	Introductory Earth Science	Integrated algebra, geometry, algebra II, trigonometry, pre-calculus	Frequently discusses in most science classes	Fulfilling a research participation requirement for another course
Mica, Novice	21	Broadcast and Digital Journalism, Sport Management	Biology, Chemistry, Earth Science	None	Probability and statistics	None	To help out in the study; extra credit

Learner	**Age**	**Major(s)**	**High School: Science Courses**	**College Science courses**	**Mathematics Courses**	**Experience with geologic timescale**	**Reason for participation**
Taylor, Novice	18	Sport Management	Biology, chemistry, physiology	None	Algebra II, pre-calculus/trigonometry, AP Calculus, AP statistics,	Middle school science courses	Fulfilling a research participation requirement for another course
Alex, Expert	31	Earth Sciences: Geochemistry	Chemistry, physics, mathematics, biology	Professional degree in Geology (32 courses)	Calculus I-IV	Several classes during undergraduate career	To "help understand difficulty in learning abstract concepts as well as see how good my own understanding of the geologic timescale is"
Jayden, Expert	27	Earth Sciences: Geochemistry	Chemistry, physics, mathematics, biology,	Undergraduate: BA in Biology (focus on ecology and evolution) College/Graduate school: Paleobiology, sedimentology, structure, paleoclimate, geochemistry	One semester of calculus and one semester of statistics	Natural history museums, interest in dinosaurs as a child and introductory geology course in college	The study "sounded interesting and maybe I will learn about how I think" Learner stated the "results from the study may help improve teaching"

Novice learners. Five novice learners were recruited from an introductory geoscience course in the fall of 2015. A faculty member of the geosciences department, not the researcher of the study, taught the introductory geoscience course. The course was designed to meet general education requirements for the university; thus, it included learners from a variety of majors. This particular geoscience course enrolled approximately 180 students.

To be included in the study, learners needed to be enrolled in the introductory course. Learners had varying backgrounds in the geosciences. As they may have had geoscience or Earth Science courses in high school prior to entering the university, they needed to provide their experience with the geosciences. Additionally, to gather information about whether the learner was a geoscience major, they were asked to specify their major. Geoscience majors may not be enrolled in an introductory-level course, unless they do not have a prior background. Novice learners enrolled in the introductory geoscience course could not be graduate students or taking graduate-level classes. They also could not have taken geoscience courses at the 300-level or above to be included in the study. Additionally, novice learners could only participate if they had taken one other introductory-level science course. For example, a learner could be a senior in communications fulfilling their science requirement with a two-course introductory science requirement.

The professor of one of the introductory courses where participants were recruited from wanted to assist the research study by offering bonus points to help recruit participants. Each learner who participated received nine bonus points for the research study, equal to one additional assignment. Additionally, learners who did not wish to participate in the research study, but would like bonus points, were offered an alternate assignment by the professor. The alternate assignment required approximately the same time and effort as the time and effort required to participate in geologic timescale activity. Bonus points were awarded at the end of the semester when the professor added all assignments with bonus points. Offering extra credit was a good way to increase participation. However, there were drawbacks to offering extra credit. For example, learners may not have been fully invested in their answers or time spent on the activity, as they would get credit for participation regardless of effort.

Novice learners were given a maximum of two weeks to consider their participation in the study. As the study was dependent upon their initial ideas and thoughts about geologic time, it was important that the study start as early as possible in the semester before they had class material that discussed geologic time. Geologic time material was not covered until mid-semester, approximately ten to thirteen weeks into the semester.

Expert learners. Graduate-level participants had to be currently studying in the Geosciences department only. As they already learned about geologic time, there were not any time constraints on their participation. The experts, Alex and Jayden, focused in geochemistry, but Alex had a specialty in hard-rock processes in the Earth Sciences. Hard-rock processes can include mineralogy, petrology, geomorphology, and geochemistry. Jayden’s specialty was focused on the biological aspects of the geosciences, such as ecology and evolution.

Data Collection. Task-based interviewing allowed for observation and recording learners’ actions, representations, and discussions while completing the model. Audio and video devices were used to record data: these collected all learners’ descriptions and reasoning during the activity and interview. Recordings were used to further study learners’ reasoning that may not have been noticed during the interview, specifically strategies for placing events on the geologic timescale, their reasoning for how they spaced the events in relation to one another, and their discussions of their understanding of scale.

In addition, video recordings of the participant's hands while placing event cards on the timescale while they are talking (to record their gestures) were obtained. Video recordings were taken using iPads placed on stands above the table where the learner worked on the model. This recorded the changes learners made to the model and where they placed assigned values on the model. Questions were asked about event card movement, but the video was used to record actions or words missed during the task-based interview. The iPad was not aimed at learners' faces but at their hands in order to keep each learner unidentifiable. Although video recordings supported this research by capturing actions it was not infallible. There may have been key expressions learners made that could have provided insight or supported interpretation of language learners used. However, anonymity was chosen over capturing these expressions. Technology is not always reliable. Two interviews were conducted back-to-back and the iPad battery died during the second interview. The last 20 minutes of the second interview were lost.

Data Analysis

In order to compare novice and expert learners' model construction, interviews were first transcribed. Verbal data were then coded by emergent coding and examined for similarities and differences in event ordering, value assignment, and scaling strategies. After the transcription and coding process, digital scaled versions of learners' models were constructed and examined to determine percent error in learners' models in terms of event order, event placement, and scale, including the assigned values and scale card use, and their placement. Discourse analysis was conducted to examined the words and phrases commonly used and repeated by novice and expert learners, their sources of knowledge, and how that related to their identity with the geosciences. Table 3.7 outlines the research questions, source of data, and the method(s) of analysis for each question.

Table 3.7
Methods of analysis: discourse analysis

Research Questions	Data	Analysis
How do learners understand and represent the placement of events and their relationships on a blank timescale?	Geologic timescale activity Part I Task-based interview	Data sources to answer the question: Examination of temporal ordering of event cards on model and learners' discussion of the strategy for ordering events and relationships between events. Discourse Analysis: Ways of representing: information focus, lexical relations, lexicalization and relexicalization (Rogers, 2013); funds of knowledge (Moje, 2008)
How do learners understand and represent the scale of geologic time?	Geologic timescale activity Parts II and III Task-based interview	Data sources to answer the question: Examination of learners' assigned values of time and scale cards compared to placement on the model (duration and scale), and reasoning for how they determined the values and used the scale cards. Discourse Analysis: Ways of representing: information focus, lexical relations, lexicalization and relexicalization (Rogers, 2013); funds of knowledge (Moje, 2008)
How do learners discuss their conceptions about geologic time? And what do these conceptions about geologic time reveal about their prior knowledge and science identities?	Geologic timescale activity Parts I, II, and III Task-based interview	Data sources to answer the question: Use of discourse analysis methods to analyze what learners know about geologic time, how they talk about it, and what sources they draw on for understanding. Discourse Analysis: Ways of representing: information focus, lexical relations, lexicalization and relexicalization (Rogers, 2013); funds of knowledge (Moje, 2008); strategies, and identity to the Earth Sciences affinity group (Gee, 2000)

Under the analysis column in table 3.7, the source of data to answer the question is provided. However, the data is not presented as such in this dissertation. For the ease of reading and understanding, the findings are presented as three separate chapters: a chapter on event ordering, a chapter on scale and duration as understood through assigned values and scale card use, and a chapter on findings from the discourse analysis.

Transcription. Participants' language while conducting Parts I, II, and III was a large part of this data set. According to Lemke (2012) "verbal data can only make sense in relation to the activity context and to other social events and texts with which we normally connect them, their intertexts. Meaning is not made with language alone" (p. 1474). Therefore, the actions in the activity and the verbal data obtained during the task-based interview cannot simply be separated. In order to make meaning from the geologic timescale activity, participants' speech and body language, "situational and paralinguistic (e.g., pitch, volume, intonation, etc.,) information" along with coding of words and actions (p. 1474) obtained during the geologic timescale activity were included. Therefore, the "meaning of any text or discourse event always depends on how we connect it to some (and not other) texts and events" (p. 1474) (on general intertextuality, see Lemke, 1993).

Verbal data were not analyzed directly from collection, or from the audio and video recordings, but from written transcriptions (Lemke, 2012). Transcription provides a new text to be analyzed (Lemke, 2012). Transcription of the original verbal data began by utilizing the preliminary analysis methods described in Bogdan and Biklen (2006) for the original transcription methods. These methods included using software to playback the audio recordings for transcription, writing words verbatim, using a new line every time a new person spoke, noting who the speaker is, marking intonation and breaks in speech, and leaving room for "coding and comments" (p. 129). Transcriptions were combined with the descriptions of the people, actions, and setting from the field notes into the transcription, in order to best capture the observer's frame of mind (Bogdan & Biklen, 2006).

Audio recordings were uploaded to software program *Dictapad* (Panchromatic, LLC, 2015). Dictapad allowed for the interview speed to be reduced in order to capture each word. Transcript construction included first listening and writing words verbatim at a reduced speed. The interview was then listened to again and the transcript was read at the same time to add or correct words and phrases, and pauses in speech. Pauses in speech had to be recorded in real-time otherwise they could be viewed as longer with the reduced speed used for the initial transcription. Gestures and body language from the field notes and video recordings were added in to more fully understand learners' movements and language during the activity.

Field notes taken during the task-based interview included body language, hesitations and gestures, as well as the ordering and questions to follow-up with learners during the activity. In terms of specific gestures, learners often pointed to areas on the model or event cards rather than saying the name of the event. Additionally, participants' posture, such as rigidity or relaxation, and facial expression, such as smiling, laughter, and blushing, were all included in the transcript to support the analysis of learners' conceptions and feelings while conducting the activity.

Coding. After the verbatim recordings and field notes were combined, the interview transcripts were read multiple times. Phenomenography guided the data analysis process. During data analysis, the data was read closely to find "similarities and differences in informants' accounts on how they experience/perceive the phenomena" (Kinnunen & Simon, 2012, p. 201). Transcriptions were first given general codes line-by-line, noting the actions of the participants or topics of their statements. These codes became the "preliminary categories" consistent with the emergent coding process (p. 201). As data analysis is an "iterative process", meaning the data were examined multiple times, these ideas were refined over multiple read-throughs (p. 201).

After the line-by-line coding, the second round of coding focused on the emergent codes and relating them to the research questions (Kinnunen & Simon, 2012). Words and phrases that captured a specific theme were highlighted and general descriptions of the theme were written by each highlight (Kinnunen & Simon, 2012). Each learner had a list of tentative themes. The themes were written out, and compared for similarities and differences. The codes were not theory-driven. Instead, they were "supported by observation in the transcripts" (p. 204). The transcripts were examined again to make sure the list of codes was "complete and consistent" (p. 204).

Finally, the last round was to "refine and redefine" the list of tentative of themes and codes (p. 205). The data was re-read this time for patterns. These patterns could include certain words, phrases, behaviors, subjects' ways of thinking, and events that repeated or stood out" (Bogdan & Biklen, 2006, p. 173). These patterns in words or phrases then became the coding categories. This type of coding is *emergent thematic coding* (Bodgan & Biklen, 2006; Male, 2016). Emergent codes were used in the first phase of analysis, as they come from the data set and were not pre-determined codes. The codes were then categorized and structured to reveal the relationship between codes and to the overall themes. The "outcome space revealed similarities and differences" among the novices and experts, as well as "hierarchical order in how some perceptions" were more sophisticated "than others (as seen from a pedagogical point of view)" (Kinnunen & Simon, 2012, p. 205). As these hierarchies were consistent with the expert-novice theoretical framework, the "last phase of analysis was both data and theory-driven" (p. 205).

Data were compared against the videos to look for participants' movements throughout the activity. Data were then coded the fourth and final time. Learners identity associated with the geosciences was reflected through their time spent on the activity, use of scientific terminology, science experiences discussed, sources of knowledge referenced, and the confidence or anxiety expressed through their body language.

This method of coding was done four different times: first as a read-through to familiarize myself with the data, followed by a general development of codes for the whole activity among participants, after that the event ordering, assigned value, and scale portions of the activity were coded, and finally for the words and phrases that stood out through learners' discussions of the activity that assisted them to make meaning throughout the activity. Code lists were made with examples from each learner for support. Memos were written about each code to define the situation of the code with the most salient examples from each learner that supported the code, as well as any counterexamples or negative cases, that contradicted the code.

As phenomenographic analysis of the data results in an outcome space constituting "qualitatively different categories of conceptions or ways of experiences phenomena", the codes were "not stand-alone descriptions of conceptions, but stand in relation to each other" (Kinnunen & Simon, 2012, p. 201). The codes "represent the variation of conceptions within a group of interviewees – not the variation of conceptions of an individual in a group of interviewees" (p. 201).

To overcome issues with rigor and trustworthiness of qualitative study, verification strategies were used to ensure acceptance by the phenomenographic community in terms of validity and reliability. First, I provided an "open and full account of the study's methods" (Cope, 2004, p. 8). As developing a relationship with the data is important for the researcher, it is essential to define the researcher's background as part of the relationship. In these accounts, I included my background to show my subjectivities while conducting this research. Illuminating my prior experiences as a geoscientist and with "scholarly knowledge of the phenomena" examined provides “context within which the analysis took place” for both myself and the readers of the study (p. 8). Additionally, backgrounds of the participants, design of the interview questions, and strategies to collect unbiased data, detailed accounts for data analysis, and an “approach to data analysis with an open mind rather than imposing existing structure” were justified and acknowledged (p. 8).

Triangulation, or cross-checking, of the data, as well as peer debriefings, were conducted by use of different investigators (Schwandt, Lincoln, & Guba, 2007). Themes and codes were often discussed with my advisor and other graduate students. The other graduate students were not involved in this study and therefore considered “external, disinterested peers” that could provide honest feedback and support, as they had no connections, involvement, or reliance on the data (Schwandt, Lincoln, & Guba, 2007). This was done through the entire course of the dissertation from developing and designing the study, to interpretations of quotes and themes for coding. Codes were fully described and adequately supported with quotes from the learners in the study (Cope, 2004; Schwandt, Lincoln, & Guba, 2007). The data provided was intended to be “thick, descriptive data”, ranging from learners’ thought processes and reasoning for event ordering, assigning values and scale, but also included a discourse analysis, so that results could be transferable (Schwandt, Lincoln, & Guba, 2007, p. 19). Thick, descriptive data allows for “judgments about the degree of fit or similarity may be made by others who may wish to apply all or part of the findings elsewhere” (p. 19). During the theme and coding process, negative cases, evidence that contradicted my interpretation, were also established or presented to provide “assurances of credibility, dependability, and confirmability of my interpretations about the value and appropriateness” of the situation (Schwandt, Lincoln, & Guba, 2007, p. 13). Furthermore, the data, participants’ thinking, was analyzed in multiple ways (e.g., phenomenographic analysis of learners' reasoning and discourse analysis) including both the artifacts of model creation as well as the careful record of how learners went about conducting meaning through the activity. Finally, I try not to overextend the claims made in the study by being forthcoming and acknowledging what I deem to be the limitations of the study.

Event ordering, assigned value, and scale data analysis. After verbal data was coded, the 4.6-meter-long models were measured and smaller digital copies were made for comparison. Events names, assigned values, scale cards and their placement in centimeters were marked on the digital models. Tables were made for each learner comparing their event ordering and placement to the order and position in geologic time. The percent error was calculated for the event order.

Assigned values were represented and calculated to understand learners' use of scale and duration on their models. These were calculated in three different ways known as the *divergence*, *deviation*, and *distinction*, and were represented in absolute value. The divergence was the placement of assigned value on the model and the value that position on the model represented. The deviation was the difference between the assigned value the learner chose and the event's value according to geologic time. The distinction was the difference between the learner's assigned value and the value represented by placement on the model. These values were compared between learners.

Finally, scale card values were examined to further understand learners' use of scale constructing their models. Scale card values were compared to their placement on the timescale, and the difference was calculated known as the *dislocation*. As learners used various assigned values and did not use the scale cards in the exact same way, percent error could not be calculated to compare among each learner.

Strategies that learners used for each part of the timescale activity were listed out and compared to understand the methods they used to construct their models. These strategies were then examined for similarities and differences. Similarities and differences were first established for the novices and then the experts, and then the two groups were compared for similarities and differences between the two groups. After the strategies were compared, the data was examined for similarities and differences in language, practices, and sources of knowledge.

Discourse Analysis. Verbal data obtained during the task-based interview were analyzed to determine which phrases were commonly stated and repeated by all learners. Further, the sources of knowledge, known as *funds of knowledge*, were identified to gain insight into how learners construct their knowledge. For analysis of the verbal data, discourse analysis techniques were employed.

To examine verbal data, this research employed discourse analysis to examine learners' talk about geologic time over the course of the activity. Discourse analysis assisted in revealing how the learner used language to express their learning of scientific phenomena, semantic patterns in the learners' dialogue, and examined how their meaning is produced and explained. Examination of discourse between the researcher and the participant revealed learners' conceptions, scientifically correct or alternate, as well as the source of learned knowledge. Participants' actions, such as their ordering of event cards, assigning values of time to the events, event duration and the scale of geologic time, rearrangement of events, and how participants interpreted the events were examined (Gee & Green, 1998). Examination of learners' moment-by-moment actions and discourse provided an opportunity to understand how learners construct their existing knowledge during an activity (Gee & Green, 1998).

To analyze learners' construction of their existing knowledge, this dissertation drew on the work of Elizabeth Moje, Rebecca Rogers, and James Paul Gee. The next two sections present the methods of discourse analysis used throughout this dissertation.

Funds of knowledge. Learners were prompted to provide their reasoning for placing event or scale cards in particular areas or how they assigned values to their models, as well as when or where they learned this information. Sometimes learners volunteered this reasoning without prompting from the researcher. Participants cited various *funds of knowledge* (Moje, 2008; Moll, Amanti, Neff, & Gonzalez, 2001) for their reasoning ((e.g. school, social networks, museums, group practices, etc.,), experiences, beliefs, or practices of knowledge. Citations to various funds were then coded as existing within an institution, such as a university or media, or from particular groups, such as the geoscience affinity group. Comparisons were then made between the expert and novice learners to establish similarities and difference between types of funds used by the two groups of learners.

Identifying learners' funds of knowledge was important as it allows insight into what knowledge and sources learners' draw from when constructing their model. This can assist with addressing alternate conceptions, and designing tasks to further their own knowledge construction. Lack of articulation and understanding of learners' funds of knowledge can "hinder learners' deep conceptual learning in science because students and teachers use the same words but mean very different things" (Moje, 2008, p. 344). Therefore, it was important to gain insight into learners' funds of knowledge for construction a geologic timescale model.

Finally, becoming a member of a scientific community, especially a scientific discourse community, can be challenging as learners "encounter different ways of talking, reading, and writing (discourses) in their science classrooms". Knowing the various funds in which learners use to engage in scientific practices and discourses reflects learners' identities with the scientific community, specifically the geosciences for this research. However, as Moje et al. stated in 2007, that although identities are *enacted* in times, spaces, and relationships", "Gee's (2000, 2001) notion of identities as *recognized* by others is critical to theorizing how identity matters in learning" (p. 593). It is important to note that this research distinguishes the ways of knowing and doing that the learner exhibits through their practices, funds of knowledge, and discussions throughout the activity. As "identities shape and are shaped by practices that include material dimensions" (Moje, Tucker-Raymond, Varelas, & Pappas, 2007, p. 595), such as the geologic timescale model, the combination of the practices, funds, and discussions reflect the learners' identities associated with the geoscience community. Therefore, there was an interpretation of the reflected identities throughout the activity, meaning that it is how the researcher used various features to recognize their identity throughout the activity. However, funds of knowledge allow the learner agency and power in their learning as they were able to incorporate links between their funds and school practices.

Ways of representing. Rogers work in discourse analysis, specifically participants' "ways of representing" (Rogers, 2013, p. 32), refers to the "ideational component of language or discourse" (p. 25). This assisted in focusing on the ideas that were represented and foregrounded, the selection of words and their repetition and themes that were presented during the activity. Table 3.8 outlines the questions that guided the analysis of participants' ways of representing their geologic timescale knowledge.

Table 3.8
Guiding questions to analyze learners' discourse in *ways of representing* geologic timescale knowledge

Discursive feature	Description of feature or interaction	Guiding questions
Information focus	Themes that are represented in the first part of the clause and are generally the known information	What ideas are represented? What information is foregrounded by being in the theme position?
Lexical relations	Relation and classification of experiences through an unfolding series of activities	What social categories underlie the lexical strings in the text? What taxonomies are represented?
Lexicalization	Selection of wordings	How are ideas represented through word choice? What is the level of formality?
Relexicalization	Renaming or re-voicing of words	What words or phrases show up again and again in the transcript?

From Table 2.A.3 on page 32 in Rogers, R. (2013). Critical discourse analysis in literacy research. *New Methods of Literacy Research*, 19.

In addition to using Rogers' work for analyzing verbal data, discourses of learners' responses were analyzed by drawing on the work of James Paul Gee. Gee's work on identity (2000, 1989) as well as Moje's work on funds of knowledge and science identities was used to establish learners' identities associated with the geoscience affinity group throughout the activity. In order to assist in curriculum or activity development, changes in pedagogical practices, and to better understand how learners' construct knowledge (toward expertise), it is necessary to understand how the learner draws on their preexisting knowledge, the fund they draw from, and how they feel and associate with the geoscience community.

In order to identify and analyze the domains and discursive features of participants' talk, transcript data was broken down into lines and stanza's following Gee's model (1989) during the third round of coding. Lines are "simple clauses, a verb of saying and what is said, or a "heavy" pre- or post-clausal modifier, for example, something like: "and then you know just all of a sudden" (p. 288). Lines tend to begin with conjunctions such as "and" or "but". A stanza is a "group of lines about a single topic with its function to mark a perspective" (Gee, 1989, p. 288).

In other words, a new topic or viewpoint marks the start of a new stanza. Lines and stanzas foreground topics of discussion during the timescale activity and made it easier to establish patterns in the data to compare and contrast learners' discussions. Finally, by setting up the transcript data in line and stanza format, it allowed the researcher to determine foregrounded and backgrounded information, again to assist in establishing patterns in the data. The following example shows the breakdown of a task-based interview from the pilot study coded using Gee's lines and stanzas.

Table 3.9
Example of Gee's Model: Lines and Stanzas

Symbols	
A	Alex (name is a pseudonym - participant)
R	Researcher
-	self-interruption; break in the intonational unit
.	end of intonation unit; falling intonation
,	end of intonation unit; fall-rise intonation
…	pause for greater than 0.5 seconds
[ ]	clarification from the researcher
OC	observer comment (in this case, the researcher)

Stanza: Assigning values
R: How did you feel about having to add the numerical values to the post-its?

A: Uh,
that was really hard.
And I actually think that I have an idea of what the major events in geologic time are,
but not the numbers associated with those events.
So I think that that was harder,
cause yeah,
I can tell you when Pangea starts or when it breaks, but the actual time
…I know Pangea starts in the Permian [Pangea's formation],
but I don't really have a number for that, so it was hard to put into numbers.
Because we usually use the names on the geologic timescale a lot more than the numbers in a lot of situations,
it's much more common for us to discuss the name of when something happened but not the numbers.

R: That was my next question, how do you talk about it in class?

A: Right.
And so,

even in the short course that I did last week.
We were talking about the Devonian and the Marcellus Shales in the Devonian,
and I don't think in the entire course that anyone actually ever said one number.
It was discussed as Early Devonian or Late Devonian and that was it.
It wasn't 416-380 or whatever it is.
It's like,
hm,
it's harder.
So for the sake of just talking,
we talk about the ages or well,
the eras or even eons.
We talk about the Paleo-Proterozoic
and nobody talks about when does it starts or when does it finishes.
Nobody talks about what is the actual number of the beginning of the Archaean to the Paleo or Proterozoic,
or when the actual Archean starts and the Hadean ends.
Those numbers are really not used that often.

R: What do you think the reasoning is for that? For not using the values?

A: Uh,
I think it depends a lot on the type of geology you are using

R: Can you elaborate on that a little bit more?

A: Well,
uh,
so for example,
I found that if you're working with,
maybe I'm making this up,
but when I'm working with zircons,
what you're given is an actual number
and then you have to correspond it to the geologic timescale.
So when I'm working on my zircons,
I'm always thinking of the numbers,
like oh I have a 4.6 age or a 5-6-or 700 [Ma] or a 1 Ga and what happened in those ages?
So depending on what you are working with you can find the numbers more easily to manage.
In my paleo classes,
besides just studying the geologic timescale as a separate thing,
for the most part,
it was like,
when did trilobites start,
oh over in the Cambrian when did they die?
Shortly after
…so we didn't really use numbers.
I think in some classes or parts of geology using numbers is easier than others.

If I'm talking about ages of zircon populations,
I'm not going to use the ages or names of the periods,
I'm going to use numbers because it's easier.

From the example above, you can see the overall topic is assigning values. Individual events are foregrounded, indicative of the title of the stanza, while their placement in time in the discussion is backgrounded. The lines display breaks in ideas or thoughts or natural pauses by the participant. In addition, the use of lines and stanzas to display discourse data helped identify the information focus, word choice and ideas that were represented in the data clearly. Examples shown in the dissertation are kept in their original format, before line and stanza formatting, to reduce the length of the chapter.

Although the data analysis conducted examined learners' event ordering, assigned values, and scale cards prior to analysis of learners' discourse, the discourse findings are presented first in chapter four. As learners discussed their strategies and reasoning throughout the entire activity, it made sense to present their discourse first as the way they spoke and what they spoke about underpinned the findings presented in the card sorting and value assigning tasks. Waiting to present the discourse analysis until after the findings of learners' card sorting and value assigning tasks, meant that references could not be discussed until reaching the discourse chapter or were repeated. This structure reduces repetition and provides a foundation for the findings presented in chapters five and six.

Delimitations and Limitations

This study had several limitations and delimitations, listed below.

Delimitations. Delimitations to the study focused on the research setting, learners' responses, and elements of the activity's design.

1. This study was confined to a large, private university in upstate New York. However, the findings from this study can be applied to other colleges and universities. Although this study was conducted in one particular area, the task itself is easy to setup and events can be adapted based on what the instructor or researcher wants to learn about learners' backgrounds, content knowledge, or representations of time.
2. Learners' responses were reflections of their past experiences with science or lack thereof, as well as their own ideas about events in time and its magnitude. From the pilot study, non-majors had knowledge about events and they were able to order their events, but struggled to place them in an absolute temporal order and discuss event duration. Participants' event ordering was based on what they remembered learning (from school, television, museums, etc.…). Learners in the pilot study discussed where they learned something, or more specifically mentioning what they had not learned (e.g. Pangea), and how/when events occurred based on how it was explained to them or how they pictured the event. Going into the research, I anticipated that graduate students would discuss geologic time by using specific points in time that were significant to them, and they would be able to place those events on the timescale first and the other events around them. The possibility existed that graduate students in hard-rock geology (e.g. petrology or mineralogy) would struggle with portions of temporal ordering that were more biologically-based as they do not work with those events on a daily basis. Graduate students with paleontology-based backgrounds deal with a range of events in time, thus would be expected to have a better understanding of the general temporal ordering of events versus students that do not work with biologically-based events in time.

3. Non-major undergraduate participants were from one introductory geoscience course. There was not enough time to recruit participants from all introductory courses. An introductory course can contain 80-200 undergraduate students and the task took approximately one-hour to complete. There would be too many factors to control.
4. The events used were chosen based on what the researcher and various professors in the geoscience, chemistry, and biology departments viewed as most important for learners to know. The timescale activity had 18 event cards for the participants to order. When combined with a task-based interview, the activities took approximately one-hour to complete. More event cards would lengthen the activity, or require participants to focus only on the temporal ordering and relationships portion of the task, and less time spent on the spatial aspect of the task. Work on previous timescale events with only four event cards seemed to be too few event cards and did not provide enough data to examine students' understanding of relationships between events *through* time and where they were placed in absolute time. Therefore, informally interviewing professors about the events they deemed most important provided an understanding of what students were expected to know entering the university, as well as what events should be the basis of the activity.
5. The design of the model-eliciting activity was based upon combining two major themes in research on geologic time: 1) learners' understanding of temporal ordering and 2) learners' difficulty with magnitude on micro and macro scales.
6. Questions during the task-based interview were based on how learners placed event cards on the timescale. Therefore, some of the questions varied for each learner. For example, if a learner placed an *asteroid hitting the Earth* and then *Pangea breaking*

apart, the questions asked the learner to explain their reasoning for placing them in this order. The questions were slightly different if a learner placed the *asteroid hitting the Earth* before *dinosaurs go extinct*. The line of questioning changed because the relationships between the event cards were different.

Limitations. Limitations to the study were focused on samples, participant selection, video recordings (discussed on page 26) and potential risks.

1. As the samples were convenience samples, the researcher cannot claim the degree to which study participants were representative of a population.
2. The potential risk involved students' discomfort during the activity, specifically when expressing their ideas of scale. Many learners during the pilot study expressed their discomfort verbally, through hesitations such as sighs, deep breaths, or their faces turning red, and explaining at the end how they felt during that portion of the study.
3. As I participated in geology-related activities in upstate New York, and have connections at various universities by my involvement in the geosciences, there was the possibility of knowing some of the learners who agreed to participate. This could potentially affect the analysis and interpretation of participants' responses in the study, as well as learners' willingness to respond to questions during the study.

Summary

The purpose of this study was to gain insight into novice and expert learners' understanding, representations, and discourse regarding geologic time. The insight gained from this study can be used to understand learners' development of skills to excel in the geosciences, as well as activities to gain insight into student learning of geological phenomena. This insight will be added to the literature to support geoscience educators, along with pedagogical and curriculum development. Experts typically have points that they use to reference for scale, develop patterns, and retrieve information quickly as seen in other studies (Tretter et al., 2006a; Tretter et al., 2006b). Examination of experts' strategies and discussions during the geologic timescale activity was to establish any patterns and reference points, if used, which assisted in their skill building. The final goal of this study was to emphasize the key events or reasoning of novice learners in order to position them as knowers. Positioning novice learners as knowers breaks the deficit language used in regard to novice learners' ability to succeed in the geosciences. It was important to establish the points that learners do not understand or hold alternate conceptions about when entering the university so that we can address these in the K-12 and university-level curriculum, but it is also important to recognize what novice learners do understand entering the classroom. Recognizing both sets of knowledges not only assists in adjusting the curriculum at both the K-12 and university levels, but hopefully, increase skill development in geoscience learners, as well as increase interest and scientific literacy for future scientists.

In the next two chapters, learners' strategies for completing the model will be discussed. Chapter four will focus on learners' strategies during the event ordering portion of the activity, specifically, where learners placed event cards, their strategies to place the event cards on the model, their conceptions of the events, and the challenges and successes they faced in order to place events on their models. Chapter five focuses on the scale and duration of the models. Although scale and duration are related to event ordering, the two sections were separated to clarify how novice and expert learners completed their models focusing on the similarities and differences between their geologic time representations during each activity.

Chapter 4

Findings

Timescale Activity Part I: Event Ordering

The purpose of this study was to gain insight into novice and expert learners' understanding, representations, and discourse regarding geologic time. This chapter will describe the ideas that participants expressed during the geologic timescale task-based interview. Findings presented here were ideas expressed by two or more of the novice learners and both expert learners. For novice participants, emphasis is on the key events or reasoning that novice learners knew, while their challenges are backgrounded.

Consistent with previous literature (Tretter et al., 2006a; Tretter et al., 2006b), analysis of experts' knowledge focused on *anchor points*. Learners that knew the order of eons, era, periods, and epochs, the duration of time they represent, or a particular event in Earth's history, were able to mark the model to reflect this particular point of knowledge (e.g. the anchor point). For example, if a leaner knew the supercontinent Rodinia assembled approximately one billion years ago, they could use Rodinia's formation as an anchor point. The learner can then think about other events that occurred before, after, or at the same time as Rodinia to produce a relative timescale. Furthermore, the value, one billion years, can then be used an initial value to scale the timescale model.

Each learner in the study was unique. They had varying scientific backgrounds, personalities, confidence levels, and educational circumstances. These characteristics led to a range of explanations and variation among the representation learners' models. Despite these idiosyncrasies, there were similarities within the models created.

As expert-novice theory and phenomenography were the foundation for this dissertation, they guided the analysis of the data. The whole of the activity was based upon novice and expert learners' understanding, representation, and discussions of geologic time through a task-based interview and how it provided insight into their strategies to construct this knowledge. Event ordering was broken up into incorrect and correct event ordering. Within each section, novices' conceptions of event ordering are presented first, followed by experts' conceptions. Then, novice and expert learners' strategies to complete the model were presented. Although the conceptions and strategies learners used to order events, assign values, and use scale cards were connected, they are discussed separated to allow for clearer understanding of the similarities and differences between the novices and experts representations of time. This is not meant to add redundancy to the dissertation. Instead, it is meant to show how these conceptions and strategies influenced learners' model construction throughout the entire activity. Discussions of duration and scale from learners' placements of the events on the model, assigned values, and scale card use are located in chapter six.

Event cards with organisms all end in the phrase "appears on Earth", such as *small mammals appear on Earth*. These events will be referred to by just the name of the organism, with the exception of *dinosaurs appear on Earth.* The dinosaur event cards, *dinosaurs appear on Earth* and *dinosaurs go extinct* are referred to with their full descriptions for clarity.

Incorrect event card ordering and conceptions

Novice learners. All novice learners with the exception of Mica, placed both *humans* and *large mammals* in the correct order and as the last two events to occur before *present day*. Additionally, all novice learners placed *Earth's atmosphere forming* as the first event to occur after the Earth formed. The event cards between *humans* and *Earth's atmosphere forming* were mostly placed incorrectly. Although the ordering was mostly incorrect, novice learners provided logical reasoning for event placement. Reasoning that stood out in particular were explanations for the placement of organisms, specifically animals, both *Pangaea* event cards, and *photosynthesis*. These explanations stood out for two reasons: 1) the majority of novice learners brought up the same topic to discuss in great detail and 2) novice learners had questions, alternate conceptions or logical reasoning but incorrect ordering of the same event.

All five novice learners misplaced the same six event cards: *enough oxygen to sustain life*, *photosynthesis begins on Earth*, *birds*, *small mammals*, *reptiles* and *vascular plants*. Events incorrectly ordered were listed in Table 4.1 and color-coded by the number of learners that placed the events in the incorrect order. For example, if all five novice learners incorrectly order an event, it was coded blue.

Four out of five novice learners placed both *Pangaea breaks apart* and *Pangaea forms* in the incorrect place, as well as *fish*, *trees*, *vascular plants*, *flowering plants, dinosaurs go extinct*, and *dinosaurs appear on Earth*. Only three out of the five novice learners placed *trace fossil/first evidence of life* and *an asteroid hits Earth* in the incorrect order. Finally, one novice learner placed *large mammals* and *earth's atmosphere forms* in the incorrect order. Table 4.1 is evident that examining learners' event card ordering only, had the most difficulty with the evolutionary order of plant and animal evolution, when photosynthesis began, and when there was enough oxygen to sustain life.

Table 4.1
Events novice learners ordered incorrectly during the geologic timescale activity

Harper	Taylor	Frankie	Cameron	Mica
Pangaea breaks apart	Dinosaurs first appear on Earth	Small mammals first appear on Earth	Small mammals first appear on Earth	Pangaea breaks apart
Dinosaurs go extinct	Reptiles first appear on Earth	Birds first appear on Earth	Birds first appear on Earth	Asteroid hits Earth

Harper	Taylor	Frankie	Cameron	Mica
Small mammals first appear on Earth	Small mammals first appear on Earth	Reptiles first appear on Earth	Pangaea breaks apart	Large mammals first appear on Earth
Birds first appear on Earth	Fish first appear on Earth	Fish first appear on Earth	Dinosaurs go extinct	Birds first appear on Earth
Reptiles first appear on Earth	Birds first appear on Earth	Dinosaurs go extinct	Asteroid hits Earth	Small mammals first appear on Earth
Trees first appear on Earth	Trace fossil/first evidence of life	Asteroid hits Earth	Fish first appear on Earth	Dinosaurs go extinct
Flowering plants first appear on Earth	Enough oxygen to sustain life	Dinosaurs first appear on Earth	Reptiles first appear on Earth	Fish first appear on Earth
Vascular plants first appear on Earth	Photosynthesis begins on Earth	Flowering plants first appear on Earth	Dinosaurs first appear on Earth	Reptiles first appear on Earth
Photosynthesis begins on Earth	Vascular plants first appear on Earth	Vascular plants first appear on Earth	Pangaea forms	Photosynthesis begins on Earth
Enough oxygen to sustain life	Trees first appear on Earth	Trees first appear on Earth	Flowering plants first appear on Earth	Trees first appear on Earth
Pangaea forms	Pangaea breaks apart	Trace fossil/first evidence of life	Vascular plants first appear on Earth	Vascular plants first appear on Earth
	Pangaea forms	Photosynthesis begins on Earth	Trace fossil/first evidence of life	Flowering plants first appear on Earth
		Enough oxygen to sustain life	Photosynthesis begins on Earth	Pangaea forms
			Enough oxygen to sustain life	Dinosaurs first appear on Earth
				Earth's atmosphere forms
				Enough oxygen to sustain life

Blue writing: Indicates 5/5 learners ordered the event incorrectly
Orange writing: Indicates 4/5 learners ordered the event incorrectly
Green writing: Indicates 3/5 learners ordered the event incorrectly
Purple writing: Indicates 1/5 learners ordered the event incorrectly

There are conceptual commonalities between the events in the table. For example, learners that think of photosynthesis as linked primarily with terrestrial plants would place *photosynthesis* and *enough oxygen to sustain life* closer to plant life. A learner that knew about bacteria with links to photosynthesis to produce oxygen would place the *trace fossil/first evidence of life*, *photosynthesis*, and *enough oxygen to sustain life* closer to *Earth's formation*. In terms of plant evolution, learners that have not learned about or remembered the differences between *vascular plants*, *trees*, and *flowering plants*, would not know how to order plants based on their complex development. A similar challenge can be seen with animal evolution. Learners would need to know that animals evolved in marine environments before evolving to transition to terrestrial environments. Furthermore, learners require knowledge of the differences between organismal classifications in terms of taxonomic rank (i.e. Kingdoms) in order to properly order plants and animals. Lacking this information results in confusion as to what category the organism falls under, and in turn, the learner would not know how to order the events.

It is not as easy to simply say that the novice learner did not understand the event and therefore got it incorrect. Incorrect events were placed in the incorrect scientific order, but that does not mean that all of the ideas that novice learners had were completely incorrect. Novice learners made a range of moves: 1) novice learners had incorrect or alternate reasoning for events and therefore placed the event in the incorrect order; 2) novice learners had correct conceptions and placed the event in the incorrect order in relation to other event cards; 3) novice learners had correct conceptions and placed events in correct orders; 4) novice learners placed event cards in the correct or incorrect place originally and moved the card based on their reasoning for other event cards or 5) novice learners guessed on event placement resulting in either incorrect or correct placement of the event cards. There is cognitive work involved in order to think backwards in time. Thinking about events that occurred 4.6 billion years ago compared to events that occurred 2 million years ago requires understanding that when something happened *first* it happened longer ago, which is not easy.

In the following section, select topics will be discussed as *challenges* to event card ordering. These ideas were discussed among two or more novice learners. Novices wrestled with event placement, relationships to other events, or knowledge of the event, making it challenging to place the event card on the model. Learners may have presented logical reasoning for event relationships and ordering, even if they differed from the accepted timescale. For example, participants might say that Pangaea broke apart due to an asteroid collision with Earth, instead of by the mechanism of plate tectonics. Successful conceptions were ideas that learners were very close or correct in their reasoning. These ideas were supported by the correct mechanism or description of a relationship, placement of an event in geologic time compared with the scientifically established norm, or displaying an understanding of a scientific phenomenon. For example, putting Pangaea close to *Earth's formation* in time and explaining that there was a supercontinent early in earth's history, would be an example of an incorrect event placement. However, if the learner supports their reasoning for placing Pangaea in early Earth history with correct ideas, the conception can be considered successful, even if the placement is not correct. This example illustrates an understanding of changes in continental arrangement over time and knowing that there was a formation early in Earth's history, even if it wasn't Pangaea. The significance of the statement is that the learner was expressing ideas regarding changes and development of continental movement over time, even though Pangaea was not the first supercontinent. The following section begins by discussing novice learners' incorrect event ordering and what challenges they faced while ordering events, as well as emphasizing the successful conceptions expressed even though learners' events were not ordered correctly. This is followed by learners' correct event ordering with the successful conceptions and strategies used to create their timescales.

Not all of the events were discussed in detail during the 30 to 60-minute task-based interviews. As stated above, novice learners provided logical explanations and confidence in their reasoning for placing events in a particular order, even though they placed the majority of the events incorrectly.

Challenges. *Kingdom classification: what is an "animal"?* In order to place event cards on the timescale, learners discussed their conceptions of how the cards were related to each other. In doing so, learners discussed and questioned the classification of organisms. Novice learners struggled between the classifications of organisms, in terms of whether or not the organism could be considered an animal or how the organism in question related to other organisms. Event cards depicted dinosaurs, fish, bacteria, and plants.

The classification of dinosaurs was discussed by each novice learner. Three out of the five novice learners, Cameron, Mica, and Frankie, were unsure how to classify a dinosaur or its relationship to other organisms. For example, Cameron wondered how fish related to dinosaurs.

> Cameron: Yeah (*drags word out "yeeeeeeah"*). Um…the fish, I'm still going back to the whole like, reptile and like dinosaurs and how they would kind of classify them.
>
> Researcher: Can you explain a little bit more about that? What do you mean with dinosaurs, reptiles-
>
> Cameron: I remember in a class talking about how…there were like, certain kinds of like, dinosaurs technically I guess that were sea and land, but then it would-we would learn about the comparison between that and an alligator

Researcher: Okay

Cameron: So I'm thinking like fish and dinosaurs and how the connection is

Researcher: Okay

Cameron: Or if there's a more recent definition of fish that differs from dinosaurs. (pp. 4-5)

As stated in the interview, Cameron discussed the idea of dinosaurs that were "land and sea" (Interview with Cameron, pp. 4-5), resulted in questioning the origin and classification of dinosaurs, as well as their relationship to fish.

Multiple learners brought up the idea of dinosaurs not being an "animal" or as being separate from "other animals". For example, from Mica:

> Um, I guess I just thought about like, like, time (*drags word out, "timmmme"*), like timeliness in my head. What made sense to go first. And like, I don't know, I don't know much about…this stuff, but I felt like just from like high school classes, I was thinking like, okay dinosaurs were first [organism to appear in time] and then they were extinct and then animals came. (p. 3)

Frankie brought up this idea as well, questioning if a dinosaur could be considered an animal.

> And then dinosaurs, they need to eat so, they are herbivores. So they needed to eat plants. Um, and then I gave it time, before the asteroid hit. And then-not necessarily the same time but… relatively close in time, the dinosaurs were extinct. (10:00) And then trace fossil, I wasn't necessarily sure if the first animal trace could have been fossils from dinosaurs or just general animals. I didn't know if a dinosaur could be considered an animal? (pp. 3-4)

Although the evolutionary lineage of dinosaurs is still debated, participants questioned whether a dinosaur was an "animal". It may be because they were extinct that it was hard for participants to justify them to be another "animal", as it is not an organism they have encountered. Even after participants discussed their ideas regarding the lineage between dinosaurs and birds or reptiles, they still discussed them separately.

> So that's why I put it there. Reptiles I put because I feel like through-reptiles and birds through-earth science that I've taken, they are descendants of dinosaurs. I don't know if that's true or not, but that's what I was taught it is. I put those as two (*points to reptiles and birds on the timescale*) of the first animals. And reptiles are before everything else-all the other mammals. And then for them [mammals] I put small mammals first, which is the mouse, smaller mammals. (Frankie, p.4).

Although Frankie mentioned that reptiles and birds were descendants of dinosaurs, Frankie still considered reptiles and birds to be the "first animals". Additionally, the way that Frankie stated that "reptiles are before everything else-all the other mammals" suggests two meanings for the statement, 1) that Frankie simply meant to state that reptiles were before mammals or 2) that Frankie considers reptiles to be part of the mammalian class.

Finally, Frankie and Harper discussed what animals were when discussing the *trace fossil/first evidence of life* event card. Frankie still questioned the relationship between dinosaurs and animals, but this time in relation to a trace fossil. Frankie is unsure whether the *trace fossil/first evidence of life* event card was an animal and what that animal would be.

> I kind of marked time in between here. There is no trace, um, and then I put fossil, first animal trace, because I wasn't sure if the first animal trace was necessarily a dinosaur

> trace or a new form of bacteria. I didn't know. It could have been from dinosaurs. I don't know if dinosaurs are considered animals. (p. 12)

As Frankie continued to discuss the first animal trace, they classified it as possibly a "new form of bacteria". When Frankie discussed whether dinosaurs were animals or not, they were prompted to describe what they were thinking or picturing. Frankie answered to the question with the following response:

> I don't know. I guess this card kind of threw me off, because I was like, oh, first evidence of life. Before or after? Because I guess dinosaurs were still living. The-um, well, that's really stupid, I guess I totally just answered my question. The plants are considered animals still, because they are living organisms, so it could have technically been a fungus that created the first living organism on earth. So that could have gone right before-or right next to oxygen or photosynthesis. (Frankie, p. 13)

Frankie listed various kingdoms of scientific classification and grouped plants into three different categories, animals, bacteria, and fungi. There is overlap in the descriptions of each kingdom,[1] which could result in Frankie's classification confusion. However, plants, animals, and fungi are different, even though they are all living organisms.

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[1] Animals are from the Kingdom Animalia which is made up of eukaryotes and are multicellular, but lack a cell wall. Eukaryotic organisms consist of a cell or cells with genetic material in the form of DNA consisting of chromosomes with a distinct nucleus. They depend on other organisms directly or indirectly for food, which classify them as heterotrophs, most of the organisms are motile, and the kingdom does not contain prokaryotes (single-celled organisms such as bacteria and cyanobacteria). Plants, from the Kingdom Plantae, are also multicellular and eukaryotes, but have the ability to produce their own food through photosynthesis. They have cell walls made of cellulose and are chlorophyll containing-organisms. A fungus is different from a plant and animal. They are in the Kingdom Fungi which are also eukaryotic, heterotrophic organisms that include unicellular microorganisms, such as yeast and mold, and multicellular organisms, such as mushrooms. They are classified, and distinguished from animals and plants, by their cell walls made of chitin and polysaccharides (carbohydrates consisting of sugar molecules bonded together). Unlike plants, fungi do not photosynthesize.

Finally, Harper also began to question the classification of the *trace fossil/first evidence of life* event card in relation to fish and animals.

> Alright. Well, I figured-I knew photosynthesis would be the next one because no other life happened, or came about before photosynthesis and the basic plants. That happened like, on the water, or in the water. Like sea algae and stuff like that. Um fish are a little more complex, so I figured they would come after the plants that were…in the water. I have no idea what this is (*points to trace fossil/first evidence of life card*). So I thought it would be a good idea to place it early, somewhere between fish and animals. (p. 2)

It could be that Harper misspoke when discussing the placement of the *trace fossil/first evidence of life* card and meant to say "between fish and *the other* animals", as Harper did not continue to question the classification of fish as animals. When Harper continued to discuss the placement of the *trace fossil/first evidence of life* card, they discussed reptiles as "…first animals on land [that] were fish that tried to climb their way out of the water" (p. 2). This does not clearly state that Harper thought fish are animals, instead it suggests that Harper may have previously misspoke when discussing fish and animals. Alternatively, Harper could separate aquatic organisms from terrestrial animals or simply clarified their ideas regarding classification of fish as animals.

The Pangaea cards. Two different event cards represented Pangaea in the timescale activity, *Pangaea forms* and *Pangaea breaks apart*. The purpose of two different cards was to prompt learners' thinking and to discuss the mechanisms for plate movement and continent formation. Pangaea was the only supercontinent card presented since it is the "most rigorously defined supercontinent" (Meert, 2011, p. 987), and most likely to be recognized. As another supercontinent card was not given, this cannot be confirmed.

Despite this consideration, when learners discussed their strategies for ordering the event cards, all five novice learners said *Pangaea* troubled them. The *Pangaea forming* card was troubling for two reasons: learners either put Pangaea as the first supercontinent or did not know when it occurred. The quotes below demonstrate learners' difficulty with Pangaea's formation.

Frankie: Pangaea, I put over there (*by earth forms*) because I knew Pangaea was the first formation. (p. 2)

Harper: Pangaea, I'm not sure about. Pangaea happened a long time ago. (p. 7)

Taylor: The Pangaea cards, the asteroid…because the asteroid could have-it could have been how Pangaea began to break up or the asteroid that killed the dinosaurs. And then… (p. 9)

Cameron (…) I also realized that I have no idea when Pangaea formed. (Cameron, p. 6)

Novice learners also had difficulty with the event card labeled *Pangaea begins to break apart*. Novice learners appeared to have difficulty with this event because they wondered if an asteroid could have caused the break-up of Pangaea. This exchange with Taylor was illustrative:

Researcher: Explain *the breaking up of Pangaea* and *asteroid* a little bit more about what you are thinking.

Taylor: I'm assuming the asteroid hit um earth and a bunch of earthquakes formed along the fault lines would loosen up and that could potentially cause Pangaea to start drifting apart. (p. 9)

Although Taylor thought of an alternate mechanism to plate tectonics, Taylor's idea was logical. Taylor knew about tectonic plates, as they stated knowledge of earthquakes formed along faults lines and the term "drifting apart", and that an indicator of plate movement was an earthquake. Evidence of tectonic action includes earthquakes, changes in continental arrangement or continental drift, and fossil distributions across continents. However, Taylor took these ideas one step further and questioned whether it was possible that an asteroid hitting Earth caused the earthquakes and continental drift.

Photosynthesis, oxygen, and life. All five participants ordered *photosynthesis begins on Earth* and *enough oxygen to sustain life* in the incorrect order on their models. Novice learners did not talk about photosynthesis as being oxygenic, nonoxygenic, or existing without plants, although most of their reasoning implied they were thinking about oxygenic photosynthesis with plants as they discussed photosynthesis in association with plants. As the placement of photosynthesis was dependent upon their understanding of its relationship to terrestrial plants, novice learners' placement of *photosynthesis* on the model was deemed incorrect according to the start of photosynthesis and early oxygenation on Earth. Novice learners placed terrestrial plants too close to *Earth's formation* to be deemed correct scientifically. For example, if the placement of plants was over 50 centimeters away from the *present-day* end of the model, they were already 100 million years off from the point in geologic time when vascular plants first appeared. Novice learners, with the exception of Harper, did not discuss early plant life as being aquatic. Beyond this, the novice learners provided logical explanations for their placement of *photosynthesis* and *enough oxygen to sustain life*, and their relationship to life, such as plants and animals. All novices had some understanding of a relationship between photosynthesis, oxygen, and terrestrial plant life. The examples below are from each of the novice learners' discussions of photosynthesis.

> Taylor: I moved them [photosynthesis, vascular plants and trees] because photosynthesis creates oxygen. So…uh….so the atmosphere-earth was formed, so I'm assuming the atmosphere had to form for anything else to happen. (p. 3)

> Cameron: And then, I kind of put these all together because…I don't know, there's a connection between photosynthesis and plants (…) Just the process of it. It's taking in carbon dioxide and releasing oxygen, so I figured that would be after the oxygen, levels…but that might be before (*begins to move the event card and then stops*). (pp. 8-9)

> Frankie: I did it by putting them between groups, if it was a mammal or modern day um, organism. And then I put all of the earth formed, atmosphere, crater and dinosaurs and oxygen and well-Pangaea I put over there (*by earth forms*) because I knew Pangaea was the first formation (7:32). And oxygen with photosynthesis because you can't have one without the other. (…) So we wouldn't have photosynthesis without the presence of oxygen. So I put those altogether. Because I assumed that once Pangaea formed, we would have oxygen and we would have uh photosynthesis because the atmosphere has formed. (p. 2-3)

Although novices understood a relationship between photosynthesis, plants, and oxygen, there appeared to be misperception about the mechanism for photosynthesis. For example, Frankie discussed photosynthesis requiring oxygen in order to work instead of producing oxygen. In the quote above, Frankie stated both oxygen and photosynthesis were required "because you can't have one without the other" (p. 2). Contrast these ideas with Mica, who discussed photosynthesis as occurring after plants appear since plants are needed "to make photosynthesis" (p. 3).

> Mica: Um, I did the oxygen-well, first I had this here, because it just made sense. I figured the earth formed and then the atmosphere formed. And then I was like, we need oxygen to live and eventually have life on earth, so I as- well I don't know if it's before or after it. So that was like, that part and then I, getting into this I thought, um, maybe fossils weren't found back then. Oh! First evidence of life, yeah, and then I was like oh dinosaurs, and this I-I I don't know why I-I knew that [photosynthesis] was probably before plants.
>
> Researcher: So what was making you think about photosynthesis before plants?
>
> Mica: Because I think that, photosynthesis, oh wait, no. This would go after. Because you need plants to make photosynthesis. Right?
>
> Researcher: So what were you thinking about just before that too? You started to-
>
> Mica: Ummm, for some-for some reason, I haven't done photosynthesis in a while. But I thought they needed that-to get energy and for plants to live and get more life, so I thought that would be-come very early.
>
> Researcher: Okay.
>
> Mica: Um, but now I'm thinking it's backwards. So close after that would be plants because they need photosynthesis to thrive. (p. 3)

Mica originally placed photosynthesis before plants and then changed the placement after thinking about needing photosynthesis for plants to thrive. Mica's thinking was not wrong; plants do thrive on photosynthesis, but the way Mica discussed photosynthesis as the product versus oxygen as the product may have resulted in confusion. Mica made it sound like photosynthesis wasn't a mechanism but a requirement to grow. In other words, like a seed needs water to germinate, a plant needs photosynthesis to exist. However, Mica's thinking for the original placement of photosynthesis before plants was clearer and more accurate as they discussed plants needing energy, which aligns better with the description of plants photosynthesizing.

Harper discussed photosynthesis and oxygen separately, but was the only one to discuss that it would take a long time to have enough oxygen on Earth to sustain life. Harper, like Cameron, Taylor and Mica, discussed photosynthesis in relation to plants.

> Um…I've seen like documentaries on science and it's like-how it's just a lot of molten rock because the earth was so hot and the atmosphere wasn't blocking out any of the sun's rays or anything um…always getting hit by asteroids and a lot of storms for some reason. Um…so I knew once the atmosphere formed that things would start happening because for life to form. ... Oxygen, uh…it would take a long time for oxygen to build up in the atmosphere before there would be enough to sustain life, so I gave it about 300 million years. Um…and then I figured this happened over a long stretch of time. Like, all-because you go from photosynthesis and basic plants, um…then, from, to get to reptiles a lot of evolution had to happen so I gave it 1.8 billion years. (p. 7)

Harper, Frankie and Cameron discussed photosynthesis in the ocean or related to organisms in the ocean. Frankie discussed early life as bacterial in origin, Harper referred to the organisms as "sea algae and stuff like that" (p. 2) and Cameron could not remember a name to refer to the organisms.

> Harper: Alright. Well, I figured-I knew photosynthesis would be the next one because no other life happened, or came about before photosynthesis and the basic plants. That

happened like, on the water, or in the water. Like sea algae and stuff like that. Um fish are a little more complex, so I figured they would come after the plants that were…in the water. (p. 2)

Researcher: (…) So now you're placing it [trace fossil/first evidence of life] towards photosynthesis, oxygen and Pangaea. What is your reasoning for placing it with those three cards?

Frankie: Because through schooling, I've learned that the first evidence of life was bacterial origin.

Researcher: Okay.

Frankie: So (38:12) it could-I-burrow, fossil, is not necessarily…the trace fossil could be bacteria. So I will put that there, because before we have any kind of vegetation we have bacteria. (p. 14)

Cameron: I was just thinking, what do they call it? In the ocean, they do photosynthesis, I think. So those are still there because those are just land plants. But those need oxygen too. So it [photosynthesis] must have been earlier than that. Okay, so it will go somewhere in there (*laughs and place photosynthesis down*). (p. 12)

Although none of the novice learners placed photosynthesis or oxygen in the correct order on the model, they knew that photosynthesis was associated with oxygen or oxygen creation and plant life. Harper, Frankie and Cameron knew there was an association between photosynthesis and organisms in the ocean, and in some cases bacteria was mentioned as a source of photosynthesis, assisting them to place it earlier in time. Additionally, all of the novice learners mentioned a relationship between photosynthesis, plants, and oxygen. However, this relationship between plants and photosynthesis often misled novice learners when thinking about the phrase on the card stating, *photosynthesis begins on Earth*.

Expert learners. Both expert learners placed *humans*, *large mammals*, *dinosaurs go extinct* and the *asteroid hits the Earth* just before *present day*. Out of the 18 event cards presented, the expert learners had approximately half of the event cards in the correct scientific order, with Alex placing nine cards correctly and Jayden placing eight. Alex had five events that were very close and flipped in their ordering. For example, in the correct ordering of events, *trees appear on Earth* is before *reptiles*. Alex placed *reptiles* before *trees*. Alex placed the events *enough oxygen to sustain life*, *photosynthesis begins on Earth*, and *trace fossil/first evidence of life* on Earth in the incorrect order. However, Alex placed the cards very close together. Jayden did the same thing. Jayden had six cards that were very close and flipped in order. Listed in Tables 4.2a and 4.2b below are Alex and Jayden's event ordering compared to event order according to geologic time. The red highlighting is used to display events incorrectly ordered. Asterisks mark events that could be switched to achieve order accuracy.

Table 4.2a
Events Alex ordered during the geologic timescale activity

Alex's event ordering	**Correct event ordering**
Humans	Humans first appear on Earth
Large mammals	Large mammals first appear on Earth
Dinosaurs go extinct	Dinosaurs go extinct
Asteroid hits earth	Asteroid hits the Earth
Pangea breaks apart	Flowering plants first appear on Earth
Birds first appear on Earth	Birds first appear on Earth
Dinosaurs first appear on Earth	Pangea begins to break apart
Small mammals first appear on Earth	Small mammals first appear on Earth
Pangea forms	Dinosaurs first appear on Earth
Flowering plants	Pangea forms
Trees (knew it would be near the carboniferous)	Reptiles first appear on Earth
Reptiles	Trees first appear on Earth

Vascular (Land) Plants first appear on Earth	Vascular (Land) Plants first appear on Earth
Fish first appear on Earth	Fish first appear on Earth
*Trace fossil/First evidence of life on Earth (cyanobacteria) *Photosynthesis begins on Earth	Enough oxygen to sustain life
	First evidence of life on Earth (cyanobacteria)
*Enough oxygen to sustain life	Photosynthesis begins on Earth
Earth's atmosphere forms	Earth's atmosphere forms
Earth's formation	Earth's formation

Table 4.2b
Events Jayden ordered during the geologic timescale activity

Jayden – expert learner	
Jayden's event ordering	**Correct event ordering**
Humans first appear on Earth	Humans first appear on Earth
Large mammals first appear on Earth	Large mammals first appear on Earth
Dinosaurs go extinct and asteroid hits Earth	Dinosaurs go extinct
	Asteroid hits the Earth
Flowering plants first appear, small mammals first appear on Earth and birds first appear on Earth	Flowering plants first appear on Earth
	Birds first appear on Earth
	Pangea begins to break apart
Dinosaurs first appear on Earth	Small mammals first appear on Earth
Pangea begins to break apart	Dinosaurs first appear on Earth
*Reptiles first appear on Earth	Pangea forms
*Pangea forms, *Vascular plants first appear on Earth and *Trees first appear on Earth	Reptiles first appear on Earth
	Trees first appear on Earth
	Vascular (Land) Plants first appear on Earth
Fish first appear on Earth	Fish first appear on Earth
*Trace fossil/First evidence of life on Earth (cyanobacteria)	Enough oxygen to sustain life
*Enough oxygen to sustain life	First evidence of life on Earth (cyanobacteria)
Photosynthesis begins on Earth	Photosynthesis begins on Earth
Earth's atmosphere forms	Earth's atmosphere forms

Events written in red are incorrectly ordered; Asterisk represents events that if they were flipped would be in the correct order; events listed in one line were represented to occur at the same time or approximately the same time

Alex originally placed the *trace fossil/first evidence of life* card close to *present day* and associated it with the Great Oxidation event (the event was not provided by the researcher, but added to the model by Alex), but then moved the event card closer to the beginning of the Cambrian (542 million years ago), as Alex marked on their model, at 542 million years ago. Alex moved the card because of the term “trace fossil”, associating the trace fossil with a solid shell and discarding their original ideas of the event card referring to cyanobacteria.

> Alex: That’s what I interpreted from that…then…I know that there’s an oxygenation event that is associated with something and I can’t remember what it is and there are a lot of studies…there’s a lot of students here working on that event, and I know it’s probably early in the geologic record…probably…happening around there…then the first trace fossils – so we know based on the geologic record that life started…3.06? there’s a potential record of bacteria, I think its cyano-bacteria or some little bacteria around 3.8 Ga and I actually know that number very well from listening to a podcast and it’s a topic they keep bringing up for whatever reason the origins of life…and so it’s like…that number seems to be in my brain very good because of that.
>
> Researcher: Okay.
>
> Alex: And so, those are already trace fossils. So that’s when we’re starting to see more than just-OH that’s wrong! I think that that’s when we start seeing stromatolites, actually, the more I think about it. Those are stromatolites.
>
> Researcher: Okay.
>
> Alex: And the trace fossils would be closer to the Cambrian. I would say…I believe…maybe I am wrong.
>
> Researcher: So you’re moving-
>
> Alex: the trace fossils…down [the model closer to the ‘present day’ marker]
>
> Researcher: down.

> Alex: So the stromatolites are technically…are still part of our fossil record…yeah.
>
> Researcher: Okay.
>
> Alex: That would be representing more of the first trace the… the basically animals that had skeletons or more movement than just algae or cyanobacteria, where we think we have traces, but those are more developed by animals-closely associated with the Cambrian explosion around 542…542 Ma (*says the individual letters "M" and "A", geologic shorthand terminology for "million years ago"*). (Alex, p. 4)

Alex debated between the idea of the stromatolites made of cyanobacteria that existed early on associated with increasing oxygen into the atmosphere being the representative of early life and the classification of a trace fossil. Stromatolites are structures created by cementation of sediments to form microbial mats or sheets of bacteria that stack on top of one another. Stromatolites currently date as early as 3.5 billion years ago. As Alex continued to speak, they associated algae with the oxygen that formed on the Earth but placed the card closer to the *present day*, based on the ideas regarding the stromatolite as a fossil.

> I think that that's uh probably what I was having in mind um. I think that there might have been an association on the geologic record of the stromatolites so that's like when we start seeing more of the algae development and stuff when we have an increase in the oxygen in the atmosphere as a theoretical or O_2 actually. Um, I do know that-that happened fairly early in the history of the early, relative to life. (p. 4)

Similar to Alex, Jayden also discussed a relationship between early life from small cellular organisms with the event cards *photosynthesis* and *enough oxygen to sustain life*. Jayden designated the event card *photosynthesis* to represent nonoxygenic photosynthesis and placed it early in Earth's history.

> Okay. So I'm going to say that this is photosynthesis without oxygen because it happens a lot earlier. And um…so about 4 million years ago, like 3.8-3.5 I think that would be about here [for the age of photosynthesis]…reptiles, somewhere in the Paleozoic after plants. Mammals are in…mammals happen ooh! Do mammals happen before or after birds? I have no idea…trace fossils. I feel like there might have been-they're definitely in the Cambrian or maybe a little before then. Well, no, there's the trace fossil that defines the Cambrian, so I will put that there just before the first land plants. Flowering plants…are…sometime ooh. There are a lot of things I don't know. Um…(Interview with Jayden, p. 3)

Furthermore, Jayden placed the *trace fossil/first evidence of life* event close to *enough oxygen to sustain life* and *photosynthesis*. In their reasoning, Jayden discussed the "cell-fossil" or "microfossils" (Interview with Jayden, p. 9) as some of the first life on Earth. Jayden explained that there had to be oxygenic and nonoxygenic photosynthesis on Earth before there was oxygen on Earth, as there was evidence of carbon isotope depletion that was a result of life on Earth.

> Jayden: (…) So I'm going to put… um, photosynthesis…I have no idea where to put photosynthesis, so…so like in, like there are these fossils at about 2 point-at 3.8 billion years ago. There's a carbon isotope signature that's depleted that well only life could have done that. And so like obviously there had to have been life, and there are people that say that's total crap. But then um, these 3.5 billion years ago is how old the first like little cell-fossil or microfossils, or like the first actual fossils of life.
>
> Researcher: Okay.
>
> Jayden: And probably they were photosynthetic because how else would they eat, um, but then like, for photosynthesis to develop like as a process, it pretty much faced

> RuBisCO to this point at 2.8 it's the point people talk about "well if there was photosynthesis happening, why did it take so long for oxygen to accumulate why is there this 400-million-year gap between them the two of them". So there must have been nonoxygenetic photosynthesis before there oxygenetic photosynthesis. (pp. 9-10)

Discussions with Alex and Jayden revealed that they both knew that there were two different types of photosynthesis, nonoxygenic associated with bacteria or microorganisms and the Great Oxidation Event in early-Earth history, and oxygenic associated with plants, as it is typically discussed.

> Alex: (*laughs*) there was a massive amount of things happening ah…shortly after-shortly after the earth formed. I think it was around 2.8 [billion years] and…uh…this looks…that's tricky… Because first evidence of life was at 3.8-do you consider micro or trace fossils? So it's not the micro-whatever that started about 3.8, from the picture, so I will put it at 2.8….(*speaks to themselves again*). When I see oxygen, I'm thinking the Great Oxidation event. Is that what you are referring to? I have no idea when it happened, but I think it's at the same time. Because we are in the Proterozoic…(p. 3).

> Jayden: I might do some of each. So I think-so the Great Oxidation event was 2.4-2.3 billion years ago. So the earth is 4.6 billion years old, so I'm going to put that [oxygen card] in the middle. Earth's atmosphere forms, that would have happened pretty soon after the earth forms, but I don't know exactly when. So I'm just going to put it like that [close to earth formed] (p. 2).

In regard to the placement of plants, Alex discussed their knowledge of plants to be “pretty bad” (p. 2). However, Alex maintained an understanding of the complexity of plant growth and provided a few relative times plants would appear on Earth.

> So fish appear, I think it’s…after the Cambrian in the Ordovician…and plants first appear in the Silurian or something of the sort. So we’re not really, we’re starting to have some plants on Earth, although the bigger plants like trees and flowers and more developed plants appear in the Carboniferous and that’s why we have a lot of coal deposits. Right, so reptiles show up before that. We don’t have amphibians (researcher comment: we don’t have an *amphibians* event card to place on the model), but actually after the reptiles we have the development of the amphibians (…) I know that the flowers took longer to develop because they are like sexual and have more complex systems, but I really can’t remember how closely after trees and like, bigger plants showed up and if it was shortly after or if it took a really long time. They could be at the end of the Carboniferous or um later in the Permian and I would not really know that.
>
> Researcher: Okay. What do you mean wouldn’t know that? Or what makes you think you wouldn’t know that?
>
> Alex: I don’t know how long it took for-from the step of having plants and having bigger plants with um…trees basically like a hard, *wood* stuff.
>
> Researcher: Okay.
>
> Alex: I think plants developed as a sexual-flowers as a way of reproducing is much later. But I don’t know how much later. In the geologic timescale it could be like 5 million years or so, or a hundred million years (*laughs*). (pp. 5-6)

Although Alex was unsure of the relative time and duration of plant development, they had a clear understanding of the complexity associated with plants developing into flowering plants. Jayden discussed flowering plants and reptiles as some of the events they did not know, but were able to discuss being able to place these event cards in a relative order and using periods of the geologic timescale.

> Jayden: I don’t know like which reptiles, like what…like so dinosaurs are like a particular clade within the reptiles but I don’t know how early on in reptile history dinosaurs would have first-like when they would have appeared. What the first reptile was ever, I don’t know…although, there must have been reptiles in the Paleozoic and there were no dinosaurs yet. I think dinosaurs were Mesozoic. So we will do that. First fish…fish happened…so the earliest land plants would have been sometime into the Silurian, possibly the Ordovician, but definitely the Silurian and fish are older than that.
>
> Researcher: How do you know or how are you remembering the plants-
>
> Jayden: So the Rhynie-the Rhynie chert is Early Devonian. Or maybe it’s Silurian. Um…and I think there’s pollen or some like, just there are fossils in the Rhynie chert that are-it’s one of the oldest plant fossil like, ahh…what do they call it, the plant fossil lagerstätte. But I feel like…oh no…that’s a good question isn’t it? Because were they vascular plants or were they just mosses? Mmmm…so this looks like it’s a representation, okay because there’s like, I assume this is for the K-T event. (p. 4)

Finally, Alex and Jayden drew on knowledge that went well beyond the information on the event card. Alex and Jayden added events to the model that were not provided, that Tretter et al., (2006b) referred to as anchor points. Anchor points are significant references of experiential knowledge for an individual. For example, in order to attempt to scale their model, Alex added the event "Rodinia" for the supercontinent Rodinia that formed approximately one billion years ago. Rodinia was then used as an anchor for Alex. Alex used Rodinia to mark where one billion years was on the model and then referenced whether events occurred before or after Rodinia. Jayden used the Great Oxidation Event and the first eukaryote fossil on their model as anchors for placing events on the model before or after those events.

Correctly ordered event cards and conceptions

Correctly ordered event cards were those in which the learner matched the relative order of geologic time. Placing the event card in the correct order did not always imply deep understanding of the event. For example, some novice learners stated they guessed when placing the event cards down. In some cases, the reasoning for the placement of an event card in the order is correct, but not due to accurate conceptions of the event. Additionally, learners often had logical reasoning that guided the placement of an event card, but placed the event cards in the incorrect area of the model.

Both novice and expert learners were ranked based on the number of answers they got correct. There were 18 events total. The experts ranked nine and eight, by Alex and Jayden respectively. The novice learners ranked from 2-6 for events correct. Harper and Taylor both had six events correct, followed by Cameron and Frankie with four events correct and Mica with two events correct.

Novice learners. As mentioned previously, all novice learners placed *humans* in the correct order (Table 4.3). Four out of five novice learners placed *large mammals* as the event to occur before *humans*. Additionally, four out of five novice learners placed *Earth's atmosphere forming* as the first event to occur after *Earth's formation*. Mica incorrectly ordered both *large mammals* and *Earth's atmosphere forming*.

Table 4.3
Events novice learners ordered correctly during the geologic timescale activity

Harper	Taylor	Frankie	Cameron	Mica
Humans first appear on Earth	Humans first appear on Earth	Humans first appear on Earth	Humans first appear on Earth	Humans first appear on Earth
Large mammals first appear on Earth	Large mammals first appear on Earth	Large mammals first appear on Earth	Large mammals first appear on Earth	Trace fossil/first evidence of life
Asteroid hits Earth	Dinosaurs go extinct	Pangaea breaks apart	Trees first appear on Earth	
Dinosaurs first appear on Earth	Asteroid hits Earth	Earth's atmosphere forms	Earth's atmosphere forms	
Fish first appear on Earth	Flowering plants first appear on Earth			
Earth's atmosphere forms	Earth's atmosphere forms			

Blue writing: Indicates 5/5 learners ordered the event correctly
Orange writing: Indicates 4/5 learners ordered the event correctly
Green writing: Indicates 3/5 learners ordered the event correctly
Red writing: Indicates 2/5 learners ordered the event correctly
Purple writing: Indicates 1/5 learners ordered the event correctly

Although the majority of their events may not have been correct, there were ideas that novices had correctly representing geologic time. Novice learners knew 1) humans were last to evolve, 2) their scale was off during the task, 3) about on-going debates or relationships between birds and dinosaurs and reptiles and dinosaurs, 4) fins-to-limbs transition, 5) asteroid being related to the dinosaurs' extinction, 6) a relationship between photosynthesis and oxygen, 7) atmosphere forming after Earth formation, and 8) early life beginning in marine environments. The next section first focused on learner's ideas about the scale of their models during the event ordering activity. The event to be focused was the "fins-to-limbs transition", the transition of organisms from aquatic to terrestrial environments (e.g. *fish, amphibians, reptiles,* etc.,). The events were chosen because the majority of learners discussed these ideas.

Knowing their scale was not correct. All of the participants at some point mentioned that their scale, in terms of their event cards, was not correct during the task. Harper, for example, realized that as they attempted to discuss their scale cards that the scale they chose to use to space the event cards out was still not correct. When asked about how the event cards were spaced, Harper stated that they tried to represent each gap as millions of years, but that the cards would still need to be moved to meet that scale.

> Researcher: Great, so one of my other questions for you about the event cards, before we move on to the next part of the activity was, how did you decide to space them [the event cards] out?
>
> Harper: Um, I knew that each gap would be like millions of years so I tried to make it as accurate as possible. But I mean, humans should still be down more at the end. (p. 4)

Frankie also stated during the event ordering portion of the task that their "timescale is not scaled to time by the way" (p. 6). Cameron also discussed that the scale was like a puzzle, but they were unsure of the size of the puzzle.

> Cameron: it's like a really complicated puzzle
>
> Researcher: (*laughs*) yeah. What makes it so complicated?
>
> Cameron: For me, it's figuring out how I should scale it. I know humans are a very small part of the whole thing, but I'm still not sure how big to make it. (p. 2)

Each learner, novice and expert, changed the scale of their model as they went through each part of the activity. After being prompted to describe what the space between events represented on the model, learners responded that a bigger space indicated more time. Expert learners made conscious choices from the beginning of the activity as they began by scaling their models in order to place events on the model. Experts' strategies for scaling their models is discussed in chapter five.

Fins-to-limbs transition. Most of the discussions by the learners revolved around when plants and animals appeared on Earth. In this timescale activity, organisms such as trilobites, eurypterids or brachiopods, although older than fish, were not used in case novice learners had not encountered them in their prior background. Therefore, on this model, fish were the first animals represented. Additionally, terrestrial plants evolved after fish, and approximately 55 million years before animals moved from marine to terrestrial environments.

The fins-to-limbs transition is a reference to aquatic organisms' adaptation to terrestrial life. Knowing about the fins-to-limbs transition meant the learner understood that early life existed in marine environments and transitioned from water to land. Three of the five novice learners discussed the organisms that appeared first and typically compared the existence of fish as being before or after another organism. For example, "fish I put first because…I don't know, I didn't even know if there was fish before the asteroid? But I feel like it came before reptiles" (p. 4).

> Alright. Well, I figured-I knew photosynthesis would be the next one because no other life happened, or came about before photosynthesis and the basic plants. That happened like, on the water, or in the water. Like sea algae and stuff like that. Um fish are a little more complex, so I figured they would come after the plants that were…in the water. I have no idea what this is [trace fossil/first evidence of life card]. So I thought it would be a good idea to place it early, somewhere between fish and animals. (…) I figured the plants moved up onto land first. So I put the land plants, flowering plants and then the trees because I figured they get more complex. Um, I knew reptiles would come next

> because the first animals on land were fish that tried to climb their way out of the water. (p. 2)

A few things were reflected in Harper's statement. First, Harper had a good understanding that there was complexity in plant development from vascular plants to trees and flowering plants. Second, Harper thought that fish started in water and a transitional organism moved to land. Harper described reptiles as "fish that tried to climb their way out of the water", indicating that they knew life started in water and eventually moved to land. Harper did not mention amphibians as a transitional link. Since amphibians were not an event card, Harper may have used only the event cards provided to describe the transition from marine to terrestrial life.

Cameron also discussed this idea of marine and terrestrial life, but in terms of an organism that can live in both marine and terrestrial environments.

> I feel like I remember learning about um, 'cause it was land and sea, so there was a similar dinosaur that was land and sea. It had legs but it swam. Um, and then I put fish near that, because the land and sea dinosaur and then thought maybe lead into fish. (p. 11)

Although Cameron put fish as possibly an ancestor to dinosaurs, indicating that Cameron thought dinosaurs existed before fish instead of fish existing before dinosaurs, they still discuss this idea of life in water. Mica also discussed dinosaurs as existing before fish, but Mica stated that they would place amphibians near reptiles and fish as they thought that "it makes sense to put it with the reptiles and first life that appeared" (p. 11).

Expert learners. The expert learners had six events that they both placed in the correct order: *humans*, *large mammals*, *dinosaurs go extinct*, *an asteroid hits Earth*, *fish*, and *Earth's atmosphere forms*. Although Alex and Jayden had differing specialties, they both spoke of events that were not provided in order to figure out where to place the event cards they were given. Additionally, the reasoning Alex and Jayden provided for event placement reflected their different backgrounds. Alex and Jayden both used anchor points to order the events in their models.

Alex referenced the supercontinent Rodinia and used their knowledge of the periods, eras and eons of the geologic timescale, or geochronological units, to scale the model. Jayden spoke primarily about the Great Oxidation Event, but also their knowledge of the Rhynie Chert. Only one anchor point is discussed for each expert because other anchor points provided were not discussed in great of detail. To be clear and consistent, the examples chosen below are those that the expert learners, 1) discussed in great depth or 2) provided evidence for the relationships between the anchor point and other events on the model, such that the anchor assisted the learner in placing the event on the model or discussed its relationship to another event card.

Anchor points. *Jayden and Alex: Great Oxidation Event*. Both Alex and Jayden spoke about the Great Oxidation Event to determine how to place events in deep time. Jayden had a background in evolutionary biology and paleontology. Jayden discussed the Great Oxidation Event more than Alex, as Jayden said that they studied it frequently in their classes and research.

Jayden began by describing what the Great Oxidation Event was and when it occurred. After referencing when the Great Oxidation Event was, Jayden placed *enough oxygen to sustain life* on the model.

> Jayden: There is another oxygen-uhhh this is like life that likes oxygen or great oxidation event kind of. So that was like somewhere, well basically in the middle…um (…) So I think-so the Great Oxidation Event was 2.4-2.3 billion years ago. So the earth is 4.6 billion years old, so I'm going to put that [oxygen card] in the middle. Earth's

atmosphere forms, that would have happened pretty soon after the earth forms, but I don't know exactly when. So I'm just going to put it like that (*close to earth formed*). (p. 2)

Jayden discussed the reference to the Great Oxidation Event as reference point, in order to decide how wanted to place the event card for enough oxygen to sustain life on the model. Jayden began by talking about photosynthesis, but was unclear about where to place *photosynthesis* in early Earth history and in relation to e*nough oxygen to sustain life* because of the lack of specifics regarding oxygenic photosynthesis compared to nonoxygenic photosynthesis. Jayden was able to discuss the early cell-fossils that fixed carbon and produced oxygen, but was unsure of where to place *enough oxygen to sustain life*, *photosynthesis,* and the *trace fossil/first evidence of life* cards for a few reasons: 1) the debate regarding early organisms' ability to produce oxygen through photosynthesis, 2) why it took 400 million years between photosynthesis occurring and oxygenation for life to be sustained, and 3) whether the photosynthesis card represented oxygenic or non-oxygenic photosynthesis. However, Jayden went on to further discuss this in relation to the Great Oxidation Event and other evidence they knew of, such as sulfur isotope signals.

Jayden: (…) And um, I tried to be a little more precise where I knew more than like-well, oxygen for instance, this is like, from the Mesozoic, we've never actually managed to date like when it was. This is the date of when the particular signal, like this is the last instance of a particular signal. And then like the signal is different in rocks, so something happened in between.

Researcher: What is the signal you're describing?

Jayden: Oh this is disappearance of mass in independent fractionation of sulfur isotopes. That is often taken as the boundary for when the Great Oxidation event is or kind of started.

Researcher: Okay.

Jayden: It rises and fits and starts and there's a second rise that's hypothesized at the very end of the Proterozoic. But this [Great Oxidation Event] is like the first one. (p. 11)

Jayden discussed above that there were multiple signals for sulfur fractionation indicating a rise in oxygen levels, but that the event card for *oxygen* they were placing on the model was the first signal seen. As these multiple signals occurred at different times throughout Earth's history, Jayden's placement use of the Great Oxidation Event and placement of *enough oxygen to sustain life* with it, implied it was the first, and thereby oldest, signal for oxygenation. Additionally, Jayden stated that the Great Oxidation Event was associated with the first signal of oxygen on Earth. After Jayden's discussion about the Great Oxidation Event and evidence they could provide to support their answer, they were finally able to conclude that the event card for photosynthesis referred to "photosynthesis without oxygen because it happens a lot earlier" and was able to place it on the timescale at "about 4 million years ago, like 3.8-3.5" (p. 3).

Alex did not discuss the Great Oxidation Event in terms of signals, but instead referred to the relative dating of the Great Oxidation Event in the Proterozoic. Additionally, Alex tried to clarify what was meant by a *trace fossil* and if a trace and microfossil meant the same thing. Further, Alex asked if the microfossil was supposed to represent the organism that appeared around 3.8 billion years. Alex determined that the microfossil in the image on the card is not meant to be the same as the cyanobacteria associated with the Great Oxidation Event, because of the scale on the card. Later, Alex decided to put the *trace fossil* card with *photosynthesis* and *enough oxygen to sustain life*. Although Alex put them together, they were not in the correct order. However, these cards were meant to go together, so had Alex just rearranged them within the group they placed them in, Alex would have been correct in their placement.

> Alex: (*laughs*) there was a massive amount of things happening ah…shortly after-shortly after the earth formed. I think it was around 2.8 [billion years] and…uh…this looks…that's tricky… Because first evidence of life was at 3.8-do you consider micro or trace fossils? So it's not the micro-whatever that started about 3.8, from the picture, so I will put it at 2.8….(*inaudible*, *speaks to themselves again*). When I see oxygen, I'm thinking the Great Oxidation Event. Is that what you are referring to? I have no idea when it happened, but I think it's at the same time. Because we are in the Proterozoic….Yeah I will put them together (*enough oxygen to sustain life, photosynthesis begins on earth* and *trace fossil/first evidence of life* event cards)
>
> Photosynthesis-as in this photosynthesis (*points event card for photosynthesis*). (p. 3)

Alex continued to discuss the relationship between the Great Oxidation Event and the *trace fossil/first evidence of life* card in the next two quotes from their task-based interview. In the first quote, Alex referred to their fund of knowledge as a podcast that discussed bacteria, cyanobacteria in particular, as the first origins of life and the value of time associated with it. In the second quote, Alex distinguished between the first traces of life by cyanobacteria and physical trace fossils left by organisms, which originate in the Cambrian around 542 million years ago.

> That's what I interpreted from that…then…I know that there's an oxygenation event that is associated with something and I can't remember what it is and there are a lot of studies…there's a lot of students here working on that event, and I know it's probably

early in the geologic record…probably…happening around there…then the first trace fossils – so we know based on the geologic record that life started…3.06? There's a potential record of bacteria, I think its cyano-bacteria or some little bacteria around 3.8 Ga and I actually know that number very well from listening to a podcast and it's a topic they keep bringing up for whatever reason the origins of life…and so it's like…that number seems to be in my brain very good because of that. (p. 4)

Alex: That would be representing more of the first trace the basically animals that had skeletons or more movement than just algae or cyanobacteria, where we think we have traces, but those are more developed by animals-closely associated with the Cambrian explosion around 542…542 Ma.

Researcher: Okay…you originally had them though, the…trace fossil next to oxygen

Alex: Yeah.

Researcher: So what made you place them together originally?

Alex (17:57): I think that that's uh probably what I was having in mind um. I think that there might have been an association on the geologic record of the stromatolites so that's like when we start seeing more of the algae development and stuff when we have an increase in the oxygen in the atmosphere as an theoretical or O_2 actually. Um, I do know that-that happened fairly early in the history of the early, relative to life. (pp. 4-5)

Alex discussed both of these times, Cambrian at 542 million years ago and the Proterozoic around 3.8 billion years ago, to justify their reasoning for placement of the trace fossil/first evidence of life card.

Both Alex and Jayden had ideas regarding the Great Oxidation Event. Both expert learners referenced cyanobacteria associated with oxygenation on Earth, and placed the *trace fossil/first evidence of life*, *photosynthesis,* and *enough oxygen to sustain life on Earth* event cards close to one another on their models with justification for their placement. Most importantly, Alex and Jayden both used the timing of the Great Oxidation Event as a means of placing event cards on the model and establishing a scale according to when they thought the Great Oxidation Event occurred in geologic time.

Jayden: Rhynie chert. Jayden not only referred to the Great Oxidation Event to assist in placing events on the model in the correct order and relative scale, but also referred to the Rhynie chert and the Cambrian period. The Rhynie chert is known as a lagerstätte in the geological sciences. A lagerstätte is an example of exceptional preservation of fossils, which can include soft body parts, in a sedimentary deposit. The Rhynie chert is a lagerstätte specific to the Early Devonian that displays examples of extremely clear detail or completeness, specifically of primitive plants that lacked leaves, fungi and animals. Chert refers to the silica-rich, microcrystalline rock in which these fossils are contained. Additionally, the majority of organisms found during this time are from lagerstätte sedimentary deposits. Jayden's use of knowledge regarding the Rhynie chert assisted in placing the plant event cards.

> Jayden: (…) First fish…fish happened…so the earliest land plants would have been sometime into the Silurian, possibly the Ordovician, but definitely the Silurian and fish are older than that.
>
> Researcher: How do you know or how are you remembering the plants-
>
> Jayden: So the Rhynie-the Rhynie chert is Early Devonian. Or maybe it's Silurian. Um…and I think there's pollen or some like, just there are fossils in the Rhynie chert that

> are-it's one of the oldest plant fossil like, ahh…what do they call it, the plant fossil lagerstätte. But I feel like…oh no…that's a good question isn't it? Because were they vascular plants or were they just mosses? Mmmm… (p. 4)

Jayden questioned whether the Rhynie chert was Early Devonian or Silurian but ended up placing it on the model closer to Early Devonian. This placement allowed Jayden a way to relatively order events (e.g. as occurring before or after the Rhynie chert). For example, Jayden used the Rhynie chert to mark they knew plants existed. For a plant to be preserved as a fossil it had to exist first. By using the Rhynie chert as an anchor point, Jayden stated that they knew plants already existed at that point in time.

Jayden further discussed the relationships between plant evolutions on land as coming around the same time or shortly before that of terrestrial organisms.

> Around the same times as land plants; you kinda get a lot of-a lot of like, I think plants get on land first before the first amphibians do. Um…but it should happen like, so maybe like between land plants and reptiles. Like there, I think there was vegetation on land already before amph-before you find amphibians. It's around the same time you find a lot of land plant fossils. Why?...well, I mean…I've always learned that life evolved in water and then like, moved up on to terrestrial environments and so, um…like amphibians have-they breathe in water but they also have lungs that allow them to breathe on land. Terres-reptiles some of them are totally terrestrial, so they would have evolved from amphibians, um…also…also like, in the class, there's a classic transition fossil series going from fish to the first amphibians, like *Tiktaalik* and *Edenopteron* and like, all of the other lobe-finned fishes that had more weight-bearing appendages in the front of their-in their anterior fins and sort of like, allowing crawling. Allowing them to support

themselves, like in water they didn't have to support weight, but on land they'd like, need to be able to support themselves against gravity um…so just in terms of like how they, I've learned about that, evolutionary transition and like first and then the order of particular fish and then amphibians and like, that's kinda recorded in fossils, especially the appendages. (pp. 5-6)

Jayden's ability to establish a relative time, marked by the Rhynie chert, allowed them to establish a before and after relationship between plants and terrestrial organisms, allowing Jayden to place events on the model. From first discussing the Rhynie chert, Jayden provides further support for the transition of marine to terrestrial life by evidence of plant and animal fossils.

Alex: Rodinia. Alex had an anchor point that they referred to, which Jayden did not, called Rodinia. Rodinia, like Pangaea, was a supercontinent that assembled around 1.3-0.9 billion years ago in the Neoproterozoic. When Alex first pulled out the events cards and laid them out, they grabbed Pangaea first. Alex moved the cards around and said "oh-we don't have Rodinia" (p. 2). Immediately after that, Alex began to walk the length of the model to determine a relative scale to make their event ordering more accurate spatially. In order to discuss Pangaea, Alex began by discussing the history of supercontinents beginning with Rodinia. Alex stated the date of Rodinia, and then associated the date, approximately one billion years, with an area on the model that they designated as approximately one billion years ago. Alex waved their hand over particular areas of the model to relate to when Rodinia would have occurred, followed by Pangaea and Gondwanaland (another supercontinent).

Alex: So I *do* know that Rodinia kinda like became um we were having Rodinia at the Grenvillian origin, around 1 Ga (*speaks the letters "G" and "A", which is shorthand for* *billion years ago*) which is kinda around here (*waves hand at the end of the first meter stick near 'present day'*). Rodinia breaks up, and we have Gondwana develops, um at 600 Ma and stuff and we get the creation of Pangea. And Pangea starts in the Permian, somewhere in the Permian. PP [Pangaea and Permian] is a good thing to know. (p. 6)

Alex further discussed when they began learning about various continental arrangements and how they were able to reference Rodinia. Alex took classes that focused on the continental movement to arrange the supercontinents. Additionally, Alex worked in a laboratory where they work with materials the same age as Rodinia.

Alex: Well, I think I've learned them in dif-so in my paleo class, uh we focused a lot on, on like the animals themselves and a lot of the continental events and trying to associate the major um orogenesis, how to do you say orogenesis in [English]-

Researcher: orogenic events?

Alex: orogenic events, yeah, so we tried to associate major orogenic events and supercontinents and the break of those associated to life in the history of the earth, which is like not my paleo class. And I think a lot of those things in those classes kinda like really didn't stick very hard in my mind, but then just like, as I revisited in different classes and those things come up. It's like you start being able to connect those dots a bit better. So like…knowing that Rodinia has to do with Grenville. My [advisor] works a lot with Grenville, and so that's easy to remember. But they're like obsessed with zircons about 1 Ga old, so it's like okay, I can make that connection and remember those things because of that, if that makes sense. (p. 8)

Repetition of events in university courses, experience in a lab, and working with a particular professor assisted Alex in the remembering events placement in geologic time and connections to other provided events. Alex even made an anchor point for Rodinia and its date of one billion years and placed it on the model to assist them with placing other event cards. Alex heavily relied upon Rodinia, as it was the starting point for the placement of event cards on the model.

Jayden and Alex had anchor points that they referenced to place the events in a relative order on their models. None of the anchors used by Alex and Jayden were events provided to them for the activity. Jayden and Alex discussed the Great Oxidation Event and the relationships between photosynthesis, oxygenation, and cyanobacteria, in order to more accurately place the *photosynthesis*, *enough oxygen to sustain life* and *trace fossil/first evidence of life* event cards on the model.

These anchor points were specific references of interest, learned from experience or repetition that the expert learners worked with frequently. These were not simply topics discussed in university courses, but also events in time that the expert learners worked with or researched on a daily basis.

Additionally, a point that was not discussed above was Jayden's and Alex's frequent references to the geochronological units of geologic time, such as periods and eras. They both discussed what they knew occurred during those time periods as well as roughly how long they thought the period or era lasted, to assist them during the event ordering portion of the task in Activity I. Using the geologic timescale so frequently allowed specific geochronological units to become anchor points for the expert learner as well. However, the anchor points focused on here were specific events that the learners brought up in order to order their models.

Strategies discussed to create the model. In order to identify the similarities and differences between how novice learners and expert learners created their models, they were asked at the end of the event-ordering task in Activity I to share their strategies for creating their models.

Similarities between novice and expert learners' event ordering strategies. Expert and novice learners referenced learning or encountering the events they were given in previous classes. Novice learners often referenced their high school classes, media, or children's books as sources of prior knowledge. One novice learner, Cameron, did reference the current geoscience course they were recruited from for knowledge used in the task, but it was only referenced once for the *humans appear on Earth* event card, and not repeated throughout the course of the activity. However, it does make sense that novice learners' knowledge would come primarily from their K-12 courses as some of the students have not had any other science courses at the university where the study took place and some of the novice learners were freshmen. Expert learners also referenced prior courses, but typically university courses from their undergraduate and graduate careers.

Novice and expert learners both took the time to pre-sort the event cards and tried to sort them into groups. Watching the videos of all of the learners, both novice and expert learners took the time to go through the cards, and read what was represented on each card prior to placing it on the model. Some learners were able to jump into sorting the events or placing them on the model faster than others, however timing was not a variable of interest in this study.

Differences between novice and expert learners' event ordering strategies. Novice learners often referenced thinking about time itself, ability to sort events into groups, referencing their "basic knowledge" (Harper, p. 2), or discussing the relationships between events in time to discuss their strategies for placing events in a relative order on the model. As mentioned previously, knowledge regarding event cards were from different sources. While expert learners relied on their university backgrounds, podcasts, and experiences in laboratories, novice learners referenced high school courses, children's books, and media. Media includes movies such as "Dinosaur" and "Jurassic Park", as well as movies shown in high school classrooms that related the scale of geologic time to length of a day. One novice learner, Taylor, referenced a children's book to try to determine if there was a relationship between dinosaurs and small mammals stating,

> Taylor: So…birds, fish and small mammals were probably all close to the reptiles and the dinosaurs. I think because…I don't want to use this evid-evidence but I don't know, I always pictured that when the dinosaurs were alive there were little rats running around their feet. Uh…and the same thing when the fish and birds. They had to be there. Maybe not birds, but…they're all very similar.
>
> Researcher: Do you remember what was making you…where you first started to picture the dinosaurs with smaller animals.
>
> Taylor: There was a book that um…there was a book I read when I was really young called like-it was about this kid and he loved dinosaurs and he read a book about dinosaurs every night.
>
> Researcher: Oh that's neat.
>
> Taylor: Yeah…And there were always rats on the ground. I don't know how I remember that (*shakes head*) but-
>
> Taylor: (…) I loved that book. And then they were in Jurassic Park, I think. (p. 4)

This example shows what learners remember out of media portrayals of Earth's history. Taylor stated that they "don't want to use this evidence" as an indication of being weary of using a children's book for evidence, but from this book, Taylor still remembers rats running around the feet of dinosaurs. Movies and books are seen by viewers of all ages and can introduce ideas that we did not previously have about particular phenomena. For example, would Taylor have previously thought small mammals would have overlapped in time with dinosaurs if they have not read this book as a young child, if they did not encounter the topics of mammalian evolution overlapping with dinosaur existence anywhere else? Prior knowledge is important because it can help to reveal alternate or correct conceptions, confusion or clarity of topics.

Expert learners referenced anchor points, or pivotal points for the learner based on their background or experiments that help them to develop the scales of their geologic timescale models (Tretter et al., 2006b). Alex and Jayden had specific events, not provided by the researcher, that they referenced in order to place the events on the model in a relative and spatial order. Both Alex and Jayden referenced the Great Oxidation Event in order to discuss relationships between cyanobacteria or the trace fossil/first evidence of life, photosynthesis, and enough oxygen to sustain life event cards. Additionally, they both referenced periods of time, such as the Cambrian period, in order to most accurately space their events cards while placing them in the correct relative order. Alex and Jayden also had anchor points specific to their backgrounds that they used in order to place events in the correct order. For example, Alex referenced Rodinia at one billion years ago and Jayden referenced the Rhynie chert lagerstätte.

Expert learners further used their anchor points to scale out the model prior to the activity parts II and III that required learners to provide their assigned values for their models and scale card tasks. For example, after beginning to place events on their model, Alex began to walk the length of the model, placing one foot in front of the other. When asked what they were doing, Alex replied, “I’m pacing it to come up with a-distance of major numbers. I ha-have seven…, which would make it. Each ruler is about a meter. One, two, three, oh! This is 4 meters.

Oh! I see it now, so it's about 4 and a half or 4.8 meters roughly-great" (Alex, p. 1). Alex then realized they did not have Rodinia, yet marked where Rodinia would be in order to begin placing other events on the model. Jayden also discussed that the sheer size of the model was difficult to work with by just placing events on the model and it was necessary to first determine a way to divide the model in order to place events in the correct relative place on it.

> It's just-it's like-I mean the, it's a long, time, and a lot of the stuff that happened in the Phanerozoic is like, the Phanerozoic is, I don't know, like the last 12% of Earth's history. So that's all over here. So this part will be like really crowded. But I haven't decided-I don't wanna. First humans will be at present day on this scale, I think. I guess even though I don't know how best to like divide it into precise fractions, I can probably figure out the order I can put these in. So maybe I will do that first and go back (Interview with Jayden, p. 3).

Jayden further stated that in order to place an event on the model, they needed to be able to have an event they could recognize in order to "put it where I thought it made sense" (p. 15).

Conclusion

Overall, relative event placement was much easier than exact event placement as seen in the literature (Cheek, 2011; Catley & Novick, 2009; Hidalgo & Otero, 2004; Libarkin et al., 2007; Trend, 1998, 2000, 2001). Discussions with expert learners in regard to events placed on the model revealed ideas concurrent with scientific conceptions, even when events were placed out of the correct order. Expert learners would often assign an event card a particular meaning. For example, photosynthesis could be photosynthesis with or without oxygen present in the environment. Expert learners would then decide where they were going to place photosynthesis based on whether it was oxygenic or nonoxygenic photosynthesis.

Novice and expert learners also had correct conceptions even when placing events in an incorrect order. Novice and expert learners referenced learning or encountering the events they were given in previous classes. However, they varied in the sources of the knowledge. Novice learners often referenced thinking about time itself, ability to sort events into groups, referencing their “basic knowledge” (Harper, p. 2) or discussing the relationships between events in time to discuss event ordering placement, while expert learners referenced points of significance in their experience, general classes, being teaching assistants, or specific background knowledge.

Finally, the nature of past experiences, research or college courses, assisted in the development of anchor points that expert learners used to represent the scale and event ordering of their models. Anchor points were also primarily grounded in the expert learners’ area of research. Although there were discussions of material from courses during their undergraduate and graduate careers, the expert learners primarily referenced points in time that were specific to their research. Expert learners were able to use anchor points to scale out the geologic model as well as place event cards in a particular order based on whether the other events occurred before or after the anchor point. Novice learners did not discuss any particular point in which they were basing all of their decisions around. Therefore, novice learners varied from the experts in their lack of an anchor point(s).

This chapter examined learners’ when learners thought events occurred through their strategies and reasoning for event ordering and placement on the model. Chapter six examines learners’ conceptions of how long they think events took place and the length of time between events. Chapter six is a detailed discussion of scale and duration through learners’ placement of events, assigned values, and scale cards on the model, and how those placements compare to geologic time.

Chapter 5

Findings

Timescale Activity Parts II and III: Scale and Duration of Time

Although most research focused on students' ability to temporally order events and scale them on the geologic time model, few studies focused on the duration, or intervals, of geologic time (Dodick & Orion, 2003b). Duration has been studied far less in geoscience education than temporal order and succession (Cheek, 2010). Geoscientists struggle with duration as well since it is continuously revised through additional research (Kastens & Ishikawa, 2006). Previous research focused on the magnitude of geologic time while ordering of events and on the difficulty associated with understanding how long periods of time can be represented in geologic time.

Duration has been difficult to study since there is no one particular interval that is applicable to everything. Duration and scale are related in geologic time. In order to understand the duration of time between or during events, one must understand its scale. This chapter focuses on describing learners' representations of scale through the placement of event cards, learners' chosen assigned values they associated with the events in geologic time, and their use of scale cards. Placement of the event and scale cards, as well as their assigned values, have implications of scale. The chapter presents learners' strategies for event card scale, assigned values and scale, and strategies for scale card placement and use. These strategies are discussed by making comparisons of: 1) event's placement compared to its position on the model, 2) the event's date assigned by the learner in geologic time to the learner's placement of the event on the model, 3) the assigned value applied to an event, 4) the scale card placement and the position that represents in geologic time, and finally, 5) the intended use of the scale card compared to the values on the model.

Geologic timescale activity parts II and III: assigned values and scale card use

In the Geologic Timescale Activity Part II, learners assigned their own values of time to the events on the model. Learners wrote these values on post-it notes, then described their reasoning for the value they chose and how they planned to use the value. For example, some learners used it to mark events, or increments in time, while other learners chose to mark the duration between events. After discussing the assigned values on the model, the researcher provided the accepted times for *present day* and *Earth's formation*. Based on new values, learners either kept or adjusted their original values.

In the Geologic Timescale Activity Part III, learners were provided scale cards to think about the scale of their models, as well as the duration of time. Scale cards were intended to provide a different way to visualize time by providing a visual representation of time in relation to the distance or length of an object. Learners chose to use scale cards to mark increments of time, duration of time between events, to mark a range of time, to add values in time, or a combination of the options listed.

Assigned values created by the learner and the use of scale cards in Geologic Timescale Activity Part III provided a visual of the learners' representations of three items: scale, duration, and event dating. Scale and duration overlap. The timescale model is proportional to the timescale itself. As scale in this activity is a ratio between the linear dimensions of the learners' model against the original geologic timescale, duration represents a portion of the ratio, and is discussed with learner's ideas of scale. Scale was represented by the spacing of event cards, the assigned values of time learners associated with those events, and alignment of the scale cards to their assigned values and points on the model. Event duration was associated with scale, as this is represented by the spacing between events and learners' ideas of how long events lasted. Duration was also represented by scale card use. Learners' ideas of event dating were represented by their assigned values and their discussion.

Findings regarding novice learners' strategies to construct their model's values, duration, and scale are discussed first, followed by the expert learners' strategies. After the expert learners' summary, the similarities and differences between novice and expert learners are summarized.

Novice learners' strategies: *event card scale.* Novice learners' strategies for scaling their event cards varied. Each novice learner placed events in a particular order and when prompted to provide their strategy for placement, they discussed how they thought each event related to others. Additionally, each novice learner spaced out the event cards to show time between events but when asked to discuss their strategy for using the event cards, they did not discuss the space as representing time between events without being prompted, with the exception of Cameron. Novice learners were asked about what the space between event cards meant and how they decided on the spacing between event cards. At that point in the task, none of the learners discussed their scales. However, when it came to placing assigned values, novice learners would readily discuss their scale being incorrect, even before finishing the task. Taylor discussed their scale cards not aligning with their assigned values, while Harper noticed the scale of their assigned values was not correct before placing scale cards.

Cameron and Frankie both described grouping event cards as a strategy for event card scale and placement. Cameron discussed grouping their event cards based on events that occurred "a while ago" and those that were "very, very late" (Interview with Cameron, p. 3). Frankie grouped event cards by trying to categorize first and then placed them in a relative time order. Frankie categorized organisms and events as either modern day or older events, grouped the events in the two categories, and then placed them on the model in that order. Cameron discussed knowing a "good amount of time" (Cameron, p. 8) occurred between *Earth's atmosphere formation* and *enough oxygen to sustain life*, indicated by Cameron leaving a large amount of time between event cards. Cameron stated that they "did not know how long that all took" and "couldn't really explain the gap, but thinks there is a gap" between the events (p. 8). Cameron went further to explain for other events that "again, [they] were not really sure of space of it" (p.8), meaning they did not really know what the duration of time was, but would explain the relationship between the events instead.

Cameron, Mica, Taylor, and Harper discussed duration when asked about the spacing of the event cards. Mica used duration by discussing the relationship between the size of spaces, or gaps, to the amount of time that has passed. Taylor and Harper also discussed the duration of event cards as a strategy for scaling their models. Cameron, Mica, Taylor, and Harper tried to space the cards out to reflect the amount of time between event cards.

> Um, this, I just basically did shortly after. I think this was just boom, boom, boom, so its spaced closer because of that. Humans, there's a big gap, because I just didn't think humans came for a really long time after mammals. I thought mammals were on earth a really long time before humans. (Mica, p. 11)

Taylor discussed their strategy for event card placement as thinking back to prior science classes. When prompted to discuss the space between event cards, Taylor stated that "more space is longer time" (Taylor, p. 6). Harper also discussed the spacing, stating that "each gap would be like millions of years so I tried to make it as accurate as possible" (Harper, p. 4).

Mica also discussed trying to think about time in general and “about what makes sense to place” (p. 11). Mica discussed event card placement keeping event age in mind and what they felt “made sense to go first” (p. 3). Mica placed events based on which events were the oldest they could think of. Mica’s strategy for scaling the event cards while placing them was the same for determining their assigned values, thinking of the oldest event or lowest value.

When prompted for their strategy for event card placement, all of the novice learners discussed how they thought the event cards were related. Duration, discussed as spacing or gaps, was related to the amount of time between events by all of the learners, with the exception of Frankie. Frankie did not mention the spacing between event cards when discussing their strategy for event card placement. Instead, Frankie discussed their scale being incorrect in terms of spacing during the assigned value portion of the task.

Assigned values and scale. Novice learners’ strategies for assigned values varied. All of the novice learners discussed trying to remember specific numbers in time to gauge their scales. Mica and Frankie discussed values that related to B.C./B.C.E. and A.C./A.D., while Cameron, Taylor, and Harper tried to remember values for specific events.

Two out of the five novice learners, Mica and Frankie, tried to think of the oldest times or lowest date they could think of (a reference to B.C. and A.D.). Mica and Frankie mentioned B.C./B.C.E., and A.C./A.D., respectively, when discussing their models. Both Mica and Frankie mentioned having used B.C./B.C.E. and A.D. in a historical context; Frankie learned about B.C.E. and A.D. in an AP Art History course, while Mica learned about B.C. and A.D. in a History course.

Cameron, Taylor, and Harper discussed trying to associate numbers with events in time as well as setting their scale to the values they set for *Earth’s formation*. Mica and Frankie also used their value for *Earth's formation* to set their scale, but did not openly discuss using *Earth's formation* value as a scale strategy. As *present day* was current time, none of the novice learners wrote down a value they associated with *present day*.

Similar to Mica and Frankie, Cameron tried to "pull from memory numbers they remembered hearing" (Cameron, p. 21) and discussed citing values from college courses and television. Both Cameron and Taylor referenced dinosaurs when attempting to add assigned values and scale their models. Cameron stated that they were trying to remember the range of time when dinosaurs existed. Taylor mentioned 70 million years for when dinosaurs first appeared on Earth, but later said that the 70 million years was a guess, as were the other values that they used on the model.

Both Harper and Frankie discussed trying to think of a relative time scale (Harper, p. 5). For example, when Harper was provided the values of 4.6 billion years for *Earth's formation* and 0 years for *present day*, they chose to keep their assigned values because they used relative time. Harper explained that they though events still occurred around the same time regardless of changing the exact value for *Earth's formation*, because they made everything relative to 4.6 billion years, even though the value was off by 1 billion years.

> I think everything still happened around the same time…that's why I put everything else starting at 3.5 instead of 3.6. Like cause, I was between 4.6 and 3.6 and I know-these-I was leaning for 4.6 so I made everything more relative to that. (Harper, p. 6)

Other novices discussed a sense of "guessing" while assigning values.

Frankie also discussed time as being relative when they placed both the event and scale cards and when they wrote assigned values. Frankie first used the term relative when discussing connections between events, stating they thought that *asteroid hitting Earth* and *dinosaur* *extinction* were "relatively close in time" (p. 3). When Frankie placed the post-its with assigned values on the model, they moved the assigned values. Frankie explained that they were "moving them down relatively, because time went up" (p. 11). Frankie used scale cards to add up to a duration of time between their assigned values for 100 million and 4.6 billion years. Frankie explained that they "gave myself a relative amount of cards that would kind of add up to be close-ish" for two reasons (p. 16). Frankie stated they didn't know what the "exact time would be" and mentioned not having scale cards to align with values they wanted to use (p. 16). Hence, Frankie added 2.5 million and 5-million-year scale cards to be 7 million years. Frankie and Harper both discussed using relative times to scale their model.

Novice learners acknowledged the scale of their models being incorrect. When prompted to discuss how they knew their models were not properly scaled, learners referenced a comparison between the placements of the assigned values on the model and the assigned value they wrote on the post-it note. The comparison between the placement of assigned values and the time values were represented by the duration (spacing/gaps in time) on the model. Novice learners could tell that the assigned values they chose and their placement did not align, because the durations were not consistent. For example, when writing the assigned values on the model Harper mentioned that their "spacing is off" (p. 5), later clarifying, "I just go through the first 3 billion years right here" (p. 5). Frankie also discussed noticing the discrepancy between the assigned values and placement. In the following exchange, Frankie discusses with the researcher why they feel their model isn't properly scaled.

Researcher: … How do you know it's not to scale?

Frankie: Not to scale? (*talks at the same time as the researcher*)

Researcher: Yeah

Frankie: Because once I got to the second one I was like, "Ugh, this is definitely not right" (*lets out big sigh*)

Researcher: What didn't feel-what do you mean it didn't feel right? What isn't right, I should say?

Frankie: So for here, I put 400 billion years ago.

Researcher: Okay

Frankie: Here I put 200 [billion years] and if I was keeping that same measurement…

Researcher: Yeah

Frankie: This would not work…I would have to extend them because if I was going to say this was 200 then that should be the next increment of 200 there (p. 7).

In that discussion of scale, Frankie noticed the spacing they used represented 200 billion years was not the same for the next increment of 200 billion years. The addition of those two spaces did not represent the 400 billion-year gap they had already displayed on the model.

Cameron was unique in that they were aware of the scale of the activity and discussed it from the very beginning. Cameron viewed the geologic timescale activity as a "really complicated puzzle" (Cameron, p. 2), later clarifying "figuring out how I should scale it. I know humans are a very small part of the whole thing, but I'm still not sure how big to make it" (p. 2). Cameron tried to scale the activity as they placed their event cards on the model. Cameron discussed the scale in terms of duration and the gaps of time as the amount of time between the event cards. Cameron discussed feeling as though there was more time between events, that they needed to make the sections smaller, or being unsure of the "space of it" (p. 8). They did not explicitly state their scale was incorrect, but would talk in terms of the gap or spacing. Even as Cameron moved on to adding the assigned values, they still discussed that the event cards needed to be adjusted “I keep thinking that all of this [*Earth’s formation* and *Earth’s atmosphere forms*] needs to be closer together” (p. 13). However, Cameron noticed the discrepancy in scale based on the assigned values and their placement similar to Harper and Frankie, before explicitly stating that they think their assigned value guesses and the scale do not match.

> Yeah, cause I’m noticing that I have those as millions of years and I feel like the need to be shoved down where this is like billion. To kind of show the timescale. Because million goes all the way up to dinosaurs and all of this is billions (*“is billions” is whispered to themselves*)… I think my guesses and overall scale just don’t match. (p. 14)

As Cameron states “millions goes all the way up to dinosaurs and all of this is billions”, (p. 14) they noticed their scale was not correctly aligned between the event, assigned values, and the spacing. After placing their final assigned values on the model, Cameron adjusted the alignment of the event cards and moved the cards with millions of years closer to the *present day*. After being provided the values of zero and 4.6 billion years, Cameron changed their assigned values to align more correctly with their model values.

Taylor acknowledged their model was not to scale when they discussed their assigned values. Taylor stated “it’s not to scale” (Taylor, p. 6) and that they guessed about the times they placed on the model. Taylor also discussed that “more space is longer time” (p. 6), indicative of their understanding that bigger spaces on the model represented more time between events. After placing scale cards, Taylor stated that their model was “not to scale whatsoever” (p. 7), noting their scale card and assigned values did not align because Taylor had to use a 2.5-million-year scale card to mark the earlier point in time because there “wasn’t a thousand” (p. 7). Taylor moved a few event and scale cards toward the *present day* and then stated, “I mean it still isn’t going to be to scale because I like-10,000 to 35 million and then here I’ve got like a billion in this span" (p. 8). They attempted to rescale their model a final time after learning the activity was scaled to represent 4.6 billion years in 4.6 meters. After learning how the activity was scaled, Taylor stated that "I'm just thinking…uhh…I mean all this stuff would just be pushed that way (toward present day) really and this stuff would be more spread out" (p. 8). Taylor proceeded to move both the event and scale cards on the model. When Taylor stopped rescaling the model, they acknowledged that they still were unable to get a billion years on their model, but stated "it's as close as I can get it right now. I feel" (p. 9).

Strategy for scale card placement. Scale card placement varied in four ways. Scale cards were either used to represent 1) increments of time, 2) durations of time, 3) added to make a value (as part of an increment or duration), or 4) any combination of items one through three. Taylor primarily used scale cards incrementally, with one scale card used to mark duration. Harper only used the scale cards to represent the duration between events. Frankie's scale cards were used for duration, but they added multiple cards to create the value of time between event cards. Cameron and Mica used a combination of marking increments and duration.

Frankie, Mica, and Taylor placed and scaled their models based on their assigned values, yet they used the scale cards in different ways. For example, Taylor stated that when using the scale cards, they looked for where they had a mark [assigned value] on the model and would then just put a scale card near the mark, working incrementally through time.

> I basically-I looked at where I had a mark and then got a rough-something near it and then put it where I thought it would go in…700 million is relatively close to a billion. 200 million-I had a 200 million year, 150 million, 100 million, just near it. (Taylor, p. 7)

Although Frankie used the assigned values, they did not use the scale cards for incrementally marking time alone. Where Taylor used multiple cards to mark points in time, Frankie used multiple scale cards to add up to the duration between events. Frankie stated that they tried to add up the cards but was “not exactly sure what the exact time difference or the time between 100 million years about and 4.6 billion”, but tried to get a “relative amount of cards that would kind of add up to be close-ish” (p. 16). Frankie also used scale cards to mark increments because the values on the scale cards were too large to fit between events, “we didn’t have cards small enough to fit between these time periods or any of the other ones” (p. 16). Mica marked increments of time, similar to Taylor, but used some of the scale cards to represent durations of time between three sets of events.

Harper and Cameron primarily used the scale cards to mark durations of time. For example, Harper said they could represent time between events more easily because they could use scale cards to say this “probably happened like this long in between one another” (p. 12). Cameron described the duration by saying they were trying to “make a range for the ones I’ve grouped together” or between the “relationships” of events (p. 19).

Three novice learners, Cameron, Mica, and Harper, felt more comfortable using scale cards. Frankie and Cameron stated they felt more comfortable having values to work with. Cameron said the scale cards provided them “some exact numbers to work with, whereas with the note-the sticky notes, they were just pulling numbers” (Cameron, p. 22). Harper stated that they felt a “lot better” having scale cards was “easier” and “for the assigned times I [Harper] had to come up with values and large numbers in times just from memory; something that I [Harper] really don’t think about often” (p. 12).

Although Mica did not feel as comfortable with the scale cards they expressed feeling “less uneasy” with the scale cards (p. 12), while Taylor did not find the scale cards relevant. Mica stated:

> The scale cards were still kind of hard though because I didn't know what to base if off of. Because I really don't know when things happen. So it was really a guess I'd say. I felt uneasy about it, but not as uneasy as the times (Mica, p. 12).

Taylor expressed a similar viewpoint.

> Honestly, I thought it [use of scale cards] was a bit irrelevant, because it wasn't going to make me think any different about uh when things happened. If I had no clue already it was just placing them in comparison to my sticky notes. (Interview with Taylor, p. 10).

If used in this manner, the scale cards were irrelevant as they did not assist the learner build on their ideas of scale. For Taylor and Mica, scale cards were irrelevant because they were repetitive instead of helpful. The other three novice learners felt more comfortable being provided with values they did not need to think of on their own.

Scale cards and use of scale. Four of the five novice learners discussed their scale being incorrect when they discussed their strategies for scale card placement. Only Harper and Taylor rescaled their event and scale cards when learning the model was scaled to 4.6 meters for 4.6 billion years of time. All of the novice learners used their assigned values to guide the placement of the scale cards.

When prompted to discuss how they knew their models were not properly scaled, learners referenced the assigned values. It was not until after scale card placement and learning the activity was scaled to 4.6 meters did Harper re-scale their model and only because they felt they "probably should" (p. 9). Harper moved scale card cards to align more closely with their assigned values and the activity's scale.

Taylor and Frankie used their assigned values to guide the placement of their scale cards and cited a discrepancy between the scale card values and their assigned values. After adding scale cards, Taylor stated that part of their model was "not to scale whatsoever" (Taylor, p. 7). Taylor stated using the scale card 2.5 million because "there wasn't a thousand" (p. 7). The lowest assigned value Taylor used was 10,000 years ago. Taylor tried to find scale card values that were as close to their assigned values as possible. Frankie also stated that they weren't "exactly sure what the exact time difference or the time between 100 million years about and 4.6 billion, but I gave myself a relative amount of [scale] cards that would kind of add up to be close-ish" (p. 16). When provided the scale of 4.6 meters, Frankie chose not to re-adjust their scale stating that "I'm not necessarily sure I would be able to do it on the proper scale" but further clarified that "if we did, these [scale cards] would all be down here and then I'm not sure where these would come about and how to space it out" (p. 17). Frankie realized that their event cards would not be so spread out and that the scale that they used would need to be compressed.

Cameron scaled and rescaled the activity multiple times. Cameron chose to speak through the activity and rescaled the event cards as they expressed their ideas. When Cameron placed scale cards, they did not speak through the activity and did not re-scale the model when adding the scale cards or learning about the task being scaled to 4.6 meters. Cameron noticed that their assigned values were off, discussing that there should be more time between events such as *Earth's atmosphere forming* and animal evolution. Cameron did not adjust event cards here, but did re-write their assigned values. Cameron did not rescale all of the assigned values as they said they were had "no idea" what value to change it to (p. 17). Finally, Cameron stated that they used scale cards to make it into a "range based on my original one [assigned value]" (p. 19).

Mica used the same strategy for scale card placement as they did for coming up with assigned values: they chose the lowest and highest values they could find. When discussing their strategy, Mica stated they used the "lowest date" they could think of (p. 7), which in their model

100 B.C. was a value Mica said “felt like a really long time ago” and that they were trying to think “really far back” (p. 7). When prompted to explain their strategy for scale card placement, Mica again stated using 2.5 million years because it was “lowest” stating “I think that I used this because it’s the lowest, so I was like “oh only 2.5 million years” like life started appearing kind of” (p. 10). Mica also used 2700 million years as the amount of time after life formed, which was the largest value included for the scale cards.

Mica adjusted their event cards after discussing their strategy for event card placement. As Mica spoke, they moved the event cards to align with the relationships they wanted to represent between events. For example, Mica had the correct order for the events on the model and further revealed their thought process about the relationship between events. Mica’s view of photosynthesis as a requirement instead of a mechanism for growth resulted in moving photosynthesis after plants because of how plants “needed photosynthesis to thrive” and “plants making photosynthesis” (p. 3). After adjusting the event cards and placing assigned values, Mica did not change the scale of their model. Mica did not change their assigned values until provided zero and 4.6 billion years, and then did not rescale the scale cards, stating “I will probably leave it as is, because I don’t even know what I would change” (p. 12).

Summary of novice learners’ scale, duration, and assigned values. Although the novice learners’ strategies varied between their scaling of event card placement, use and scale of assigned values and scale cards, there were common threads among the novice learners. While scaling the event cards, each of the novice learners discussed how each event related to others and spaced the event cards to show time between events. All of the novice learners discussed duration as the spacing, gap, or time between events. They tried to remember specific numbers from school, a documentary, or that were associated with a specific event to assign values. Their references, memories, and units for the assigned values varied. For example, Mica and Frankie discussed values that related to B.C./B.C.E. and A.C./A.D., while Cameron, Taylor, and Harper tried to remember values for specific events.

Novice learners' strategies for scale card use varied. Novices chose to use scale cards to represent increments or durations of time, or a combination of those two strategies. None of the learners discussed their scale directly when placing event cards, but brought up the scale of their models being incorrect during the assigned value and scale card portions of the activity. Four of the five novice learners discussed their scale being incorrect when they discussed their strategies for scale card placement. Taylor discussed their scale being incorrect by noticing that the scale cards did not align with their assigned values, while Harper noticed their scale was incorrect when placing their assigned values. Mica was the only novice learner that did not discuss the scale of their model being incorrect.

None of the novice learners added up their assigned values or scale cards values to determine if these values aligned. Instead, learners looked at the values to see if they appeared to be similar. Finally, all of the novice learners used their assigned values to guide the placement and scale of the scale cards. However, they discussed their scale not aligning with the assigned values, but moved scale cards to fit the scale they chose. Taylor and Harper were the only novice learners that rescaled event and scale cards when learning the model was scaled to 4.6 meters for 4.6 billion years of time. Finally, none of the other novice learners adjusted the event cards or the scale cards after learning the activity was scaled out to 4.6 meters. Assigned values were harder than scale card placement for novice learners, however not all novice learners found the scale cards more beneficial. Frankie did not know what to base the scale cards or assigned values on and Taylor said the scale cards were irrelevant.

Novice learners' models reflected a range of average difference from 657 million years up to 2.33 billion years (Table 5.1). This range represented the average displacement, which is the difference between where the learner placed their event card on the model compared to where the event would be placed by geologists. The average value in years these displacements represented are listed in the right column of table 5.1.

Table 5.1
Summary of novice learners' average differences of event card placement

Novice learner	Event card displacement range (cm)	Average displacement (years)
Taylor	0.9 cm - 296.7 cm	1.00 billion years
Harper	2.95 cm - 376.8 cm	742 million years
Frankie	31.2 cm - 398.5 cm	2.00 billion years
Cameron	0.4 cm – 185.7 cm	657.0 million years
Mica	14.9 cm - 379.0 cm	2.33 billion years
Average:	**10.1 cm – 327.3 cm (100.7 million years – 3.27 billion years)**	**1.35 billion years**

Novice learners had displacements less than 32 centimeters, which translates to less than 320 million years. 3.79 billion years was the largest displacement and showed how far off in time the learner placed an event on the model as compared to geologic time.

Table 5.2
Summary of novice learners' average differences of scale card placement

Novice learner and their scale card use	Average dislocation (years)	Average discongruity (years)
Taylor (increment)	1.60 billion years	-
Harper (duration)	1.92 billion years	450.3 million years
Frankie (duration)	3.29 billion years	3.43 billion years
Cameron (increment/**duration**)	581.9 million years	163.5 million years
Mica (**increment**/duration)	2.66 billion years	771.3 million years
Average	**2.01 billion years**	**1.20 billion years**

Primary scale card use is bolded if more than one strategy to use scale cards is listed.

The dislocation, difference between the scale card value and scale card placement, for novice learners was 2.01 billion years. However, as discussed, not all novice learners used scale cards to mark incremental values of time. The second column in table 5.2 above displays the average discongruity, which is the difference between the intended use of the scale card value and the duration between events. The average discongruity of duration and scale card values was 1.20 billion years.

Summary of expert learners' scale, duration, and assigned values. Although the findings for event ordering and scale are discussed separately, the strategies expert learners used to create their models demonstrated that for the experts, conceptions and strategies about event ordering and scaling are linked. For example, expert learners' strategies for scale were relatively similar. Both Alex and Jayden established a midpoint to break their model into manageable chunks of time. Alex and Jayden discussed scale throughout the entire activity and relied upon anchor points to establish a relative order and scale of their model.

Despite these similarities, there were variations in the models between the expert learners. Alex walked the length of the model to establish a concrete scale to be more precise. Alex also discussed the length of each period in geologic time they used to further establish a more precise scale. Jayden did not walk the model but used their fingers to establish a scale. Jayden also began by flipping their model. Jayden switched the marks for *present day* and *Earth's formation* to assist them in thinking about the ordering of events and how to establish their scale. Finally, Jayden used more anchor points to relatively scale their model.

Similarities and differences between novice and expert learners' strategies

Similarities. In terms of scaling the event cards during placement, each learner discussed how they thought each event related to one another and spaced out the event cards to show time between events. Although the novice learners did not discuss implications of spacing the cards out directly during the event ordering portion of the activity, they discussed the relationship of space between events relating to time during the assigned value and scale card activities. All learners discussed duration as the spacing, gap, or time between events.

Both novice and expert learners found it difficult to place their own assigned values on the model. Novice learners were more hesitant about assigning values or had difficulty remembering assigned values, while the expert learners were more concerned with how to scale the activity from the assigned values they used. Strategies for scale card placement varied, but the placement of scale cards was guided by the placement of assigned values for all learners.

Additionally, all learners were well versed in biological processes such as photosynthesis, occurring with and without oxygen, bacteria in early earth systems, fins-to-limbs transitions, dinosaurs dying out after or associated with a meteor (although some thought this was a trick), and confusion with the *trace fossil/first evidence of life* card's use and were to place it.

Furthermore, all of the learners' experienced problems with proportional reasoning on the scale. Although novice learners had more error in the placement of their event and scale cards, as well as their assigned values on the model, the experts were not free of error. Table 5.3 below displays the percent error for event card placement on the model for each learner.

Table 5.3
Learners' event card displacement percent error

Event placement in geologic time	Novices					Experts	
	Taylor	**Harper**	**Frankie**	**Cameron**	**Mica**	**Alex**	**Jayden**
Humans	380%	1,180%	18,640.0%	580.0%	48,720.0%	220.0%	980.0%
Large mammals	200.0%	251.1%	1,735.6%	8.9%	5,433.3%	66.7%	131.1%
Dinosaurs go extinct	593.8%	100.0%	4,596.9%	558.5%	4,558.5%	30.8%	192.3%
Asteroid hits the Earth	593.8%	569.2%	4,623.1%	598.5%	3,476.9%	30.8%	192.3%
Flowering plants	800.8%	894.6%	2,943.8%	1,066.2%	2,700.8%	144.6%	196.2%
Birds	569.3%	383.3%	799.3%	18.0%	1,710.0%	9.3%	156.7%
Pangea begins to break apart	1,396.5%	63.0%	942.5%	61.0%	922.5%	77.5%	182.0%
Small mammals	341.8%	140.9%	341.3%	26.2%	1,175.6%	1.8%	71.1%
Dinosaurs first appear on Earth	230.4%	260.9%	1,513.5%	223.9%	1,647.8%	7.8%	82.2%
Pangea forms	1,098.9%	1,395.6%	1,475.9%	349.3%	1,316.7%	14.8%	1,423.0 %
Reptiles	141.9%	215.3%	440.0%	115.3%	904.1%	16.6%	97.5%
Trees	389.4%	194.7%	1,011.7%	291.7%	872.8%	6.4%	82.2%
Vascular (Land) Plants	58.5%	212.9%	841.6%	269.2%	752.7%	3.5%	54.4%
Fish	89.4%	374.3%	236.2%	18.1%	503.6%	14.2%	46.0%
Enough oxygen to sustain life	33.9%	24.5%	85.0%	22.0%	91.4%	23.3%	3.7%
Trace fossil/First evidence of life on Earth	56.5%	30.9%	21.6%	53.1%	19.5%	84.8%	76.5%
Photosynthesis	49.7%	5.4%	21.6%	51.5%	4.3%	84.8%	0.9%
Earth's atmosphere forms	0.37%	2.61%	7.6%	26.2%	6.0%	5.2%	8.7%

As depicted in the table above, novice learners were able to place event cards on the table with error as low as 0.37% (Taylor), which was not done by the expert learners. The difference between the novice and expert learners' percent error for event placement according to table 5.3

was the relative consistency of low percent error by the expert learners. However, events that expert learners expressed difficulty with, events outside of their specific disciplines, resulted in higher percent error. Additionally, novice learners had low percent error for events deeper in Earth's history, and higher error with placement of events close to *present day*. The low percent error for these events is not surprising when compared to learners' discussions of events that they were confident in and spoke in depth.

Finally, percent error tables could not be calculated for the assigned values and scale cards for two reasons. First, not every learner used scale cards or assigned values the same way. Second, because of the variation in use, a comparison could not be conducted to properly examine learners' error in placement.

Differences. Novice learners' references, memories, and units associated with the assigned values and ranges varied. For example, Mica and Frankie discussed values that related to B.C./B.C.E. and A.C./A.D., while Cameron, Taylor, and Harper tried to remember values for specific events. Although both expert learners referenced the Great Oxidation Event, the majority of their anchor points reflected their specialties.

The difference between use of anchor points for ordering and scaling was in the use of relative and absolute time. For example, anchor points first allowed Alex and Jayden to form a relative model, placing event cards before or after the anchor point. Using anchor points helped the expert learners develop a more absolute scale, by narrowing down the possible occurrence of the event in time.

Additionally, expert learners already had knowledge of the geologic timescale and were able to use their preexisting knowledge to determine assigned values and scale. The experts did not always use actual numbers, but placed the name of the corresponding geochronological units, geological era, period, or epoch, on the model. Expert learner Alex discussed thinking about 4.6 billion years, as just 4.6 in some units to find the midway point of the model.

None of the novice learners expressed thinking about the scale as a timeline to break up this value. Novice learners did not mention scale until the assigned value and scale card portions of the activity. Additionally, novice learners did not check to make sure their final scale matched the assigned values and scale cards they chose. Instead, learners looked at the values to see if it "looked right". None of the learners adjusted their assigned values placement when adding scale cards. Novice learners discussed their scale not aligning with the assigned values, but chose not to move scale cards. Taylor and Harper were the only novice learners that rescaled event and scale cards when learning the model was scaled to 4.6 meters for 4.6 billion years of time.

In terms of event card displacement values, novice learners' models reflected a range of average difference from 657 million years up to 2.33 billion years. Expert learners had an average difference range of 341.2 million years (Jayden) and 407.9 million years (Alex). This range represented the average difference between where the learner placed their event card on the model compared to where geologists would place the event on the model.

Experts' assigned values ranged from an average difference 65.8 million years for Alex, and 149.2 million years for Jayden. Novice learners had a range of difference between the assigned values and their respective placement from 319.4 million years to 3.46 billion years. The average difference between novice learners' assigned values and their placement on the model was 1.30 billion years or 130.4 centimeters.

Finally, novice learners had an average difference of 2.01 billion years for scale card placement as compared to scale card value. The difference of 2.01 billion years refers to the average difference between where the learner placed the scale card on the model, converted to years, compared to the scale card value. However, as discussed, not all novice learners used scale cards to mark incremental values of time. Values were calculated to reflect the duration of time between cards. Therefore, the average difference of duration values used by novice learners was 1.20 billion years. Expert learners' scale card value and placement on the model averaged 525.0 million years. The average difference between scale card value and scale card placement on Alex's model was 76.5 million years, while Jayden's average difference was 285.0 million years.

Chapter 6

Discourse Analysis

As novice and expert learners were conducting a task-based interview, they discussed how they made decisions during the activity. Learners explained the descriptions of how they pictured the events in time, described the relationships between events, and their funds of knowledge. It was important to examine this knowledge in-depth. Learners participating in the timescale activity came with ideas about the events and scale of geologic time. To better understand these ideas, the words they chose and repeated, as well as the sources of their knowledge discussed were important clues to understanding how learners, novice to expert, think about and represent time.

In the section below, two research questions have been addressed: 1) how do learners discuss their conceptions about geologic time? And 2) how do learners represent and understand the scale of geologic time? The first question examined learners' use of discourse to understand what learners know in their mind about geologic time and the source for this information, such as a middle school course or book. As analysis of learners' ideas regarding event ordering, scale, and duration will be discussed in chapters four and five. This section focuses on the individual words represented during each learners' interviews.

The second question examined learners' reasoning for how and why they assigned values of time, total values to see if they match that of time (duration and scale) represented on the model, and their reasoning for placement of event cards, use of scale cards, and choices for value assignment. Reasoning is the way learners think about time. Learners' reasoning is grounded in the evidence they use to support their claims, and how they make sense out of geologic time. Learners reasoning was examined for lexical patterns, to determine words and phrases that all learners used during the activity, which words and phrases were repeated, and the ideas, or conceptions, that were foregrounded through their word choice, which is their ways of representing. Learners' word choice and reasoning were representations of their "social practices" and "self-representations of the practice in question" (Fairclough, 2004, p. 228). In other words, the words learners chose and combined with their reasoning, provides insight into how they made meaning, visually and linguistically, of the information provided during the activity. This lexicalization and relexicalization analysis was grounded in the work of Rebecca Rogers focusing on the ways of representing (2013). Conceptions that were foregrounded by learners during their reasoning for event card placement, scale card use, and for assigning values, are discussed in chapters five and six. They are discussed separately to show the similarities and differences novice to novice, expert to expert, and novice to expert.

This discourse analysis section focuses on the word and phrase choice, *lexicalization*, and repeated words and phrases, *relexicalization*, used by all learners. The analysis of discourse presented is a basic overview of learners' discourse, as it presents only the spoken utterances learners used and repeated throughout the task, and the meaning behind these utterances. An in-depth analysis of discourse examining syntax and gestures would be another dissertation entirely. This section on discourse was included as the goals of the two of the research questions were to identify the sources of knowledge, the ways in which learners represented geologic time through lexical patterns, and how this relates to their identity. Therefore, it was important to include the ways in which learners represented their ideas through their speech.

After the introduction to the lexicalization and relexicalization section, findings of perspectives, known as *identities*, in which learners are situated combined with their funds of knowledge. In order to understand how learners completed their models, it was important to gain insight into their perspectives and association with the geosciences and the sources they draw on (funds of knowledge) for meaning. An examination of learners' word and phrases (lexicalization and relexicalization) and funds of knowledge, combined with their practices expressed during the modeling activity, provides insight into learners' geoscience identities.

Funds of knowledge are based on the premise that "people are competent and have knowledge, and their life experiences have given them that knowledge" (Gonzalez & Moll, 2002, p. 625). A funds of knowledge approach "facilitates a systemic and powerful way" to represent the learner, novice and expert, "in terms of the resources and knowledge they possess" (p. 625). The section on funds of knowledge is grounded in Elizabeth Moje's work in 2008 and Moll et al.'s work in 2001, while the analysis on identities was grounded in the work of James Paul Gee's work on identity (2001). After the descriptions of the identities have been introduced, the learners' ideas of how their knowledge, funds, and discourse is connected with their identities is presented.

Ways of representing: lexicalization and relexicalization

Lexicalization is the process of selecting words and phrases, and the ideas represented through word choice (Rogers, 2013). Relexicalization is the pattern of words and phrases that show up "again and again in the transcript" (Rogers, 2013, p. 34). Over the course of the activity, novice and expert learners repeated specific phrases when providing their reasoning. These phrases were known as *hedges* and *claims*, and indicated uncertainty and certainty, respectively, in learners' reasoning. Hedges and claims fall under the category of lexicalization and relexicalization because each learner chose to use particular words to either make a clear statement about their ideas or to soften their claims. Each learner made these choices during the activity and repeated these phrases. The next two sections present the types of hedges learners used, the number of times and context for the hedges, followed by learners' claims.

Linguistic forms of uncertainty: hedging. While discussing their processes for completing the model, learners used and repeated words that indicated certainty and uncertainty. These were prominent with both novice and expert learners. These particular words or phrases are known as *hedges*. Hedges are often used to soften an utterance. In other words, it can be used intentionally or unintentionally to tone down a potentially risky claim (Hyland, 2000). George Lakoff (1972) first used the turn hedge to refer to a word or phrase "whose job it is to make things fuzzier" (Clemen, 1997, p. 235). Hedges such as *about*, *around*, *think*, *believe*, *not sure*, and *not exactly* are examples provided by Lakoff to convey uncertainty or vagueness (Clemen, 1997). In the following section, hedges will be described and examples from both novice and expert learners' discourse will be used. Novice and expert learners used a range of hedges and the examples are mixed in this section to provide clear examples of the hedging phrases used. Tables will summarize novice and expert hedges at the end of this section. Italicized words in the following sections are not used to indicate emphasis; rather they are used to clearly depict the hedge being analyzed.

Research in mathematics education further classifies hedges. These classifications are applied to the timescale activity as different hedges indicate differences in meaning. Hedges can be further classified as shields, a *plausibility shield* or an *attribution shield*, and approximators, *rounder approximator* or *adaptor approximator* (figure 6.1).

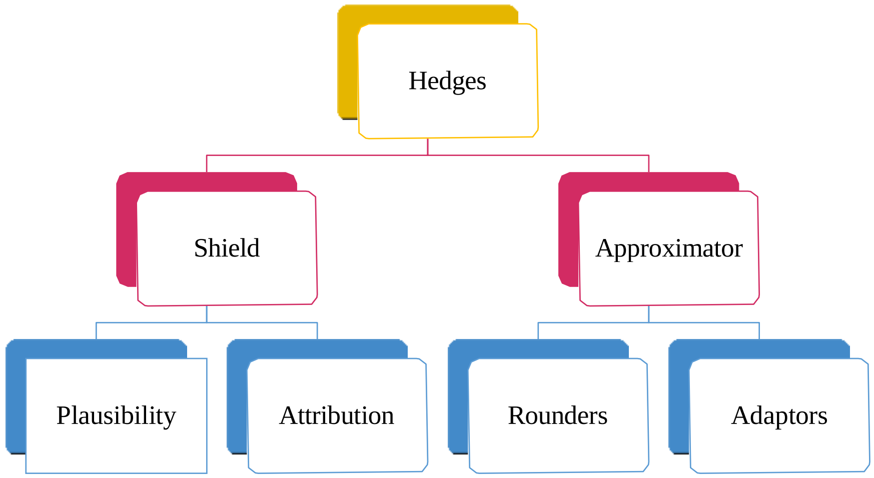


Figure 6.1 from Rowland (1995, p. 337).

A shield “lies outside of the proposition, which follows it” (Rowland, 1995, p. 334). The phrase *I think* is an example of a shield. For example, during the interview with expert learner Alex (p. 4), they used a shield “*I think* plants developed as a sexual-flowers as a way of reproducing is much later, but I don’t know how much later”. In this statement, Alex discussed flower development occurring later, after basic plant development, because of the complexity associated with sexual reproduction. Alex clarified this in another quote stating,

> I know that the flowers took longer to develop because they are like sexual and have more complex systems, but I really can’t remember how closely after trees and like, bigger plants showed up and if it was shortly after or if it took a really long time. They could be at the end of the Carboniferous or um later in the Permian and I would not really know that. (p. 6)

Further, this shield, *I think*, can be classified as a plausibility shield. Plausibility shields infer a “belief of a position to be considered, as well as indicating some doubt” in case the comment(s) were scrutinized by the listener (Rowland, 1995, p. 335). Examples of plausibility shields include, but are not limited to, the phrases *I think*, *I believe*, *maybe*, and *probably*.

Attribution shields differ from plausibility shields in that they “implicate a degree of quality and are attributed to knowledge from another source or third party (p. 335). According to Rowland, attribution shields are “typically set up as “According to N, S”, where N is the third party and S is a proposition” (p. 335). The examples in this data were not always as clear as an N/S format. However, the learner usually provided a source of their knowledge, akin to the N as a third-party idea. For example, novice learner, Taylor, used an attribution shield from a media source.

95 Well, now that I’m saying it out loud like…it’s kinda like…I’ll be honest with you, *a lot*
96 *of this knowledge that I’m going to spew out right now is like Jurassic Park stuff*. (p. 3)

By explaining that the information was from *Jurassic Park*, Taylor pushed the responsibility of the comment onto the media source. In other words, should the person, in this case, Taylor, be incorrect in their statement, a source has been provided as a reason for the uncertainty they expressed.

Approximator hedges often modify a proposition, making it vaguer (Rowland, 1995). Approximator hedges include phrases such as *sort of*, *somewhat*, *fairly, a little, approximately, around, about, roughly, or almost*. Further, *approximately*, *about*, and *around*, can be classified as *rounders*, a subcategory of approximator hedges as they deal with measurements of quantitative values (Rowland, 1995). A “second subcategory of approximator hedges is an *adaptor*. Adaptors are nouns, verbs or adjectives that can be attached to propositions such as *sort of*, *somewhat*, *fairly*, and *a little*” (Rowland, 1995, p. 336). Their use in this data often was used to generalize or explain values or events that were hard to describe otherwise.

Tables 6.1 and 6.2 below summarize the types of shield and approximator hedges used by each learner and the number of times it was used in the transcript. Words can have multiple meanings depending on the context. Words such as *around* or *about* were only counted as hedges if they were used to tone down a claim. For example, if a learner said that “rats were seen running *around* the feet of dinosaurs”, the word *around* was not used as a hedge, and therefore, was not counted as such. If a learner stated “I think it was *around* 2.4 billion years ago”, the statement would be included in table 6.2 below since the learner made a reference to an approximate quantitative measurement.

Table 6.1
Shield hedges made by learners during geologic timescale activity

	Shields			
Novice learner	**Plausibility**	**# Times used**	**Attribution**	**# Times used**
Harper	I think (3)/Probably (6)/I guess (2)/I thought (4)/I figure (1)/I figured (12)/I remember (1)	29	K-12 science classes	1
Taylor	I think (4)/I'm just thinking (1)/Probably (5)/I'm assuming (4)/I assume (2)/I'm pretty sure (1)/I guess (1)/I just kinda guessed (1)/I feel (2)	21	Reference to Jurassic Park (2), children's book (1)	3
Frankie	I think (2)/I was thinking (1)/I feel or I feel like (10)/Probably (2)/I assumed (3)/I just thought (1)/I kind of thought (1)/I remember (1)/I always just remember (1)/I've learned (1)/I guess (7)	30	K-12 Earth science class (1), K-12 Art History class (1)	2
Cameron	I think (14)/I'm thinking (3)/I'm kind of thinking (1)/I was just thinking (1)/I keep thinking (1)/I feel (21)/Probably (3)/I remember (11)/I remembered (2)/I could have remembered (1)/I can't remember (3)/I couldn't remember (2)/I couldn't really remember (1)/I vaguely remember (1)	65	Reference to professor (1), university course (1), a K-12 class (1)	3
Mica	I think (6)/I just didn't think (1)/I just thought (4)/I thought (10)/I'm thinking (1)/Probably (1)/I figured (3)/I guess (2)/complete guess (2)/a guess (3)/I felt (2)	35	N/A	0
Expert learner				
Alex	I think (36)/I'm thinking (1)/I remember (3)/I believe (2)/I should know (1)/I guess (5)/Probably (8)	56	Reference to professor (1), podcast (1), university course (3)	5
Jayden	I think (27)/I guess (7)/probably (6)/I feel (14)/I felt (5)/I just feel (1)/I'm pretty sure (1)/I assume (1)/I've learned (1)/I remember (1)	64	University course (3), professor (1), journal article (1)	5

Notes in parentheses mark the number of times a source was referenced

Table 6.2
Approximator hedges made by learners during geologic timescale activity

	Approximators			
Novice learner	**Rounders**	**# Times used**	**Adaptors**	**# Times used**
Harper	About (5)/around (9)	14	A little (2)	2
Taylor	About (2)/around (3)	5	Kinda (4)	4
Frankie	About (1)	1	Kind of (10)/kinda (1)	11
Cameron	Around (3)	3	Kind of (40)/kinda (5)	45
Mica	About (1)	1	Kind of (2)/a little (1)	3
Expert learner				
Alex	About (11)/around (13)/roughly (1)/slightly	26	Fairly (2)/somewhat (1)/a little (1)	4
Jayden	About (6)/around (11)	17	Kind of (11)/kinda (6)/a little (5)	22

Novice and expert learners both used plausibility shields, rounders, and adaptors over the course of the task-based interview. All learners, with the exception of Mica, used attribution shields. In the example provided previously, Taylor stated the source of knowledge from *Jurassic Park*, while Alex referred to a professor and podcast for knowledge of the reference point for *Rodinia*. Jayden referred to journal articles that they read for a university course that provided information about the transition from marine to terrestrial life. Cameron, Frankie, and Harper all referenced their K-12 education, and specifically noted the type of classes, from basic science classes, to History, and A.P. Art History.

Adaptor hedges, such as *kind of*/*kinda*, were typically used in two ways: quantitative values or descriptions of strategies to complete the activity. For example, while ordering event cards, Jayden discussed relating the relationship between the Pangaea cards provided and the times in which they occurred geologically. To do this, Jayden discussed the beginning of the opening of the Atlantic Ocean. Jayden referenced this event as being “kind of Late-Mesozoic” (Interview with Jayden, p. 7) when trying to place the event card as accurately as possible on the model. Although this is not one of the events provided in the activity, Jayden used prior knowledge of events and time to support the activity. Jayden refers to the opening of the Atlantic Ocean as being kind of Late-Mesozoic, not that it was Late-Mesozoic, which can be understood in a few different ways. As periods and eras in geologic time can be divided into groups such as early, middle or late, there is not always a precise cut off for these categories. Jayden's use of *kind of* suggests that it may be borderline middle to late in the Mesozoic, it might be between the Mesozoic and Cenozoic, or there is the possibility that it might not have occurred in that time frame. Either way, using *kind of* leaves the statement open in case of error, as Jayden is not claiming that the Atlantic Ocean opened in the Late-Mesozoic and assisted in their strategy for placing events in geologic time.

Disfluent speech: hedges versus fillers. All learners during the activity spoke with disfluent speech. Disfluent speech, particularly during a task-based interview when speech is spontaneous, is not uncommon. According to Brennan (2001),

> Spontaneous human speech is notoriously disfluent. Speakers hesitate, interrupt themselves mid-phrase or mid-word, repeat or replace words, abandon phrases to start afresh, and season their talk with expressions like *um, uh, or, I mean,* and *oh*". (p. 274)

The expressions Brenna discussed above are also known as *fillers*. A filler is a sound or spoken word that suggests a person has not finished speaking but paused to think. Given these utterances, meaning-making can be difficult. Disfluency poses a problem for listeners as they must make sense of the speakers' utterances. Given this challenge, the discourse analysis conducted focused on the utterances of speech that were considered relevant to learners' portrayals of their conceptions and feelings during the activity. The phrases chosen were supported by context and paralinguistic cues such as pitch, volume, intonation, and length of the spoken word. For example, the term *I don't know* indicated that a learner felt they did not know the topic being discussed, but could also be used as a filler. It was not always clear if learners were using repeated utterances for their conceptions or fillers alone. Indications that the utterance was used as a filler would be the increasing the length of the spoken word by dragging the word out or saying it multiple times in the middle of a phrase. However, the argument made was that the repeated use of a term was not as a filler alone, but as a hedge. Hedges used to preface or follow a claim was to protect the knowledge provided by the learner and are further discussed in the next section.

Hedging phrases: mitigating phrases. Hedges were also made with clear phrases to indicate uncertainty or "tone down potentially risky claims" (Hyland, 2000). These phrases, will be deemed *mitigating phrases* a subcategory of plausibility shields, as they are phrases that still hedges that place doubt in a belief, position, or claim, but they are longer phrases (Figure 6.2). Plausibility shields are one to two-words long. Mitigating phrases are longer than two words and cast doubt to the learner (e.g. themselves). As the source of doubt may not be explicitly listed, mitigating phrases are not a subset of attribution shields, however there can be overlap if the doubt is attributed to a particular source.

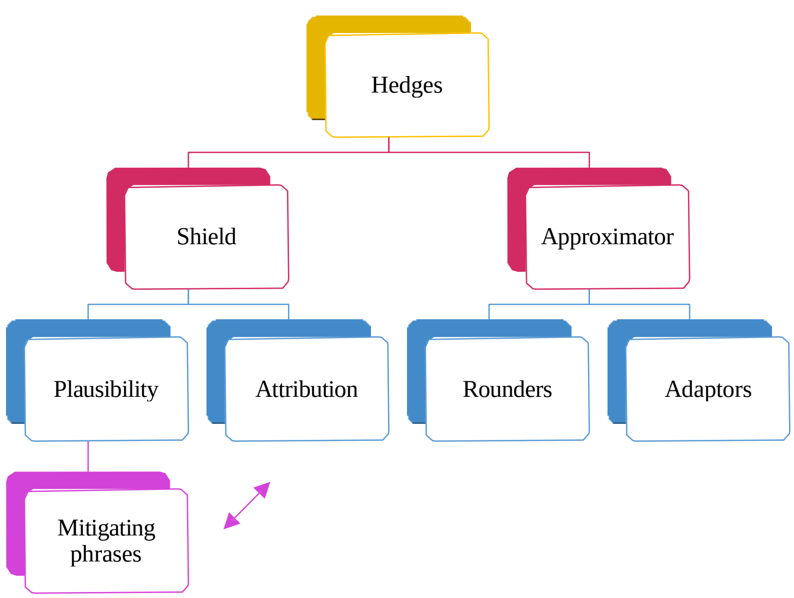


Figure 6.2: Adapted figure from Rowland (1995) that includes mitigating phrases (in purple) as a subset of plausibility shields.

Mitigating phrases are not always the same phrases used by each learner, but they serve the same purpose. These hedges serve the same purpose as the plausibility shields, which is to reduce the strength of an utterance or the claim the learner was stating, but enhances their strength of their doubt. Taylor stating their knowledge came from *Jurassic Park* prior to making the statement would also fall in this category. Although Taylor does not state outright that their knowledge may be incorrect, they preface the statement with the source of knowledge to protect themselves in the case they are wrong.

As most of these phrases were not categorized as shields in the mathematics literature, but with the overlap in common words and purpose, these phrases are being discussed as a subset of plausibility shields. The majority of shields discussed in the literature are one or two word phrases, whereas these hedging phrases consist of two or more words. For example, learners would preface a comment with phrases such as *maybe I'm wrong, maybe I'm making this up, what I know about X is pretty bad, this is not something I know, I know this is wrong probably,* or *I haven't done this in a while*. Additionally, these phrases were used by expert learners to question themselves. For example, when placing events on the timescale, Alex stated, "and the trace fossils would be closer to the Cambrian. I would say…I believe…maybe I am wrong" (Interview with Alex, p. 4). Although typical hedges are words such as *might*, *probably,* and *seem*, hedging phrases consist of more than two words, and are either adjectives, adverbs, or clauses.

Mitigating phrases can be used to reduce the learner's ownership of the claim. For example, stating that knowledge might come from a particular source alleviated the pressure from the learner.

155 Reptiles I put because I feel like-reptiles and birds through-Earth Science that I've taken,
156 they are descendants of dinosaurs. I don't know if that's true or not, but that's what I was
157 taught it is. (Interview with Frankie, p. 4)

Frankie made a statement about their knowledge coming from an Earth Science course, attributing their knowledge to the course (attribution shield), but questioned whether the knowledge was true. Although Frankie questioned the knowledge, they still use the knowledge to place the event card and make the claim, as that is the knowledge they recall. Frankie is not the only learner to do this. Another example came from expert learner Alex, who attributed their knowledge to their memory. For example, during Alex's interview they stated,

854 And then I put these, which adds to 200 million years if I'm not wrong, which is what my
855 memory says more or less, of what would be the melting-remelting of the crust of the
856 Earth and creation of the different layers of the atmosphere. (p. 18)

Stating, for example, that knowledge was what a learner remembered from a course, documentary, or memory, served to put the weight of the comment on the source or the learner's interpretation of certainty from the source into question, rather than on themselves. In other words, if the learner is wrong, it is because they remembered it incorrectly versus not knowing the content.

Mitigating phrases were used more often by the expert learners than the novice learners. Expert learners made between 15-20 mitigating phrases, while novice learners made between one to eight mitigating phrases (table 6.3). Table 6.3 contains the number of mitigating phrases used by each learner with an example. Numbers each time a phrase was used are not included. As mitigating phrases were not always the same, the table would be too long. Instead, examples of phrases from the learners with one example of it used in a sentence is included to show meaning.

Although novice learners used mitigating phrases less often, the number of hedging comments with increased strength, which will be referred to as *unknowing mitigations*, increased. Unknowing mitigations are phrases that claim a lack of awareness, familiarity, or knowledge, such *I don't know*, *I don't remember*, *I had/have no idea*. Mitigating phrases, such as *maybe I'm wrong*, were used to soften a claim, but not as strongly as when learners stated they *didn't know* or *had no idea*, regarding a subject. Softer mitigating phrases, which will be referred to as *knowing mitigations*, question the claim or the learners' familiarity with the subject, while unknowing mitigations preface or follow that information provide more powerful feelings of the learners' sentiment of a lack of knowledge toward the subject. Unknowing mitigations are stronger because they are used with an auxiliary verb or "be" in a negative form, whereas knowing mitigations are still viewed as possible and more positively. Additionally, low familiarity with a subject does not imply not knowing. Responses other than *I don't know* or *I have no idea*, can be a result of other than not knowing. Hence, the categorization of knowing mitigations. The difference between the unknowing and knowing mitigations are slight, but are indicative of the learner's feeling as to whether or not they possess they do or do not possess the necessary knowledge or indicate familiarity with the knowledge. The importance of these phrases is in their relationship to the learner and their identity to the geoscience community.

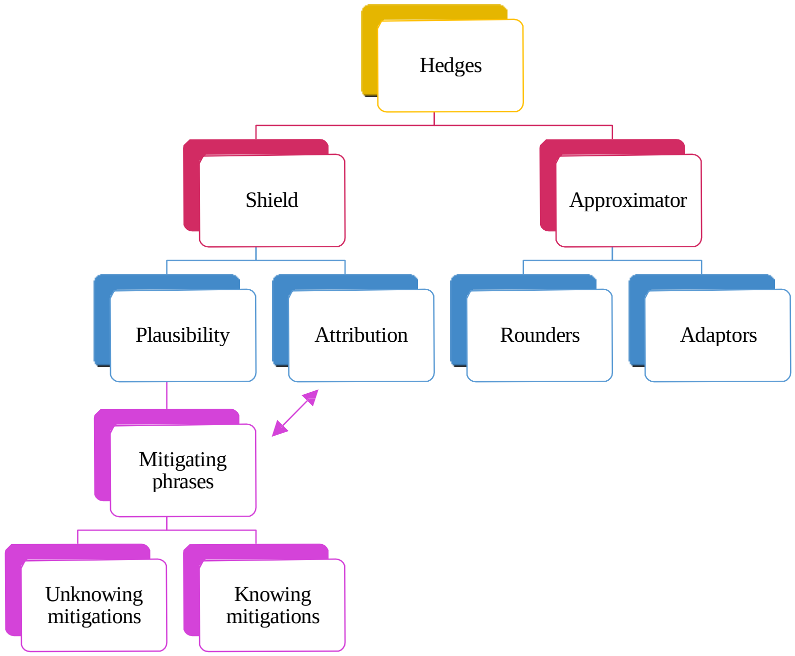


Figure 6.3: Includes the types of mitigating phrases, unknowing mitigations and knowing mitigations, which serve to soften a claim. Unknowing mitigations claim a lack of awareness, familiarity, or knowledge, while knowing mitigations reduce certainty in a claim of knowledge.

Although novice learners are positioned outside of the community, their lack of unknowing mitigations compared to the expert learners, expressed their phrases were grounded in claims and positioned them as *knowers*, regardless of whether they are inside or outside the geoscience community. Novice learners, viewed by their verbal discourse alone, possessed confidence in and of their expression of their knowledge. They possess certain knowledges and were confident in those knowledges. Table 6.3 below lists an example of the knowing mitigations used by each learner and then the example in context. As the knowing mitigations were not always the same, only a couple of knowing mitigations were provided.

Table 6.3
Knowing mitigations made by learners during geologic timescale activity

Novice learner	Examples of mitigating phrase(s)	# Times used	Knowing mitigation phrase in context
Harper	Not something I think about often	1	"I was able to-ugh for the numerical times I had to come up with values and large numbers in time just from memory; something I really don't think about often" (p. 11).
Taylor	I know it's wrong, probably	6	"The asteroid, the dinosaurs…I know it's wrong, probably" (p. 2).
Frankie	I don't know if that's true or not/That's what I was taught it is	1	"Reptiles I put because I feel like-reptiles and birds through-Earth Science that I've taken, they are descendants of dinosaurs. I don't know if that's true or not, but that's what I was taught it is" (p. 4).
Cameron	It's how I remembered hearing it/I could be wrong/I only did like Earth Science freshmen year in high school/	8	"I feel like I remembered hearing numbers for like dinosaurs and stuff but I could have remembered them totally wrong. So that's what I started with there. It's how I remembered hearing it but I could be wrong. And then I kind of just, was building off those" (p. 15).
Mica	That might not be totally right/the only thing that made sense/I haven't done photosynthesis in a while	5	"And then…dinosaurs go extinct, I thought they went extinct before mammals appeared. But that might not be totally right" (p. 4).
Expert learner			
Alex	Maybe I'm wrong/ maybe I'm making this up/if I'm not wrong	23	"For example, I found that if you're working with, maybe I'm making this up, but when I'm working with zircons, what you're given is an actual number and then you have to correspond it to the geologic timescale. So when I'm working with zircons, I'm always thinking of the numbers" (p. 20).
Jayden	I'm not saying/I can't present it	15	"I'm not saying fish evolved to have useful eyes, to me it makes sense that the placement of the eye more to the side is useful for having a better field of vision…" (p. 7)

Listed below are common unknowing mitigations and the number of times they were used, followed by the example in context (Table 6.4). As the unknowing mitigations were not always the same, only a couple of examples were provided.

Table 6.4
Unknowing mitigations made by learners during geologic timescale activity

Novice learner	**Unknowing mitigation phrase(s) used by each learner**	**# Times used**
Harper	I don't believe (1)/I have no idea (1)/I wasn't sure (1)/I'm not really sure why (1)/I didn't know (1)/ I don't know (1)	6
Taylor	I don't know (4)/I'm not sure (1)	5
Frankie	I'm not sure (2)/I'm not necessarily sure (1)/I'm not exactly sure (1)/I'm not even sure (1)/I wasn't sure (3)/I wasn't necessarily sure (1)/I can't necessarily tell you (1)/I don't know (12)	22
Cameron	I'm not sure (3)/I'm not really sure (1)/I don't know (5)/I just don't know (2)/I just have no idea (1)/I have no idea (5)/I still have no idea (1)/I don't think (1)/I really don't know (1)/I don't have much information (1)/I figured (2)/I guess (8)/I'm kind of just guessing (1)	32
Mica	I don't know (11*)/I don't even know (4)/I don't know much (1*)/I really don't know (2)/I didn't know (2)/I wasn't sure (1)/I just wasn't sure (1)/ I'm not sure (1)/ I had no idea (1)/I can't remember (1)	25
Expert learner		
Alex	I don't think (3)/I have no idea (3)/I don't know (10)/I can't really tell you (1)/I really can't remember (1)/I can't remember (5)/I don't remember (5)/I would not really know that (1)/I should be able to know more (1)	30
Jayden	I don't know (23)/I don't really know (1)/I didn't know (1)/I have no idea (3)/I'm not sure (2)/I'm not really sure (2)/I don't remember (2)/I couldn't (1)/I know very little (1)/not something I know much about (1)/not something that I know (1)/I don't remember much of that (1)/I don't really remember (3)/I'm still not entirely sure (1)/I'm really not sure (1)/I'm not sure (2)/I'm not confident (1)/I don't really feel (1)	48

**I don't know much* was not included in the count for *I don't know*

Mitigating phrases were not always stated alone. Sometimes, they were followed by a claim or shield. Unknowing mitigations combined with a claim or shield reduced the strength of the claim, but also the strength of the unknowing mitigation. For example, Alex stated "*I have no idea* when it happened, but *I think* it's at the same time" (Interview with Alex, p. 3). If Alex alone had stated "I have no idea when it happened", the feeling of the statement is clear. The statement Alex made indicates that Alex feels they do not know the information regarding when the event occurred. However, adding on the statement "but I think it's at the same time", softens the strength of the unknowing mitigation as they provide more information, putting into question whether they really have no idea when the event happened, as they are now providing information about the timing of the event. In other words, if Alex had simply stated I have no idea when it happens, they are stating they don't know when the event occurred. Adding the phrase, "I think it's at the same time", Alex has added more information than stating they don't know when the event occurred. With the added information, Alex reduced the strength of the unknowing mitigation "I don't know when it happened" because Alex does have an idea of when the event occurred. If Alex stated "I think it's at the same time" and they were incorrect, they have ownership over the statement. Alex protected themselves by saying "I have no idea when it happened", because they've prefaced this knowledge by stating they don't know when it happened. Additionally, Alex is not only providing information about the timing of the event, but has prefaced the knowledge with the possibility that it may not be correct stating that they *think* it happened at the same time.

Unknowing mitigations were used more frequently by expert learners, with the exception of Cameron. Cameron used two more unknowing mitigations than expert learner Alex. For the most part, novice learners used strong hedging phrases less than 30 times, while experts used strong hedging phrases more than 30 times. Therefore, Cameron, Alex, and Jayden spoke with the most uncertainty throughout the course of the activity. Cameron's use of unknowing mitigations placed them in the same category, linguistically, as the experts. The use of similar number of hedges, as well as increased time and interest in the activity, indicated Cameron's identity in relation to the geoscience community was closer to that of the experts than that of the other novices. The importance of positionality in relation to the geoscience community (learners' identities), discourses, and funds of knowledge will be discussed later in this chapter.

Overall, mitigating phrases, a subset of plausibility shields, serve the purpose to soften the claim or utterance stated by the learner. They were used to express an uncertainty, vagueness, or to attribute knowledge to a particular source alleviating the weight of the claim from the learner to the source of uncertainty, typically without explicit attribution to a source. Experts used shields and hedging phrases more often than novice learners. Therefore, expert learners often spoke with more uncertainty or softened their claims more than the novice learners.

However, the importance of this uncertainty, expressed by the use of hedging discourse, is not only in the types of hedges, but what learners were hedging about and how they hedged. Although expert learners hedged more frequently, their hedges were about the specifics of content knowledge. Expert learners' hedges were grounded in trying to determine delineations as to when specific events occurred. The segment below demonstrates Alex's use of hedges while trying to add assigned values and geologic periods to their model. The hedges are italicized for identification purposes. The italicized words in parentheses were Alex's actions while speaking.

(*Alex continues to write along times*) …the K-T boundary is *about* here…oops…so that's when dinosaurs go extinct but that thing is not very aligned (*the stick on the back of the card was angled and kept moving*)…oooh ooh ooh they [event cards] are falling …Cretaceous…happened at…that's when the Cretaceous starts and…let's see, the

454 Devonian starts at 416 Ma…that's when the Devonian starts. By putting the numbers on,
459 I have to move everything and restart again. (…) the Permian-crap-*I think* the
460 Permian…mmm…*I don't remember*. 542 Ma that's when the Cambrian starts…*I think* it
461 last *about* a 100-*about* 450, *I don't know that one very well*. Something happens at 444
462 and *I can't remember what it was*…*Probably* the transition from…mmm…it's at the end
463 of the Ordovician. Ah, my geologic timescale sucks (*laughs*). (pp. 9-10)

As Alex debated the timing of geologic periods, they hedged about the specific details associated with time such as the specific values and when the period begins and ends.

When novice learners hedged, it was in reference to general knowledge about geologic time or reasoning about placement of event cards. As seen in the knowing mitigations table (table 4.3), novice learners hedged about their funds of knowledge, questioning the fund's reliability, their memory, and relationships between events or their choice of assigned values. For example, Cameron's hedges in the following statement questioned their memory, as well as the possibility they heard the numbers for the timing of dinosaurs incorrectly.

690 *I like, feel like I remembered* hearing numbers for like dinosaurs and stuff but *I could*
691 *have remembered them totally wrong*. So that's what I started with there. It's how *I*
692 *remembered hearing it* but *I could be wrong*. And then I *kind of* just, was building off
693 those. (p. 15)

Cameron's hedges focused more on the general knowledge, relationships between events and numerical values, to complete the activity, rather than specific details about geologic concepts. This was true for all novice learners.

Novice learners spoke with less hedging statements than the expert learners, making their statements sound more certain. However, the novice learners hedged about general geologic concepts, such as relationships between events or their choice of assigned values, as well as questioning their memory, and the reliability of their funds of knowledge. Experts' hedges were focused on specifics about the relationships between events, distinguishing between the beginning and end of periods and eras, and how those apply to the scale of the model.

Linguistic forms of certainty: claims and facts. Hedges are spoken about frequently in literature, but less discussed are comments of certainty. Often the opposite of a hedge is known as a booster (Hyland, 2000). Boosters are phrases that enforce the certainty of a statement (Hyland, 2000). For example, phrases such as *without a doubt*, *certainly*, *of course*, *unquestionably*, *inevitably*, and *obviously*, are classified as boosters. Boosters can be used to both weaken and strengthen a statement, however, such clear boosters were not found in the transcripts. Both novice and expert learners' claims in certainty were grounded in phrases that would be deemed weaker than the strength of a typical booster. Instead, learners often made claims about their knowledge with phrases such as *I know*, *I do know*, or statement of "fact".

Alex used the phrases *I know* or *I do know* to refer to events, times or relationships they were certain of. Typically, the phrase *I do know* was used to follow something that Alex was uncertain or claimed to not know much about. There were statements that Alex made out of certainty that were stated as fact rather than needing to state *I know* or *I do know* and followed by information pertaining to the activity. Statements made as fact or using *I know* after a comment indicating uncertainty was common among all learners, not just Alex. Alex emphasized what they knew in some cases by saying *I do know*, not just *I know*. Using *I do know* drew attention to the fact that although they might not know everything about the event in the activity, but there was something relating to the event that helped support the claim that they are making or to emphasize something about the event that the learner knew. In the quote below, the phrase *I do know* is italicized to make it easier to find, not to indicate emphasis by Alex.

203 Alex: I think that that's uh probably what I was having in mind um. I think that there
204 might have been an association on the geologic record of the stromatolites so that's like
205 when we start seeing more of the algae development and stuff when we have an increase
206 in the oxygen in the atmosphere as a theoretical or O_2 actually. Um, *I do know* that-that
207 happened fairly early in the history of the early, relative to life

209 Researcher: Okay

211 Alex: Or like vertebrates or bigger fossil life…but I can't really tell you when that
212 happens. It could be in anywhere in that Ga and it would be good for me (*laughs*)

214 Researcher: (*laughs*) Okay.

216 Alex: *I do know* that that's somewhere there (*pointing toward the end with earth's*
217 *formation*). (pp. 4-5)

At the end of the quote, Alex says that they can't tell the researcher when vertebrates or bigger fossil life happen, but that Alex does know an approximate area as to when that would occur as they state "I do know that that's somewhere there" and pointed toward the opposite end of the timescale from where the researcher and Alex were standing [at present day end of the timescale]. Alex did also use the phrase *I do know* at the beginning of the quote to emphasize what they knew about the relationship between oxygen and the early history of life on Earth.

All learners referenced knowledge at some point during the activity stating something that they knew. Each of the novice participants, with the exception of Mica, referenced knowing humans have only been on Earth for a short period of time. Additionally, novice learners all made claims about photosynthesis occurring on Earth before plant development. Novice learners, with the exception of Mica, made a similar number of claims stated as fact as the expert learners. Frankie and Harper made 35 and 34 claims while Taylor and Cameron made 21 claims stated as fact. Mica made 14 claims. Expert learners Alex and Jayden made 37 claims stated as fact. These results with an example are listed in table 6.5 below.

Table 6.5
Claims made by learners during geologic timescale activity

Novice learner	I know	# Times used	Statement of claim/fact example	# Times claim/fact made
Harper	I know (6)/I knew (11)	17	"I know that earth was for like the first billion years or so, there's really nothing happening at all, it was like, pretty-no…atmosphere, it just kept getting hit by asteroids and any life that could form didn't because the-it was not habitable at all" (p. 6)	34
Taylor	I know (3)	3	"Pangaea created and then began to break up right away" (p. 2)	21
Frankie	I know (3)/I knew (2)	5	"And oxygen with, oxygen with photosynthesis because you can't have one without the other" (p. 2)	35
Cameron	I know (11)	11	"I know humans are a very small part of the whole thing" (p. 2)	21
Mica	I knew (2)	2	"Dinosaurs were first and then they were extinct and then animals came" (p. 3)	14
Expert learner				
Alex	I know (15)/I do know (5)	20	"This is a tree and it should be in the Carboniferous" (p. 11)	37
Jayden	I know (10)	10	"Ah so vascular plants happened before trees, but trees happened pretty soon after plants" (p. 3)	37

This purpose of presenting this discourse is to present both learners as knowers, but specifically to emphasize that novice learners know specific geological knowledge prior to entering an introductory-level university course, and that there were strong positions and feelings associated with that information, regardless of whether it is deemed geologically correct. These ideas have been carried with each learner from their background and brought to the university classroom.

Funds of knowledge

In order to understand learners' representations of their models through discourse itself in terms of knowledge, language, and practice, but also from the funds of knowledge in which the knowledge, language, and practices are generated (Moje, Ciechanowski, Kramer, Ellis, Carrillo, & Collazo, 2004). Funds of knowledge are the various sources learners draw on to construct their models. Funds of knowledge are sources that "shape oral or written texts" in order to make meaning in different contexts (Moje et al., 2004, p. 38). Funds can include information from school, families, peer groups, communities, media, books, and more. These funds house different information and explore knowledge in different ways, with different discourses, practices, and meanings. As mentioned in chapter three, learners were not consciously drawing from these funds during model construction. Instead learners would attribute knowledge to a particular source when they provided reasoning to support their decisions during model construction. Presented in the following section are the various funds that learners attribute knowledge to in order to make meaning of the geologic timescale model, as well as the similarities and differences between novice and expert learners funds.

Novices' funds. Funds of knowledge for novices were situated in institutional sources. Novice learners referenced their K-12 education, current university courses, books, and media as funds for knowledge. All of these funds are knowledge determined by an authority or within an institution. All novice learners, except Mica, acknowledged where their knowledge came from to when completing the model. Frankie, Harper, and Cameron explained why they were using the knowledge from a particular source. For example, remembering knowledge from a particular source was the most common reason discussed. Harper discussed being able to order events as a result of knowledge from their “basic science classes” (Interview with Harper, p. 2).

49 I just like, took the basic knowledge I have from my science classes and tried to uh, put
50 them in the order I think these things happened. So for example, I knew that we needed
51 an atmosphere to hold in the oxygen, so I knew that had to come first, or well, before
52 oxygen. I thought that that would be one of the first cards because without the oxygen,
53 there’s no photosynthesis and no life. (p. 2)

As university-level courses are typically offered by discipline, the phrase “basic science classes” implies that this knowledge came from Harper’s K-12 education.

Cameron stated “I remember in a class talking about how…there were like, certain kinds of like, dinosaurs technically I guess that were sea and land, but then it would-we would learn about the comparison between that and an alligator” (Interview with Cameron, p. 4).

Frankie even went as far as explaining the limitations their knowledge of time had on their use of numerical values or event ordering. Frankie, for instance, discussed their knowledge and limitations to understanding time through an Art History perspective from an Advanced Placement (AP) Art History course taken in high school. Frankie discussed being able to associate events in time from an Art History perspective stating:

397 The only way I know any of it is through art history. I can tell you what an artist-what
398 time period they are from, but I can’t necessarily tell you the events in which the
399 civilization developed. (p. 9)

Frankie further explained that their source of knowledge further limited their association with events in time outside of event ordering when they acknowledged their use of B.C.E. and

A.D. "wasn't geological" and they "didn't want to write like a thousand AD somewhere, because how-I wouldn't know where to put that [units A.D.]" (p. 9).

Taylor was also explicit about their source of knowledge. When Taylor discussed their event ordering, they began talking about the event cards an *asteroid hits Earth* and *dinosaurs go extinct*, stating "The asteroid, the dinosaurs…. I know it's wrong, probably" (Interview with Taylor, p. 3). Taylor continued to explain their timescale stating,

90 Taylor: Okay…aight. So…the…humans have been here for like no time at all, in the big
91 scheme of things. And I'm assuming the same thing with large mammals. Umm…
93 Researcher: What makes you think that?
95 Taylor: Well, now that I'm saying it out loud like…it's kinda like…I'll be honest with
96 you, a lot of this knowledge that I'm going to spew out right now is like Jurassic Park
97 stuff. (p. 3)

Taylor explained that their knowledge on the timescale was attributed to the movie *Jurassic Park* and that their knowledge could be limited due to this source, hence the hedging comment where they say "I know it's wrong, probably" as well as prefacing their knowledge with the comment "I'm going to be honest with you" in regard to their source of knowledge being a movie, providing insight into their thinking (p. 3). Taylor's comment was a 'metapragmatic' act as they were explicit and matter-of-fact in explaining the source of knowledge (Thomas, 1984).

Although the media were not originally intended to be a social institution, it has developed into an organization that is critical for "socialization" and "provides a support system for individuals to become members of a larger social network" (Silverblatt, 2004, p. 35). In this sense, the media can be viewed as institutions as they are often "tied to tradition" and as they maintain formalized "practices and procedures" in their "contribution to the stability of society"

(p. 35). Furthermore, Carvalho (2007) stated that the “media have a crucial responsibility as a source of information and opinions about science and technology for citizens. Public perception and attitudes with regard to those domains are significantly influenced by the press and other means of mass communication” (p. 223). Attributions of knowledge associated with university courses, books, professors, or assignments are more obvious classifications of institutional knowledge, but media sources, such as movies or books, should be classified in this identity as well. Therefore, Taylor’s use of *Jurassic Park* and a children’s book as knowledge sources have been classified as institutional sources.

Experts’ funds. Funds of knowledge for experts were from institutional sources and their affinity group. Although all of the participants in the study share an institutional identity through their status as students at a university, their backgrounds, including campus organizations and majors, specifically their affinity groups, differ. According to Gee (2001), affinity groups are “composed of sets of experiences” and the “source of access or power that determines it or to which the person belongs is a set of *practices*” (p. 105).

According to Jacobs (2007), these Discourses encompass more than language, including “ways of speaking, reading, writing”, but also “ways of behaving, interacting, valuing, thinking, and believing, that are acceptable within specific groups of people in particular contexts” (p. 60). These particular contexts are referred to as *semiotic domains* which have particular social practices and “content that is continually changed, negotiated, and cited”, such as an academic discipline (p. 61). As academic disciplines are a form of semiotic domain, they can be further described as “dynamic spaces inhabited by people and their meaning-making interactions through words, sounds, gestures and images, rather than static objects defined as a body of content knowledge” (p. 61). According to this definition, semiotic domains can be shared to create “common knowledge, practices, values, goals, and norms”, resulting in an affinity group (p. 61). To become part of an affinity group, learners must become fluent in these social practices, principles, and communicate complex meanings through the specific language of the semiotic domain (Jacobs, 2007). Furthermore, induction into Discourse communities or affinity groups is reliant upon mastery of the language, knowledge, and goals of those in the affinity group that share a semiotic domain (Gee, 2000; Jacobs, 2007), but more importantly, the “social practices that create and sustain group affiliations” (Bullough Jr., 2005). Finally, although participation in an affinity group can be institutionally manipulated, a person typically chooses their affinity group (Bullough, 2005). Although individuals can have multiple identities, they “actively seek one form of recognition and of identity, over another” (p. 147) as “affiliations and identifications may clash” (p. 150).

Induction and participation in an affinity group not only reflects a learner’s identity, but also reveals various types and sources of knowledge. For example, to be identified as a geologist, there are practices that a person must be able to complete to be part of the affinity group. Even though the two experts in the study are from the geosciences, their paths, specialties, teaching, and research experiences vary. However, there is common knowledge and discourses required for geoscientists to communicate, collaborate, or publish. This section explores expert learners’ affinity group knowledge as a fund and how this fund supported their model construction.

Both expert learners discussed being teaching assistants and graduate students during their task-based interviews. Not only do they identify with these categories, but these are sources of their knowledge. Alex discussed learning about the geologic timescale in depth during “general classes, TAing, paleolimnology classes…classes I have taken as a grad student at university" (Interview with Alex, p. 3). Jayden referenced timescale activities they experienced while being a TA, that were similar to the one they were participating in.

498 I've, so I've seen these um, not this, but like in one of the classes they TA for the
499 professor as an introduction for geologic time. They, or, just to explain the vastness of it,
500 they did this virtual fieldtrip on Google maps where they drove across the country, where
501 going from pulling out of the SU parking lot was in human years and then yeah. (p. 11)

Although Jayden further discussed that they did "not remember much of it" (p. 11), they still referenced seeing a timescale activity during their teaching experience. Even though Jayden may not remember much of the other timescale activity, it is unclear what parts of the activity they don't remember such as the way the content was discussed, or how the activity was explicitly scaled. This may not seem important, but knowing that Jayden had already seen a scaling activity on the same topic, means that Jayden had additional experience with the material and scaling than the other learners, and increased the sources of knowledge to influence their activity.

In addition to teaching experience, university course content and research experience were discussed by the expert learners. Alex discussed courses and research experience during the course of their academic career as a source of knowledge.

371 Well, I think I've learned them in dif-so in my paleo class, uh we focused a lot on, on like
372 the animals themselves and a lot of the continental events and trying to associate the
373 major um orogenesis, how to do you say orogenesis in- (…) orogenic events, yeah, so we
377 tried to associate major orogenic events and supercontinents and the break of those
378 associated to life in the history of the earth, which is like not my paleo class. And I think
379 a lot of those things in those classes kinda like really didn't stick very hard in my mind,
380 but then just like, as I revisited in different classes and those things come up. It's like you

start being able to connect those dots a bit better. So like…knowing that Rodinia has to do with Grenville. My boss which is *Professor Andesite works a lot with Grenville, and so that's easy to remember. But he's like obsessed with zircons about 1 Ga old, so it' like okay, I can make that connection and remember those things because of that, if that makes sense. (Interview with Alex, p. 8)

The repetitive discussion of events in Earth's history assisted with learning the occurrence of major events in time. Additionally, research experience on campus assisted Alex in their ability to recall information as well as their making connections between when events happened in time.

As Alex and Jayden are both graduate students in the geosciences, they are also considered to be in an affinity group. They discussed their experiences with research, teaching, and studying, specifically in geosciences, display their experiences and skills in the field. To be considered part of an affinity group or identity, the person needs to be able to display certain practices characteristic to that affinity. Additionally, their references to these experiences only members of the affinity group or someone gaining access to an affinity group may encounter, their knowledge is considered to be from the affinity identity.

Alex and Jayden also referenced professors from courses or research that assisted in remembering events in time. As stated above, Alex referenced their boss's work with the Grenville orogeny dated 1 billion years ago, which was one of their anchor points for the timescale. Jayden referenced a transitionary links between aquatic and terrestrial organisms, *Tiktaalik* and *Edenopteron*, when explaining their reasoning for ordering the event cards for *fish* and *reptiles first appear on Earth*. Jayden discussed a seminar that Professor Almandine led where they read classic papers of the discipline and discussed various organisms and their morphology, classifying these organisms as the link between aquatic and terrestrial organisms.

Finally, Jayden and Alex referenced sources of knowledge outside of classes that assisted them throughout the timescale such as journal articles and podcasts. Alex referenced learning about oxygenation events associated with cyanobacteria as well as the timing from a podcast.

> I know that there's an oxygenation event that is associated with something and I can't remember what it is and there are a lot of studies…there's a lot of students here working on that event, and I know it's probably early in the geologic record…probably…happening around there…then the first trace fossils – so we know based on the geologic record that life started…3.06? there's a potential record of bacteria, I think its cyano-bacteria or some little bacteria around 3.8 Ga and I actually know that number very well from listening to a podcast and it's a topic they keep bringing up for whatever reason the origins of life…and so it's like…that number seems to be in my brain very good because of that. (Interview with Alex, p. 4)

Jayden mentioned in the quote above reading classic articles for the seminar with Professor Almandine, as well as readings for what they remembered reading about in terms of numbers for oxygen, the boundary for the Archean and Proterozoic, the appearance of hominids, and the search for asteroids from the Proterozoic. All of these references were associated with establishing their event ordering and further, reasoning for their numerical value choices.

Expert learners' funds of knowledge came from institutional and affinity group sources. Similar to novice learners, institutional sources served as the main sources of knowledge. Institutional knowledge stemmed from university courses, teaching and research experiences, as well as journal articles and podcasts. Teaching and research experiences can also be classified as originating from the affinity group. There are discourses and practices specific to the affinity group that graduate students would need to navigate to be considered part of the group.

To clarify, it is not typical for a graduate student from another department to be able to teach a geoscience course. Therefore, simply being identified as a graduate student does not qualify someone to teach in the geosciences. Therefore, teaching assistants have been studying in the geosciences as undergraduates, and have or will have conducted research in their respective geoscience sub-discipline. This clarification is important to note as it denotes another fund of knowledge. Knowledge acquired via experiences and discourse unique to the affinity group can be classified as originating from the affinity group. The ways of knowing including the language, content knowledge, ability to establish research studies, and further one's knowledge specific to the geosciences. Further, the ways of doing include being able to share the content knowledge of the affinity group in conversation, conferences, conducting research, teaching, and going into the field. According to Moje (2008), "discourses are generated not only from particular group practices, but also from particular funds or social networks, making funds or networks funds of knowledge but also funds of discourse" (p. 343). Not only are there particular discourses associated with the geoscience community, but the discourses of the community are a source of knowledge. Therefore, expert learners' discourses associated with their affinity group become funds of discourse. It should be noted that in the case of graduate school, the lines between institutional knowledge and affinity group knowledge are blurred. There is overlap between the two funds as graduate students are participating and practicing the ways of knowing and doing required of geoscientists.

Funds of knowledge, lexicalization, and identity

When comparing novice and expert learners' funds of knowledge, differences between their funds are visible. Figures 6.4 and 6.5 below depict the primary funds in which both sets of learners were drawing. As mentioned previously, both expert and novice learners discussed institutional sources of knowledge, specifically media sources. Novice learners referenced children's books and movies (figure 6.4), while expert learners

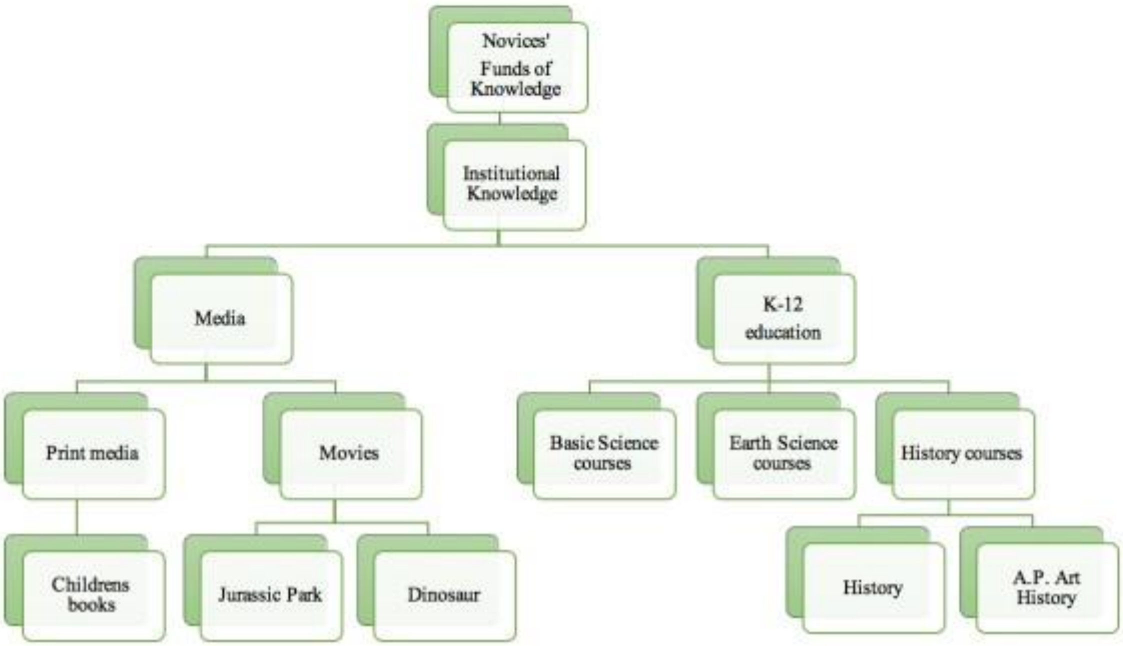


Figure 6.4: Novice learners' collective funds of knowledge

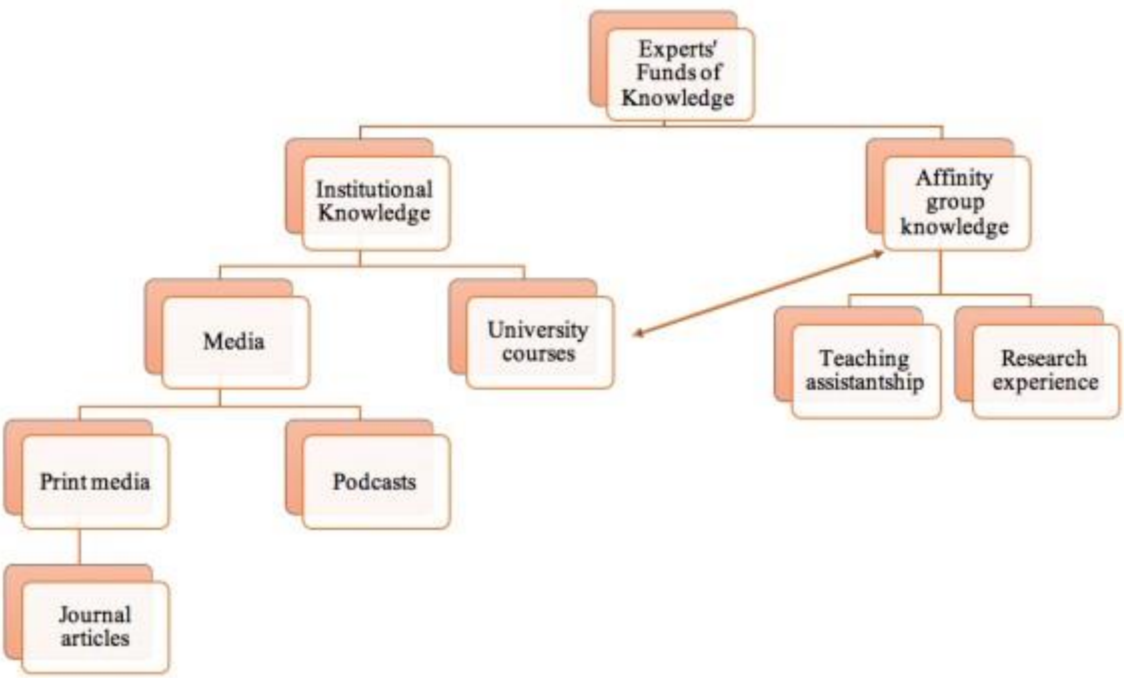


Figure 6.5: Expert learners' collective funds of knowledge

referenced journal articles and discipline-specific podcasts related to their anchor points (figure 6.5). Novice learners also referenced their K-12 backgrounds, citing their basic Science, Earth Science, History, and A.P. Art History courses as sources for content knowledge and for assigning values. Expert learners referenced their university courses. Additionally, expert learners discussed an additional fund, which is their affinity group. Affinity groups are specific groups that in order to be considered a member, the individual must be able to demonstrate specific discourses, which encompasses particular "knowledge, ways of knowing or practices, talking, and being" (Moje, 2008, p. 341). However, as the experts of this study are in graduate school, there is overlap between the funds from university courses and the affinity group. Expert learners are deepening their roots in the affinity group by teaching, conducting research, reading journal articles, and listening to podcasts. These actions are considered ways of doing or practices that Earth scientists engage as part of the affinity group. By participating in these practices for classes, but more importantly, out of interest, experts' funds from university courses and the affinity group overlap. This is represented in the experts' funds of knowledge diagram with a double-edged arrow indicating that these funds are connected.

Discourses and identity: ways of knowing and doing. Learners' funds of knowledge combined with their discourses can be understood as reflections of their identities (Moje, 2008). The way in which learners discussed the activity established their identity associated with the geosciences. Expert learners' identities and how they performed throughout the activity was more salient, as they took up the identity of the geoscience discourse community. Novices were positioned outside of the community overall, but three of the five novices demonstrated ways of doing that indicated a negotiation of the space between members of the community and being positioned outside of the community, based on discourses expressed throughout the activity.

Experts. Expert learners' hedges, such as *I should be able to know more* and *I know very little,* were used in a context to situate the knowledge that they do know about a subject, compared to what they should know according to their affinity group. Alex's statement that they "should be able to know more" (Interview with Alex, p. 12) positioned them as a part of the geoscience community, as the statement demonstrated that Alex recognized that there is knowledge known by the affinity group community that they should be familiar with.

Further, when Jayden stated that they knew *very little,* it was in regard to reptile evolution. Jayden explained that their background is focused on invertebrates and that they "know a lot more about invertebrates" and "biogeochemical changes or earth system changes that happen in the Pre-Cambrian" (p. 9).

Jayden: I guess, I know, the parts that I'm familiar with I guess I know about the P-T boundary. Um…here in New York State the rocks you see in central New York are Devonian, especially Middle Devonian, so that's probably most of the rocks I've seen. The Cambrian…is, like, Cambrian is right about there (points on the timescale), like evolution of body plans and that kind of thing. Umm…I don't know, like, I guess I know more than I think about the Cretaceous. But it just seems like the Mesozoic and Mesozoic marine evolution, but in terms of like the evolution of-like reptiles, reptiles and mammals, in terms-like and stories-reptiles in particular I know very little of the evolution of reptiles. So like-where to put that and where to put this, I'm not really sure. But actually vertebrate evolution in general is not something I know much about. Quite a few of these cards are about vertebrate evolution. (p. 9)

While Jayden expressed not feeling as though they knew much about reptile evolution because of their specialty in the geosciences, they still discussed knowing the evolution and morphological changes related to reptile evolution to demonstrate the knowledge they did have to demonstrate their participation in the geoscience community. For example, when asked about the evolution of amphibians, Jayden discussed the evolution of organisms from marine to terrestrial environments using fish, amphibians, and reptiles.

Researcher: So there’s a card that’s not in there. And it would be amphibians. If you had amphibians, where would you add that into?

Jayden: Um…after fish and before reptiles. And…-around the same time as-

Researcher: -What’s your reasoning for that? Oh sorry, I cut you off. Around the same time as?

Jayden: Around the same times as land plants; you kinda get a lot of-a lot of like, I think plants get on land first before the first amphibians do. Um…but it should happen like, so maybe like between land plants and reptiles. Like there, I think there was vegetation on land already before amph-before you find amphibians. It’s around the same time you find a lot of land plant fossils. Why?...well, I mean…I’ve always learned that life evolved in water and then like, moved up on to terrestrial environments and so, um…like amphibians have-they breathe in water but they also have lungs that allow them to breathe on land. Terres-reptiles some of them are totally terrestrial, so they would have evolved from amphibians, um…also…also like, in the class, there’s a classic transition fossil series going from fish to the first amphibians, like *Tiktaalik* and *Edenopteron* and like, all of the other lobe-finned fishes that had more weight-bearing appendages in the front of their-in their anterior fins and sort of like, allowing crawling. Allowing them to support themselves, like in water they didn’t have to support weight, but on land they’d like, need to be able to support themselves against gravity um…so just in terms of like

237 how they, I've learned about that, evolutionary transition and like first and then the order
238 of particular fish and then amphibians and like, that's kinda recorded in fossils, especially
239 the appendages. (pp. 5-6)

Although Jayden said that they were not particularly familiar with vertebrate evolution, they provide enough information to support the placement and event ordering they chose to create their model. Additionally, Jayden's comment about their specialty reminds us that there is common knowledge that experts need to possess to converse in the geoscience community, but that their specialty is where the majority of their knowledge falls. While Jayden may not know much about reptile evolution, they possess enough knowledge to discuss major evolutionary changes to the reptile clade (group of organisms with a common ancestor) with another member of the affinity group.

Although experts hedged their claims more than the novices, they provided information as to why they were uncertain about the information they were discussing and provided information as to what they did know about the event, assigned values, or scale being discussed. For example, at one point Alex discussed why the doubt themselves about the event ordering in early-Earth history stating that there was an event they know of at 4.4 billion years ago.

865 Alex: Well, I-at the beginning I couldn't remember and I'm still doubting myself about
866 the origin of the atmosphere and whether that is the event. I do know that something
867 happens at 4.4 [OC: 4.4 refers to billion years]. Um… not having more of what happened
868 in the older part of the timescale made it kinda like harder to think about because I know
869 when stromatolites showed up or I know when the first fossil record showed up, so I
870 would have been able to easily put them at 3.8 and 2.8, and then maybe not have
871 confused the trace fossil card. (p. 18)

Jayden also demonstrated the same method of reasoning when discussing the formation and break-up of Pangaea. Jayden was unsure where to place the two events, but provided what the knowledge they had to support their chosen ordering.

294 Jayden: So I'm-I think like we had in…in the De-Devonian we had the Appalachian
295 Mountains come out, and so…I know that there was subduction at the closing of the
296 basin and that happened in the Paleozoic. I think that the Paleozoic event and the break
297 up of Pangea happens…at the very beginning of the opening of the Atlantic Ocean-I
298 think that's like…kind of Late-Mesozoic maybe…or maybe the Middle Mesozoic. I think
299 like-I think this is Paleozoic [Pangea forms] whenever it starts happening and this is
300 Mesozoic [Pangea breaks apart], I just don't know…where in relation to all the life-all of
301 the life history stuff. (p. 7)

Both experts were aware of knowledge they should know according to their affinity group, but also explicit as to why they do not know this information. Specialties within the affinity group may constrain their knowledge in other areas. For example, Jayden discussed a background that focuses on invertebrates and biogeochemical changes that are associated with systems 540 million years and older. Jayden explained that based on their invertebrate background, vertebrate evolution and events younger than 540 million years are "not something that I know" (Interview with Jayden, p. 9).

Expert learners also exhibited specific practices that situated them within the geoscience affinity group. These specific practices included engagement in the task by taking their time completing the activity, asking questions for more than clarification purposes (to engage in a discussion with the researcher), analyzing and interpreting the event cards, providing background or extra information to support their claims, constructing explanations to support their claims with evidence, discussing the activity in great detail, and they discussed and displayed mathematical and spatial thinking.

Experts took over an hour (70-75 minutes) to complete the activity. Although they were quick to place events, assigned values, and scale cards, they took their time to discuss the events in detail, provided their reasoning, discussed controversies associated with the events, and constructed explanations based on evidence to support their claims. Experts taking their time with the activity demonstrated their interest not only in the activity itself, but with the information. Expert learners could have very well placed event cards, provided an explanation, and finished early. However, they took time to engage in the activity by explain their reasoning, as well as discuss controversial evidence surrounding some of the events that influenced their struggle with placement of a few event cards. The experts participated in the study to assist in the improvement of teaching and learning abstract concepts, interest in the activity, as well as to understand and gauge their own learning about the geologic timescale, seen in chapter three.

Finally, experts appeared to enjoy the task as reflected through their use of continued laughter, smiling, and enthusiasm about events throughout the entire activity. Laughter was used multiple times throughout the course of the activity (see the excerpt from Alex's transcript on page 115). Although, experts laughed at times for events they expressed not possessing much knowledge about, they did not express nonverbal cues or gestures that would indicate anxiety or nervousness. For example, their eyes did not dart side-to-side, widen without raising their eyebrows to indicate nervousness, they did not produce deep sighs, or hesitate by pausing in their speech when laughing, their hands were not jittery, their bodies were not upright and rigid (Waxer, 1977). The experts smiled and proceeded to explain what they did know, why they were pleased with specific ranges of values they used when they could not remember a value, and expressed liking with the images on the scale cards. For example, Jayden “this one has a whale on it and its pretty cool (…) I like the whale and I’m trying to put it in here” (Interview with Jayden, p. 12).

This is not to say that experts did not have any hesitation. The only time anxiety was visible and was expressed was with Jayden’s acknowledgement of being recorded. Jayden displayed nonverbal cues of anxiety, such as their body becoming straightened and rigid, twice throughout the activity when they looked up at and acknowledged the iPad recording them. The first time Jayden simply looked up at the iPad and adjusted their standing position. The second time, Jayden stated “um…I’m getting a little nervous, because I’m noticing being recorded” and pointed up to the iPad. After pointing at the iPad, Jayden laughed and bowed their head. The researcher told them they were fine and redirected the conversation to a point Jayden was previously made, complimenting them while doing so, and was able to get them to talk in depth about topic. This redirection was to get Jayden’s attention off of the iPad. After Jayden began to explain the point, they lifted their head, relaxed their shoulders, and moved on with the activity.

Additionally, when tasks were explained, experts verbally exclaimed enthusiasm. After learning about the first part of the activity Jayden said “awesome” with increased volume, raised eyebrows with widened eyes, and smiled. When Alex was told they were engaging in the second part of the activity, which was to assign values to events, they said “oh sweet”, dragging out the word *oh* like *ooohhh* with increased volume on the word *sweet*. Alex was also aware that they were adding extra information, using their anchor point Rodinia, that was not asked for by the researcher and joked around with the researcher and engaged the following conversation.

1.0 Ga we will put Rodinia. I’m cheating! I’m putting information that you are not asking! (*laughs while smiling*)

471 Researcher: That's okay! If that helps you to mark that's fine.

473 Alex: (*still laughing and smiling*) No it just helps me to get extra credit!!

478 Researcher: (*laughs and smiles*) you're trying to earn brownie points

480 Alex: Right! But I'm really just cheating! (Interview with Alex, p. 10)

As Alex was a graduate student, they do not actually extra credit for participating in the research study. Therefore, the learner was clearly joking with the researcher by making comments about extra credit.

Experts displayed mathematical and spatial thinking without using the events or scale cards by demonstrating the ability to mathematically assess the activity's scale, as well as support their choice in scale using their prior knowledge. Experts were able to look at the blank model, establish a midpoint, and then use their anchor points to assign values to the scale. As Alex stated, "I tried to divide up the geologic timescale in…more or less…based on the distance to have an idea of whether it was 4.6 and then I cut it in half. Each ruler is about 1 Ga, so I was able to separate them better" (Interview with Alex, p. 3). Alex was able to walk the model to get a sense of the scale of the activity, which is how they knew the "sticks" on the model were meter sticks, and then chose values for the endpoints based on their scale. Alex went a step further to establish their midpoint and then use an anchor point to further clarify their scale. Based off the anchor point, they were further able to manage the scale on a more absolute scale. Both expert learners were able to scale their models. Alex's example was used as they were explicit in how they created their scale.

Experts practices such as engagement in the task by taking their time completing the activity, asking questions for more than clarification purposes, analyzing and interpreting the event cards, providing background or extra information to support their claims, constructing explanations to support their claims with evidence, discussing the activity in great detail, and demonstrated mathematical and spatial thinking, combined with their funds of knowledge, funds of discourse, and gestures to indicate enjoyment and less anxiety with the activity situate them within the geoscience community.

Novices. Novice learners were primarily situated outside of the geoscience community. Novice learners were primarily situated outside of the geoscience community as they all participated in the activity for extra credit or course credit, lack of familiarity with content, mathematical, and scale knowledge, asked questions primarily for clarification purposes, and provided information for the activity from a particular source, but did not engage in reasoning from geological evidence. Instead, novices drew on their experiences in their various funds and making that knowledge explicitly known, as well as making clear claims geologic time. However, some novices, Cameron, Frankie, and Mica, were seen displaying practices that demonstrated a negotiation of their position in relation to the geoscience community.

Learners' reasons for participating in the activity also reflected the learner's identity throughout the activity. First, all of the novice learners received credit in a university course for participation in the study. Harper and Taylor had written on their survey at the beginning of the activity that their participation was to "fulfill research participation requirements for another course" ((learners' participation surveys). Frankie had "never been the "subject" in a study and thought it would be interesting; and enjoys learning about Earth Science and thought it would benefit learning the subject" while Mica wanted to "help out in the study" and get "extra credit" (learners' participation surveys). Cameron was "interested to see how you research on geologic time" and to obtain "extra credit" (learners' participation surveys). Frankie, Cameron and

Mica's reason for participation aligned more closely with those of the experts as they expressed wanting to assist in the study as well as being interested in research or geoscience material.

Novice learners answered the questions and explained their reasoning for placing events, assigned values, and scale cards in particular places, when prompted, but did not engage in further discussion outside of the questions asked of them. Cameron was the exception as there were times when Cameron went into depth about their ideas about geologic time further than other novices. Novices also asked questions, but usually to clarify directions for the activity or to question their own knowledge.

144 Harper: You want me to write how much time was in between each card? (*shakes head,*
145 *smiles, laughs*) (p. 4)

194 Taylor: Can I just write like the number and then years ago? (p. 5)

All of the novice learners had events that they had strong claims for that were correct, whether they were placed in the correct order, however, they may not have had the language or knowledge necessary to support their ideas with in-depth reasoning.

Finally, novice learners could tell that their scale was not quite correct, but this may have been for two reasons. First, novice learners could see that the assigned values, scale cards, and gaps on the timescale, did not align. Learners expressed that their assigned values did not align with the scale card values, and that their scales were inconsistent. For example, Taylor stated "this is 100 million years, 100 million years, it's still not going to be enough to get to a billion right here, but it's as close as I can get it right now. I feel. Um…yeah" (Interview with Taylor, p. 9). There were instances were novice learners knew their scale was incorrect, but were not quite sure how to adjust the model. Additionally, when novices did attempt to rescale the model, they adjusted the cards or moved the values, but did not attempt to change the values or demonstrate mathematical practices to break the model up into values they could work with.

Second, the Institutional Review Board (IRB) recruitment emails and consent forms for participation in this activity were required to explicitly state that the study was to gain an understanding of learners' representations regarding the scale of geologic time. In the pilot study for the activity, learners were told they would be participating in an activity about geologic time and not a single novice learner mentioned the scale of the activity explicitly. Therefore, it is possible that the attention to mentioning scale was at the forefront of learners' minds because of the recruitment emails and consent forms. However, there is no way to tell for certain if this was an additional reason novice learners made sure to mention the scale, but not discuss it in-depth.

Overall, novice learners' identities were primarily situated outside the geoscience community, but appeared to negotiate their position within the community. Their actions, such as not wanting to reorder or rescale the activity, placed them outside the community as they were choosing not to continue to engage with the activity for various reasons. Participating in the activity for extra credit or as a requirement for another course further placed them outside the community. However, identities with the community weren't clear cut for a couple of novice learners. Cameron, Frankie, and Mica expressed interest in the geosciences and possessed various funds of knowledge associated with topics covered during the activity. Mica had never learned about the geologic timescale, and all of the information they had was pieced together from various funds. This curiosity and knowledge positioned indicated they were caught in between a blossoming interest in geoscience community, but weren't expressing language or actions to indicate participation in the community. Cameron also expressed interest in how geologic time research was conducted, but their participation was also based on receiving extra credit for a course.

Summary

Hedging comments are indicative of a degree of uncertainty, which allows for a margin of error to be accepted in discussion. By prefacing the information may not be correct, the learner puts himself or herself in a position to know that they may be incorrect. This protects the learner if they are incorrect, as they have already acknowledged this possibility. Novice learners were not exceptions from hedging; overall, they happened to hedge their comments less often than the experts. Novice learners spoke with confidence and certainty throughout the task similar to the expert learners. Expert learners used hedging comments more frequently than novice learners, with the exception of Cameron. The number of times Cameron used a plausibility shield was in the same range as the expert learners.

The experts made 37 claims while novice learners ranged from 14-35 claims over the course of the activity when explaining their reasoning about their timescale. Two novice learners, Harper and Frankie, made almost the same number of claims as the experts, with 34 and 35 claims, respectively. Taylor and Cameron both made 21 claims, while Frankie made 14 claims. Experts made claims about events and their relationships, their reasoning for placement of an event or an assigned value, the scale of their model, as well as making claims about additional information or events not provided (e.g. discussions involving anchor points). Experts would state their claims outright or they would provide information they were uncertain about and use phrases such as *I know* or *I do know* to emphasize knowledge they possessed about a topic. Novice learners made claims about an event’s occurrence, relationships between events, or in their reasoning for event placement. Claims throughout the task were important to note because they showed the learner's confidence in the content being discussed.

Expert learners made more hedging comments than the novice learners, but had roughly the same number of claims as two novice learners.

Knowing and unknowing mitigation phrases were used more often by the expert learners than the novice learners. The absence of attribution shields, knowing and unknowing mitigations, rounders, low number of plausibility shields, and the use of almost the same number of claims as the experts, suggested that novices were more confident in their knowledge and speech throughout the activity than the experts, as indicated through this discourse analysis. This suggests that both novice and expert learners have ideas that they are fairly certain about and come into the university knowing. Although all of the learners recognized that there is the possibility of being incorrect in their timescales by the use of hedging comments and phrases, the expert learners hedged more than the novice learners to protect their answers and soften their claims in the case they might be wrong.

Funds of knowledge for novice and expert learners primarily focused on their institutional knowledge. However, there were slight differences within the institutional knowledge. Novice learners' primary source of information was their K-12 educational background, which is unsurprising, as they are first-years in college. Novice learners' information also came from institutional sources outside the university, such as media and books. Movies such as *Jurassic Park*, documentaries, children's movies and books were also referenced as sources of knowledge. Novice learners did not discuss knowledge from specific K-12 teachers, friends, or informal learning centers, such as museums. This does not mean that they do not have knowledge from these sources, but that they were either not relevant to the context in which the events cards drew from or the sources listed were most memorable and easier information to retrieve cognitively.

Expert learners' knowledge was primarily institutional. Expert funds were not only from graduate-level coursework and faculty members, but experiential knowledge from research or teaching. Expert learners also mentioned funds outside of the educational institution, but from media such as podcasts and reading journal articles of interest.

Although two novice learners did show interest in geoscience content and wanting to participate in the activity to understand how research worked, as well as one novice spending as much time on the activity as the expert learners, they were primarily situated them outside of the geoscience affinity group. Novice learners' actions, such as participation in the activity required for another course or extra credit, time spent on the activity, not wanting or attempting to rework the activity, combined with their language use, situated them outside of the geoscience community. However, these discourses effected learners' identity to the geoscience affinity group. Novice learners' may be in another affinity group that was not discussed.

Expert learners were primarily inside the geoscience affinity group because of their ways of knowing and doing. These specific discourses included their language use, content knowledge, use of anchor events to provide in-depth knowledge of particular events, constant reworking of the activity, and hedges that indicated knowledge that they knew they should know. Additionally, their research and teaching experience, as well as their interest in listening to podcasts or reading about geoscience topics outside of class, further established their identity within the geoscience community. In considering learners' funds of knowledge, their discourses, experiences, and knowledges reflect their identities, which will continue to evolve in new contexts. The use of an affinity group fund as a foundation sheds light on the opportunities and challenges of learning in the geosciences.

Discourses can be drawn from a variety of funds. As seen with both the novices and experts in this study, learners "bring everyday knowledges and discourses to their academic setting, producing possible conflicts, as well as points of intersection for teachers and learners" (Moje, 2008, p. 343). The variation of these funds demonstrated various ways of knowing and doing in university courses, as well as reflect on their identity with the geoscience community. Novices, new to the university setting as well as to a geoscience course, appeared unfamiliar with how to combine their everyday practices and discourses with those expected of the geoscience community. Novice learners appeared to negotiate their position within the geoscience community by drawing on their experiences in their various funds and making that knowledge explicitly known, as well as making clear claims geologic time. The importance of funds of knowledge, ways of knowing and doing, and identity in conjunction with learners' strategies for event ordering, assigning values, and scale card use, will be further discussed and summarized in chapter seven.

Chapter 7

Discussion and Conclusion

Frame of the study

In this dissertation, expert and novice learners' geologic time understanding, representations, and discourse was explored during a model-eliciting activity using a phenomenographic approach. The data collected and analyzed illuminated the ways in which experts and novices indicate ways of knowing as well as their ways of doing, and the similarities and differences between both groups of learners. Additionally, these discourses reflected learners' identities associated with the geosciences over the course of the activity.

The goal of sharing these data is to inform educators, K-16, how novice and expert learners think about and represent geologic time. This includes the funds they draw on for knowledge, the physical representation of events, values, and scale on a model, their reasoning, and the discourse used while completing the activity. Learners' representations and discourses provided insight into their strategies to navigate geologic tasks as well as how they associated themselves in relation to the geoscience community, specifically during the activity and geoscience course(s) they have enrolled in.

A phenomenographic approach to the model eliciting activity, while using an expert-novice framework to this research was an insightful process. The dynamic structure of the model takes into account the dimensions of "human activity", "including knowing and learning, in order to be understood" (Roth, 2009, p. 4). Further, "thinking and identity of competent experts as well as novices are transformed" through participation in this "active and interactive process" (Jacoby & Gonzales, 1991, p. 150). Phenomenography was specifically used in conjunction with expert-novice theory to identify and explore the various conceptions that learners held about the relationships between the conceptions. Specifically, the intention of the activity was focused on what learners think, and how they describe and explain about phenomena. Therefore, the focus was not simply "on what learners know, but how they know it" (Stokes, 2011, p. 23).

A phenomenographic approach reinforced the activity as it was able to get at the cognitive aspect of what students are thinking and the constructivist aspect of how do learners build and represent their knowledge. The combination of expert-novice theory and phenomenography allowed for an understanding of how the learner adapted the timescale model, by use of practices and language, while gaining an understanding of their conceptions, reasoning, and discourses.

The geologic timescale activity could have been considered phenomenographic if it was conducted a as a paper-and-pencil activity with learners' providing written answers. However, I would argue the results would not have been nearly as fruitful, specifically in regard to the discourse analysis conducted and justification of claims made by learners throughout the activity. The study was designed to have interview questions asked throughout the activity, in order to best reveal learners' experiences and ideas of geologic time. Questions about strategies used to represent and construct their model may not have been explained as clearly or in-depth, and could include less detailed or incomplete conceptions, if written on paper (Stokes, 2011). Follow-up questions about these aspects could have been conducted after completing the activity. However, follow-up questions would be dependent upon learners' availability to meet again and their ability to remember strategies or decisions made during the activity. Therefore, follow-up questions results regarding their understanding of the timescale would not be guaranteed. Additionally, time between follow-up interviews and the activity, could also result in the learner knowing more or having changed their responses about the phenomenon if they attended class or looked up material about the timescale. Therefore, in-depth interviews conducted during the activity were best for this study.

A phenomenographic approach to analysis of the findings regarding event ordering, scale, and duration constructed on the model, enabled me to compare novice and expert learners' ideas in categories with specific examples. These categories were founded only after meaning was established within the transcript as a whole for each individual learner and then separated into relatable chunks or excerpts (Collier-Reed & Ingerman, 2014). Excerpts of each individual's experience of an event in geologic time, such as thoughts about the break-up of Pangaea, or a particular way of thinking about geologic time, such as how plant evolution occurred in the context of deep time, were able to be combined to establish a collective meaning (Collier-Reed & Ingerman, 2014).

Summary of findings

Chapter one introduced the research questions and purpose of the study. The purpose of this study was to gain insight into novice and expert learners' understanding, representations, and discourse regarding geologic time. Chapters four through six reported the results from the task-based interview. Chapters four and five provided comparisons between the geologic timescale and learners' event and scale card placement on the model, as well as assigned value use and placement. Chapter six illustrated how learners discussed geologic time through an overview of the linguistic patterns examining lexicalization and relexicalization of words and phrases as well as a comparison of expert and novices' funds of knowledge.

This chapter will be organized differently. Chapter two attempted to show the complexities learners face when working with geologic time. Knowledge of geologic events and concepts such as succession and duration, coupled with large numbers, make understanding and applying geologic time challenging. In this chapter, the findings from the data in chapters four through six are summarized and tied to what is known about learning with existing literature regarding learners' conceptions about the geologic timescale from chapter two. The chapter begins by summarizing expert and novice learners' strategies to complete their geologic models. This section is followed by a summary of learners' funds of knowledge and discourse throughout the activity. Implications and limitations found during the activity are presented followed by recommendations for future work.

Connections to research questions

Before concluding this dissertation, it is important to reexamine each research question and emphasize the most salient connections from the data. The following is a summary of each research question and the important points associated with each one.

1. How do learners understand and represent the placement of events and their relationships on a blank geologic timescale? Novice and expert learners were no exception to the ease of relative event ordering, and challenge of situating an event in absolute time, which corresponds to the literature reviewed in chapter two. The difference between novice and experts' temporal ordering was their conceptions regarding events and strategies for event placement. Experts and novices faced challenges regarding event placement. Experts expressed having difficulty with knowledge of particular events, specifically those outside of their geoscience disciplines, such as the plant cards, *vascular* and *flowering plants,* as well as the *trace fossil/first evidence of life* card. More than the event itself, the experts focused on when the event occurred in attempt to scale their models accurately.

Novice learners faced challenges regarding classification of organisms at the kingdom level or how the organism in question related to other organisms. Novices also had difficulty with the placement of both Pangaea cards. The *Pangaea forms* card was troubling for mainly two reasons: learners either put Pangaea as the first supercontinent or did not know when it occurred. Novice learners had difficulty with *Pangaea breaks apart* because of the mechanism that caused the break-up of Pangaea. Some novice learners rationalized that the force of an asteroid hitting Earth could break apart Pangaea, rather than as a result of plate movement as an internal mechanism driven by convection cells within the mantle.

Novice and expert learners possessed knowledge of events at which they excelled. Surprisingly, both novice and experts possessed greater knowledge of events in Early-Earth history. Events such as *earth's atmosphere forming*, *photosynthesis beginning on Earth*, *trace fossil/first evidence of life*, *enough oxygen to sustain life*, and in some cases, *fish first appear on Earth*, were all topics in which novice and experts were familiar. As most representations of the geologic timescale are heavily weighted toward their representations of events in the Phanerozoic, 540 million years ago to *present day* (e.g. *humans*, *birds*, *plants*, *mammals*, *Pangaea forming* and *breaking*, etcetera), it was unexpected that all learners would do so well with very old events in time as they are not often represented.

Event card placement discussions, specifically the challenges, were not presented to place blame on experts and novices for what they do not know or remember. Instead, it was to establish how both novice and experts think in relation to geologic time, the funds they draw their knowledge from, and how they represent these ideas. Knowing what you don't know is just as important for learning, as expressing what you do know, if not more so. Establishing the gaps in knowledge better allows an educator to scaffold it to the material being taught, reviewing it for all students, or in some cases, finding new methods to represent the material, depending on learners' conceptions.

Although the ordering and the scale of event placement on the model was mostly incorrect, learners provided logical reasoning for event placement. Expert learners possessed more in-depth knowledge of the events related to geochronological units of time, and were therefore able to better place and scale events in time, than the novice learners. That being said, novice learners' backgrounds with geologic time varied significantly; there was one novice learner that had never experienced or learned about geologic time, one that had only learned humans' relationship to geologic time, two that learned it during middle school Earth Science, and one that encountered geologic time frequently in most of their science courses. From these experiences, most of the novice learners were piecing together information from various funds and were highly successful with their ideas in Early-Earth history.

Although they had incorrect temporal ordering, novice learners have not yet had the experience to better temporally order the events, which is no fault to them or their knowledge. Discussing novice learners' successes during the model is imperative as it focuses on what they are doing well and what knowledge they possess. This in turn helps university-level instructors focus curriculum development in their courses. Novice and expert learners have a stronger expressed understanding and representation of older events in time. Therefore, this group of learners would need to have more emphasis on events toward *present day* and how they relate to events in deep time.

2. How do learners represent and understand the scale of geologic time? Data analysis of questions one and two, presented in chapters five and six, are connected. Learners need to be able to order events and scale them represent geologic time properly. This dissertation is in agreement with a study conducted by Kim Cheek (2012) that large numbers are part of the problem. However, understandings of how life evolved, in terms of order and classification, would have helped them on the task. By helping students better understand the evolution of life over time, they could improve their relative ranking, even if their absolute ranking of time needed more improvement. This understanding was demonstrated by the expert learners who did not separate their understanding and representation of event placement and values, from their strategies to scale the model, while novice learners represented these items separately, facing more challenges with both event ordering, assigning values, and scale representation.

Experts' metacognitive strategies included anchor points that allowed for organization of knowledge, rapid application and retrieval. Each expert had different anchor points depending on discipline and interest, as well as emphasis at universities, within classrooms, and participation in research. Alex and Jayden mentioned particular courses at the same university that emphasized the same topics. In particular, they both referenced the Great Oxidation Event as a point to order and scale the older portions of their models. This may be because the anchor point used was a pivotal point in early Earth history, coincidence, or the department at that particular university emphasizes certain topics in multiple courses. It is my belief that there is great emphasis on the importance of the Great Oxidation Event as a pivotal point in Earth's history in this department because of its importance as a geochemical and biomarker of oxygenic photosynthesis that produced dioxygen (O_2) in Earth's atmosphere. Oxygen accumulation led to changes in climate, environments, and biological and mineral diversification. These outcomes are generally important for experts to know, but also related to the research interests of both experts in this study as well as those of faculty at their university.

The anchor points that overlapped were pivotal points in geologic time that are not emphasized on standard geologic timescales that the activity was based on. For example, the Great Oxidation Event is not often shown on the timescales introductory textbooks, whereas the evolution of mammals is shown. Anchor points are of importance because they begin to reveal how experts understand, represent, and apply knowledge, but also how they relate to the content. Anchor points were pivotal points of interest that were easy for experts to recall because of their frequent use of the anchor in courses and research. Both Jayden and Alex referenced multiple sources where they encountered the anchor and its value in time.

This use of anchor points to manage the scale allowed experts to unitize the model (Tretter et al., 2006a). This unitizing strategy, described by Tretter et al. (2006a), allowed experts to create a unit of scale to work with conceptually. As learners were not originally given a scale or values of time, they had to establish their own scale. Experts were able to establish units based on the value of their anchor points, in order to work with the exceptionally large scale of the model. Even though experts used the unitizing strategy, it did not mean that it was easy for experts to create their models. Jayden expressed that they had a hard time spatially as the model was bigger than they were and they couldn't see the whole model at once, but they thought the model was "fun because it was big" (Interview with Jayden, p. 14).

Experts relied on a combination of assigned values and geochronological units (e.g. eons, eras, periods, or epochs) in order to temporally order and scale their models. Strategies for temporal ordering, assigning values, and scaling were all intertwined for expert learners. Relative temporal ordering was not done without trying to distinguish a scale and discussing values or geochronological units. Likewise, determining a scale to use was necessary for the experts to assign values. Even though the assigned values and scale were in parts two and three of the activity, experts did this from the beginning of the activity without being prompted. Although most of these strategies were distinct to expert learners, there was overlap with the use of scale cards between expert and novice learners. Both expert and novice learners used scale cards to align with their assigned values.

Novice learners' strategies differed from the experts in that each part of the activity was conducted separately. Novice learners began the activity by thinking of the relationships between events. Unlike the expert learners, novices acknowledged the scale of their models after assigning values to events, instead of scaling the activity from the beginning as they did not mention any values. Novices used spatial size to infer duration, as they did not explicitly discuss the spacing of event cards on the model. Spacing event cards on the model was the development of scale and duration by the learner; all novice learners, with the exception of Cameron, were unaware or did not express awareness of their actions until prompted to explain their reasoning for spacing out the event cards.

Assigning values was a daunting activity for the novice learners. While it brought clarification to expert learners, novice learners expressed anxiety when asked to place their own values on the model. Novices tried to focus on a number they thought they had heard somewhere before from school, books, or documentaries, and then marked the events or time between events they had on the model. Original assigned values were more closely related to what learners think in terms of time entering an introductory geoscience classroom as they represented the values learners thought to document without being given values for *Earth's formation* and *present day*. *Earth's formation* and *present day* values were provided to see how learners would represent values of time with a set of parameters. After assigning values to the model, novices began to discuss scale. Awareness between the spacing on the scale and the increments or durations of time used were stated as being inconsistent. Some novice learners even discussed that they guessed when assigning values to the model.

Regardless of the guesses novice learners made, they were still aware their scale was incorrect. Novices discussed awareness of improper scaling, by comparing placements of the values provided for *Earth's formation* and *present day* on the model to the assigned value they wrote on the post-it note as well as comparing the placement of assigned values to the durations on the model. Novice learners explained that the assigned values they chose and their placement did not align. Further, they explained that the gaps between events were not consistent with the scale they chose.

Finally, both experts and novices engaged in metacognitive practices during the activity. By participating in the task-based interview as learners had to make their strategies and representations explicit to the researcher. However, metacognition is often an activity that is not expressed explicitly. Learners demonstrated metacognitive practices they may not have been aware they were making, and therefore, they could not make those ideas explicit. However, experts demonstrated a more developed metacognitive awareness toward the activity, as they reflected on their experiences and their own thinking during the course of the entire activity. Expert learners continually planned out, monitored, and evaluated their models (Kirsh, 2004). Expert discussed the relationships between the events and scale of the activity by the establishment of a midpoint and use of anchor points. Experts were also aware of the knowledge they were lacking to complete the model accurately, and provided reasoning for the lack of information, whether it was lack of knowledge or inability to remember the timing of the event, or depth of knowledge about the event. Additionally, experts were aware that the event location on the model corresponded to a value in time. Further, experts wrote out geochronological units on post-it notes to add their models to mark progress on the model as well as metacognitive aid

(Kirsh, 2004), and unitized their models. Experts were able to better visualize their models allowing themselves to evaluate their model's ordering, duration, and scale.

Novice learners demonstrated metacognitive practices, which increased in parts two and three of the model-eliciting activity when the cognitive demand on learners was higher. As part one asked learners to place events on the model in a temporal order, parts two and three required learners to represent the values they associate with events and to attempt to scale the model. Novice learners' metacognitive strategies included being aware of ideas that they weren't certain of. They were well aware of the conceptions they felt were correct or that they felt they knew nothing about, and conveyed that information. Novices arranged event cards based on what they were most confident about and then placed event cards they were unsure about, based on the placements of the events they were most confident about. Novices used this strategy to rearrange their events, assigned values, and scale cards. Novices explained their strategies for placing the events with their choice of assigned values. Finally, novices attempted to explain their reasoning and the fund of knowledge they were drawing on as the source of their reasoning, showing they were aware of the funds they were drawing on to establish their models.

3. How do learners discuss their conceptions about geologic time? What do these conceptions about geologic time reveal about their prior knowledge? Learners' discussions were steeped in knowledge from various sources, as well as particular ways of knowing and ways of doing, also known as their discourses. The first part of the discussion below will focus on learners' funds of knowledge followed by a discussion of their discourses.

Funds of knowledge. Novice learners' funds were primarily geared toward institutional sources, specifically their K-12 experience and media. Funds from their K-12 experience included History, A.P. Art History, and general science courses. Although novice learners referenced their K-12 education as a fund, they were not confident when citing their fund when making claims about event placement on the model. Media sources referenced included children's books and movies. Experts referred to both institutional and media sources, but had the additional fund from their affinity group. Experts referenced their undergraduate degrees and graduate experiences, as well as research experience as their primary funds of knowledge on geologic time. Podcasts and additional reading outside of their courses were also discussed. Additionally, as there was a particular language and practices associated with the affinity group used by Jayden and Alex, discourses attributed to the affinity group can be known as *funds of discourse*.

Similar to work conducted by Tretter et al. (2006a), experts were very specific in citing the fund of knowledge for their ordering, as well as the particular discussion or article the information around the topic, was brought up. Experts were also very specific about where they learned about scale and assigned values. Novices referenced a general course or books for their event ordering knowledge fund. For example, *Jurassic Park* and *Dinosaur*, were both specific movies referenced for knowledge on dinosaurs. However, the details to specific scenes the information they used to construct their models was not explicit.

The experts had a clearer understanding of the scale that was used because of their familiarity with the values discussed. Their knowledge was grounded in basic and applied research in specific sub-disciplines of the geoscience. They have had practice using what they know to understand either Earth and mineral formation or organismal evolution, make claims, and support their claims with evidence. Second, expert learners had a better understanding of the relationships between events because of their backgrounds, experiences, and interests. Although expert learners had made mistakes on their event ordering, event placements were close to those of geologic time, and the relationships between events were still discussed revealing that the expert learners knew the event card was in the correct vicinity on the timescale, even if placed in an incorrect order.

Novice and expert learners' strategies and funds of knowledge are important to understand as they provide insight into how geoscientists practice and develop their skills. Determining how expert learners discuss and represent geologic time, as well as the funds they draw from, provides insight into their thought processes and how they construct and incorporate new knowledge into their existing geologic time schemas. Determining how novice learners discuss and represent geologic time provides insight into the knowledge they possess prior to becoming an expert and where geoscience courses can add to and address gaps in knowledge, as well as assist with their scientific practices and skill development.

Discourses. *Ways of knowing*. As this discourse analysis, ways of knowing, was grounded in work by Rebecca Rogers (2013), learners' language was examined for patterns in lexicalization and relexicalization. It was found that novice and experts used words and phrases that served similar purposes throughout the activity were claims and hedges.

Novice learners made claims about an event's occurrence, relationship to another event, or in their reasoning for event placement, and typically stated the claim outright. Experts would state claims about events and their relationships, their reasoning for placement of an event or an assigned value, or the scale of their model. Experts would state their claim outright and sometimes they would provide information they were uncertain about and use phrases such as *I know* or *I do know* to emphasize knowledge they possessed about a topic.

Attribution shields were used by experts only a couple times more than three of the novices. Only one novice, Mica, did not attribute knowledge to a particular source. Plausibility shields were the most frequently used shields. Plausibility shields were used almost two times more by experts than novices, with the exception of Cameron who used as many plausibility shields as the experts.

In this dissertation, plausibility shields were broken down into two categories: 1) knowing mitigations which are phrases that question the claim or the learners' familiarity with the subject, and 2) unknowing mitigations which are phrases that claim a lack of awareness or knowledge. Knowing and unknowing mitigation phrases were used more often by the expert learners than the novice learners. Expert learners made between 15-20 knowing mitigations and 30-48 unknowing mitigations, while novice learners made between one to eight knowing mitigations and 5-32 unknowing mitigations.

The lack of attribution shields, low number of plausibility shields, knowing and unknowing mitigations, lack of rounders, and the use of almost the same number of claims as the experts, suggested that novices were more confident in their knowledge and speech throughout the activity than the experts, as indicated through this discourse analysis. More importantly than the number of hedges the learner made, was what the learner hedged about. Experts made hedges, specifically unknowing mitigations and rounder approximators, about the specifics of content knowledge, determining delineations geochronologically as to when specific events occurred, and how those apply to the scale of the model. Novice learners hedged about their funds of knowledge, questioning the fund's reliability, their memory, and relationships between events or their choice of assigned values. If novice learners had tried to go into more depth about a topic or spoke more frequently about the values and scale of their models, their use of plausibility shields would have likely increased.

Ways of doing. Drawing on the work of Gee (2000) and Moje (2008), the combination of strategies as well as the ways of knowing discussed above, reflect novice and expert learners' identities associated with an affinity group, in this case, the geoscience community. Expert learners' identities were positioned inside the geoscience community because their discourses included their language use, content knowledge, use of anchor events to provide in-depth knowledge of particular events, constant reworking of the activity, and hedges that indicated knowledge that they knew they should know. Research and teaching experience, as well as their interest in listening to podcasts or reading about geoscience topics outside of class, further established their identity within the geoscience community.

Novice learners' identities were positioned outside of the geoscience community. Although two novice learners showed interest in geoscience content and wanting to participate in the activity to understand how research worked, they were primarily situated outside of the geoscience community. Novice learners' actions, such as participation in the activity required for another course or extra credit, and not wanting or attempting to rework the activity, situated them outside of the geoscience community. Although novice learners do not fully identify with the geoscience community, this does not mean they do not identify with another affinity group.

Novice learners lack of unknowing mitigations compared to the expert learners, expressed their phrases were grounded in claims and positioned them as *knowers*, regardless of whether they are inside or outside the geoscience community. Novice learners, viewed by their verbal discourse alone, possessed confidence in and of their expression of their knowledge. They possess certain knowledges and were confident in those knowledges. The lack of unknowing mitigations and use of claims demonstrated novice learners' unintentional negotiation of their identity in regard to the geoscience community by drawing on their experiences in their various funds and making that knowledge explicitly known, as well as making clear claims geologic time. Novices, new to the university setting as well as to a geoscience course, appeared unfamiliar with how to combine their everyday practices and discourses with those expected of the geoscience community.

Discourse conclusion. It was learners' prior knowledge that was used to construct each task of the model, in conjunction with their language to describe and transform their ideas to physical representations on the model. Even the language used to describe the learners in the study as experts and novices, seem concrete because of their identities within or outside the geosciences affinity group. However, their knowledge and language demonstrate the fluidity of these titles. The expert-novice dichotomy portrays one as a *knower* in the geoscience and the other as a beginner, regardless of knowing their experiences, knowledge, perspectives (or lack thereof). However, to distinguish between the groups of learners, the social identities described as *expert* and *novice*, was used to more easily discuss learners understanding of geologic time at two different levels in an academic trajectory, when someone is new to the field and when someone is reaching expertise. However, the goal of the study was gain an understanding of the representations learners have about the geologic timescale upon enrolling in their first geosciences course and how those representations compare to those of geoscience graduate students. The purpose can be broken down two-fold: 1) the knowledge and language possessed by both novices and experts is revealed and positions them both as *knowers*, and 2) by gaining insight into what novice and expert learners know, we, as educators, can better support novice learners with skill and practice development toward expertise in the geosciences.

There has been a deficit languages used toward novice learners. As mentioned previously, conversations at the Summit on the future of Undergraduate Geoscience Education discussed in chapter three, were geared toward the language, content knowledge, and practices novice learners are lacking. As novice learners have not yet gained these skills or practices, they are not yet considered to be part of the geoscience affinity group. Deficit thinking is a "model founded on imputation" of the learner (Valencia, 2012, p. x). In other words, deficit thinking is seen when source of action is tied to a source. Deficit thinking in education is the idea that a learner that is not doing well "because of internal deficits or deficiencies" (p. 2). For example, phrases such as "novice learners lack the skills to succeed in the geosciences" blames the novice for their lack of geoscience skills, instead of thinking novice learner have not yet experienced or been taught the skills necessary to practice in the geosciences.

However, just because they have not yet been taught the specific skills or language, it does not mean that the novice learner comes into the classroom with a lack of knowledge about the subject. As seen in chapter four, novice learners spoke with almost as much confidence as the expert learners by making claims throughout the timescale activity. Furthermore, the expert learners hedged their comments and claims more than the novice learners did, with the exception of one participant. This implied that not only do novices had ideas about events in geologic time, but that they were confident in their claims.

Attribution of knowledge was typically made by novice learners to serve one of two purposes: 1) to shed light on the where their knowledge, and 2) to protect their ideas in case the statement was incorrect. Cope, Kalantzis, McCarthey, Vojak, and Kline (2011), argued that "learning is integrally related to learner identity" (p. 83). In other words, if you "feel as though you do not belong in the learning context" and learning does not engage your identity, where you know you contribute and construct knowledge, then "learning outcomes will be diminished" (Cope et al., 2011, p. 84). It is possible that because novice learners know they are not part of the affinity group that they feel this deficit and expressed it by hedging their comments. The hedges could also be the same as the expert learners in that they wanted to protect their statements as they knew the knowledge may not be correct. Therefore, identity around the geoscience community is something that should be kept in mind as participation, language, and the learner's perception of their association with the community, is important for personal learning gains.

Implications

As a science educator, specifically in the geosciences, I was aware of the complexities associated with learning and teaching geologic time. Through this study, I wanted to gain first-hand experience of individual expert and novice learners' conceptions related to the scale of geologic time, including the events and assigned values, and the sources of knowledge they draw on to construct their models of time.

While this dissertation used an expert-novice theoretical framework, participants were assigned to these categories because of their formal exposure to post-secondary geosciences. The label "novice" was assigned to learners that did not have a formal background in the geosciences, while "experts" were those enrolled in graduate-level coursework, indicating years of experience with the field. Traditionally, this expert-novice framework privileges expert knowledge and situates novices at a deficit, suggesting that a novice learner does not possess knowledge regarding the geoscience field. However, it should be noted that all of the learners participating in this research were positioned as knowers. Additionally, as one person might be a novice in the geosciences, they have expertise or are building expertise in other areas or disciplines. The expert-novice framework used should be thought of as a continuum for building expertise. Expertise is not static. While there were differences between the ways participants engaged with the model-eliciting activity, such as how they applied their knowledge to the model, the different funds they drew on, and the ways they spoke throughout the activity, each person in this research is continually learning and expanding their knowledge base.

In the classroom, students often do not feel comfortable expressing their ideas for fear of being wrong. Moreover, when working in groups, there can be one dominant student whose ideas are represented rather than all of the individuals. Therefore, it is difficult to gain an understanding of individual students' ideas. While there are studies that examine learners' conceptions of events and scale, they have not asked for the values learners associate with events and where they learned these values. Contemporary views of learning indicate that learners try to combine what they know and believe about geologic time and construct an understanding with the new information they acquire through their experiences (Bransford et al., 2000). Therefore, it is important to gain an understanding of the range of values, funds of knowledge, and discourses learners bring to the university.

Literature on geologic time has included primarily consisted of K-12 students' alternate conceptions, with little work done on university-aged students. Studies that have been conducted on university-aged students focused on what students did not know as opposed to viewing a balanced relationship of what they struggle with and what they know. Based on this finding in the literature, it became important to show both expert and novice learners as *knowers*. This does not mean that the alternate conceptions were ignored. It is important to note conceptions learners find challenging or where they are lacking knowledge from their previous education, specifically for curriculum development between K-12 and university courses. However, it was important to also highlight the areas that learners come into the university understand strongly.

How does this research influence of classroom practices?

From the timescale activity as well as the literature, it is clear that novice learners need more opportunities to learn the content, and to reveal their thinking and funds of knowledge. The NGSS has developed practices, crosscutting concepts such as scale and proportion, and disciplinary core ideas for K-12 education that are foundational to the sciences. However, as the standards have not been adopted by every state and were implemented in 2013, there are many learners that will be entering the university that will not be affected by the standards. In addition, there are no set standards or practices for university-level learners in the geosciences. Therefore, geoscience instructors can assist learners by helping them develop strategies to understand time. Additionally, the Association of American Universities (AAU) has recently established a framework to improve undergraduate teaching, focusing on reforms in terms of pedagogical practices, scaffolding between technology, data, facilities, and faculty professional development, and cultural change for the establishment of teaching excellence measures and expectations (AAU, 2013). This framework could provide guidance to faculty members to improve teaching and learning, with specific approaches, methods, and pedagogies to use in the classroom to assist learners in their understanding of geologic principles and provide instructors new ways to gain insight into learners' thinking.

Insight into learners' thinking about the geosciences to improve their scientific practices, discourse, understanding, and identity associated with the geosciences can be achieved through various pedagogical activities and practices. Some examples of these pedagogical activities would be model-eliciting activities, demonstrations of rates of processes, spatial metaphors and explicitly discussing temporal and spatial reasoning associated with the timescale (Cheek, 2013), explicit discussions of duration and demonstrating overlaps to mathematics to familiarize learners with the material. Developing activities that gain insight into these categories are beneficial to both the educator and the learner.

Collaboration between mathematics and geoscience instructors when teaching concepts would support learners to understand the interdisciplinary nature of the topics as well as developing the crosscutting concepts in each of the courses at the same time, assisting in improved conceptual knowledge and a better sense of the role of large numbers among science and mathematics disciplines (Cheek, 2013).

Activities and assessments to reveal thinking and metacognitive practices. The model-eliciting activity used in this dissertation was focused on revealing learners' thinking, discussions, and representations of geologic time. As learners engaged in a task-based interview throughout the activity, they engaged in metacognitive practices by making claims and providing evidence and reasoning of their thought processes. Development of metacognition results in higher levels of academic performance, as learners are actively engaged in reflecting on their processes of pattern recognition and retrieval (Cope et al., 2011), as well as their ability to transfer knowledge to new settings and events (Bransford et al., 2000, p. 19). Interactive assessments can show a learner's "potential by influencing and helping to change their performance" (p. 85).

As seen in this study, both experts and novices engaged in metacognitive activities, but to varying degrees. Novices focused more on knowledge that they did and did not know about events to construct their models. Experts' engagement in the activity revealed developed metacognitive practices that were the same as novices, but expanded to include the identification of anchor points and unitization their models. This is consistent with the literature as experts "in a subject domain typically organize knowledge into schemas and make sense of new information through processes of pattern recognition" (p. 84). Further, these "representations are then useful tools for understanding, knowledge making, and knowledge communication" (p. 84). Therefore, by developing assessments to reveal student thinking, schema-forming abilities, and reflecting on their own thinking, their knowledge organization can be explicitly expressed and developed. Development of metacognition would then assist in making thinking more effective and efficient (Cope et al., 2011). Therefore, tools such as model-eliciting activities where learners explain their thinking allows for assessment of learning in the moment as well as awareness of learners' knowledge, practices, and experiences to complete an activity. These tools are also important for revealing learners' funds of knowledge, conceptions, and support of their developing geoscience identities.

Revealing learners' funds of knowledge and conceptions. Funds of knowledge varied between novice and expert learners. Funds of knowledge are important because they provide information about the type of opportunities novice learners have had to experience geologic time. This is not meant to place blame on the funds for a learner's lack of experience with geologic time. Instead, identifying the funds along with the content knowledge that appears to be strong or lacking, can assist in prioritizing teaching the components of geologic time in terms of the events, timing, or both. Additionally, recognizing and using the funds can increase a sense of relatedness between the educator and learner by acknowledging and using the fund, and increasing feelings of competency in the learner.

Knowing that learners, Frankie and Mica, were drawing from History and A.P. Art History courses made their attempts to incorporate B.C./B.C.E. and A.D. more logical. Although the B.C./B.C.E. and A.D. are not values seen on the geologic timescale because of their vastly different scales and foci, knowing that learners are drawing on history courses as a fund, provides educators with more information as to how to address their conceptions about values and scale of time. Further, as the fund was explained to be a historical perspective and not necessarily a spiritual belief system, the conception may be easier to address as it is not questioning the learner's belief system. This is not to say it will be easier for the learner to understand. Instead, learners will have to comprehend a different scale of time than they are used to using in history courses. If the fund was a belief system grounded in a completely different scale of time for Earth's history, the conception may not be easy for the educator to discuss with the learner.

As this research shows, expert learners' funds were primarily from their university courses specific to their degree, research and teaching experiences, and external sources such as podcasts or journal articles. However, what this does not inform us is what expert learners used to support their learning during their undergraduate career. Were they participating in research as undergraduates? Did they do extra reading from journal articles? Were they listening to podcasts? If they answer to these answers was yes, it is indicative of the learner already knowing and wanting to be part of the geoscience community. The question then becomes, how can we support novice learners develop practices of the experts, while allowing them to decide if they want to be part of the community? Finding particular events of interest to novice learners in the classroom may assist in learners understanding geoscience practices, while incorporating their interests to engage their learning identities. Therefore, in order to best support learners' understanding of geologic time, as well as their identity or interest in the geosciences, it's important to understand the funds in which learners are drawing from to support their ideas.

Support for learners' developing identities into the geoscience community. University-level courses are designed to incorporate and provide learners with the experiences of being a member of the community through hands-on activities, labs, real data analysis, and geological cases studies and more. However, not every student enrolled in a geoscience course has chosen to become part of the community. It is important to try to understand the discourses, challenges and successes, and conceptions learners have in learning about the geosciences in order to understand where the learner is coming from and how they interact with the community to assist them in their understanding of the geosciences. These data have a double meaning as they are not only the conceptions learners have about events, assigned values, and scale of geologic time, but also include the discourses, including practices and language novice are familiar with, and how they are similar to and vary from those of the experts. These discourses indicate how learners engage with the geosciences and their identities associated with the geosciences as reflected through their engagement.

Scientific identity is important because it reflects how learners view themselves and who they want to become (Carlone & Johnson, 2007), as well as their funds of knowledge. Learners' speech, practices, and funds reflect learners' identities as well as express their identities in terms of their ways of knowing and doing in regard to the sciences, which was evident in the discourse analysis section of this dissertation. Knowledge regarding identities associated with the sciences allows us as educators to ask questions about the funds of knowledge, and to learn more about the unique set of "experiences, skills, knowledge, and beliefs" (p. 1189) and practices associated with the geosciences. According to Carlone and Johnson (2007), mathematics students that "engage in relevant disciplinary practices, begin to develop stronger mathematical identities" (p. 1189). Further, "if we view science as a community of practice into which aspiring members must be enculturated, it is essential that we understand how neophytes affiliate with, become alienated from, and/or negotiate the cultural norms within these communities" (p. 1189).

When learners feel they contribute and are supported, their learning increases (Cope et al., 2011). Science identities can be developed by how the individual makes meaning of their science experiences and how society structures possible meanings (Carlone & Johnson, 2007). Developing activities that are actively engaging, challenging, and include reflection, will result in more meaningful learning and increased student performance (Freeman et al., 2014; Bransford et al., 1993; Chickering & Gamson, 1987; Bonwell & Eison, 1991). Engaging activities that allow learners to partake in a range of experiences, practices, discourses, and knowledge that are relevant to the learning process, can develop stronger geoscience identities. As learners engage in geoscience practices, they can increase their competency and relatedness to the community.

Literature on motivation grounded in self-determination theory found that there are three psychological needs, autonomy, competency, and relatedness, that increase intrinsic motivation to learn (Niemiec & Ryan, 2009; Ryan & Deci, 2000). Autonomy refers to learners feeling a sense of control in their learning. An example of this could be allowing learners to choose a topic of interest for a paper. Competency refers learners' ability to complete a task successfully and relatedness refers to connections between teacher to student and student to student. Autonomy, competency, and relatedness increase intrinsic motivation. Strategies for improving autonomy include "providing choice and meaningful rationales for learning activities, acknowledging students' feelings about those topics, and minimizing pressure and control" (p. 141). Activities with autonomous structures allow for students to engage with their funds of knowledge and make meaningful connections to the topics as they will have choice in what they bring to the classroom discussion and can make connections to the knowledge they already possess. Strategies for improving competency include providing low-stakes formative assessments, early feedback, and "optimally challenging tasks" (p. 141). Emphasizing what novice learners do know to make them feel more confident and competent. Learners feeling as though they have competence in a particular area can increase their motivation on an activity (Deci & Ryan, 2000). Strategies for improving relatedness include conveying “respect and caring” for learners in the classroom (p. 141). For example, asking students about topics they are interested in the course and providing examples related to their geological, academic, and extracurricular interests and applying them as examples in class can increase their relatedness and motivation in the topic.

As there has been a deficit thinking toward novice learners in the sciences, the aspects of competency and relatedness are of utmost importance to undo deficit thinking that has occurred for so long. Emphasis on what learners know about topics to address any knowledge gaps can assist in developing a stronger sense of competency in novice learners. Creating engaging activities that involve these three psychological needs can increase learners’ motivation to engage with the topics and hopefully, build a positive identity with the geoscience community.

Standardized curriculum for undergraduate introductory geoscience courses. The structure and organization of education requirements for geoscience departments varies across the U.S. (Drummond & Markin, 2008). Geoscience departments in colleges and universities lack coherence of required courses, field camps, practices, and content. Coherence among geoscience departments has been a contentious issue as the incoherence is related primarily to variation in resources and curriculum among schools (Drummond & Markin, 2008). The “long-running controversy of disciplinary accreditation” adds to this incoherence, as there has been “no consensus for support or rejection” of this certification (Drummond & Markin, 2008, p. 113). Taking this one step further, there is no consensus on the purpose of introductory geoscience courses.

Introductory geoscience courses offer learners an overview of common geological foundational knowledge on concepts, Earth’s history, mineral and rock classification, and geological processes, for starters. Additionally, universities in the northeastern U.S. have different foci than universities in the southeastern U.S. as their geology around those areas vary. Although this variation allows for volition in learning, it lacks a standardization across universities as to the language, knowledge, skills, and practices learners receive in introductory courses.

Furthermore, introductory courses can serve the “dual purpose of satisfying general science requirements” as well as a gateway into the major (Drummond and Markin, 2008, p. 115). Although this dual purpose is seen across the sciences with chemistry, biology, and physics courses, there are two differences. First, these courses have curricular coherence across universities as to what topics will be covered in introductory courses. Second, the purpose is to provide majors within these fields with information necessary for their degree(s) first and foremost. Upper level courses in these science disciplines are built on the foundational knowledge presented in introductory courses.

However, the intention of these courses is to provide foundational knowledge to majors first and foremost, and then opened up to students taking the course for general requirements. As there isn’t a primary purpose and standardization of geoscience courses it is challenging to not only recruit learners into the field, but to also assist learners to develop science identities associated with the geoscience community. Hoisch and Bowie conducted a study in 2010, that showed out of “783 students surveyed in introductory geology classes and 23 geology majors in their junior and senior years, that only ~7% percent of students in introductory classes are possible candidates for recruitment” (p. 166). This does not mean all students within the seven percent choose to become majors or identify with the geoscience community.

Science identities reflect discourses, practices and language, required to develop successfully toward expertise. If the primary purpose is not to become majors but to gain an understanding of Earth's history, processes, and to become scientifically literate to make informed decisions to vote on contentious issues, how much of these discourses are novice learners intended to know? How are novice learners expected to identify in relation with the geoscience community? Clear discourses and content that novices should learn entering and exiting introductory courses should be established. Therefore, we need to determine ways to accept, address, and use the variance of geoscience disciplines to our advantage, and to increase learners' geoscience understanding and skills sets. A standardization and scaffolding of introductory-level courses could provide more intentional learning and development of practices, discourses, and experiences for learners to build expertise in the geosciences.

Implications for future research

While this study adds to the literature on expert and novices' understanding of geologic time, providing insight into how learners' think about scale and the funds of knowledge they draw on to think about geologic time, it also sheds light on gaps that need to be addressed in the literature. First, there is a lack of metacognitive studies focusing on the different ways experts and novices understand not only geologic time, but also its components, such as the events, organism classification, and processes. Second, as mentioned previously, further work on scale and duration needs to be conducted. While expert learners were able to provide a scale, and talk about events in detail, there was less discussion about the duration of time between events. This was seen with both experts and novices. Time constraints limited the amount of detail that could be spent on this portion of the activity, as well as limiting follow-up questions.

Third, further research into learners' funds of knowledge would be useful to the literature. As this research was only geared toward seven learners' understanding, representation, and discourse about geologic time, there wasn't a large sample size of funds to discuss.

However, discussing learners' funds was fruitful. All learners have funds of knowledge, but they tap into different funds to make meaning. It was important to show this and to learn the funds from which novices and experts drew. For example, two of the five novices discussed B.C./B.C.E. and A.D. when establishing assigned values and an initial scale. Both novice learners referenced history courses for this knowledge. Although the history courses were different, the same idea was presented and left these novices with confusion as to how B.C./B.C.E. and A.D related or fit into geologic time. Based on this study and the results of the pilot study, I would argue these are not the only learners with this dilemma. Knowing this information would allow an educator to incorporate these learners' ideas into the class curriculum and help them think through what the B.C./B.C.E. and A.D scale is and where that would fall in geologic terms. Therefore, the funds of knowledge help to not only contextualize the learners' ideas, but provides implications for interdisciplinary curriculum development.

Finally, alternate conceptions literature focuses heavily on the processes of geologic time. Process-focused alternate conceptions did arise in this study, such as thinking that if an asteroid hit the Earth, the continental crust will break up and float apart. This example indicated an alternate conception that viewed continental crust as floating on molten lava. This conception ignored the mechanisms that drive plate tectonics. However, the alternate conceptions brought up in this research were not always process-driven. For example, without having learners discuss their reasoning for event ordering and placement on the model, it would not have been clear that multiple learners struggled with classification of organisms at the Kingdom level. Therefore, it was clear that learners, novices specifically, need more opportunities to learn the content and support with Kingdom-level organism classification and relationships to one another.

Limitations

The model

The model itself is a limitation. Scale models are physical representations of an object or system that have accurate relationships aspects because their scale is 1:1. For this research, that meant that no matter what was used to mark event placement, scale card placement, or assigned values, there would always be error. In turn, this meant that the learners, no matter how close they were with event or scale card placement, would always place a card with error. A straw was used to assist the learner's placement on the model. However, the diameter of the straw was 0.6 centimeters, there was an error of 6 million years. Even if a toothpick was chosen, accuracy would be increased, but error would still exist as the width of the toothpick could still be measured to represent a value of time on the model.

Tools for the model: event cards and scale card use

Event cards. The events used were chosen based on what the researcher and various professors in the geosciences, chemistry, and biology department viewed as most important for learners to know. The researcher was told to use the scales represented in textbooks or posters in the department. This resulted in a Phanerozoic-focused Earth history. Expert learners found difficulty with this representation as their courses and research at the university focus primarily on events prior to the Phanerozoic. Therefore, examining novice and expert learners can result in a gap of knowledge, as the foci of the novice and expert courses do not align. However, it was still useful to examine how experts engaged with events outside of their discipline. Adding events into the activity would result in shallow representation of learners' models.

Currently, the timescale activity has 20 event cards with a task-based interview and took approximately 45 minutes to one-and-a-half hours to complete. Too many event cards would result in the activity being too long and focused on simply the temporal ordering and relationships portion of the task, and less time spent on the spatial aspect of the task. Work on previous timescale events with only four event cards seemed to be too few event cards and does not prove to examine students understanding of relationships between events *through* time and where they are placed in absolute time. Therefore, the addition of events prior to the Phanerozoic did not seem wise. Additionally, as professors were interviewed about the events they deemed most important, the researcher was provided an understanding of what students are expected to know entering the university and by the end of the course, as well as what events should be the basis of the activity.

Event card names and images. There were limitations to event card names and images. First, the names of event cards could be misinterpreted. The *trace fossil/first evidence of life* card was the most challenging card. The event card was intended to represent the first traces of life by cyanobacteria and meant to tie into learners' ideas regarding early life, oxygenation, and photosynthesis on Earth. For the most part, learners discussed the event card in this manner. However, the term *trace fossil* did affect the ways in which expert learners interpreted the event card, and therefore, affected their placement of the event card. The terminology *appears on Earth* was also used to be inclusive of all learners, but specifically those with views that might align with Early-Earth creationist views to encourage participation. However, learners did not express difficulty with the use of this terminology.

Images for event cards, such as *photosynthesis begins on Earth* and *trace fossil/first evidence of life* provided a narrow view of the card. Images on event cards were intended to get learners thinking about the topic and to retrieve any memories associated with the name on the event card. *Photosynthesis begins on Earth* had a picture of a tree with the cycle of photosynthesis occurring, which could be interpreted to represent only photosynthesis from plants, not including oxygenic photosynthesis. The difference being that oxygenic photosynthesis can come from terrestrial plants or oxygenic photosynthetic bacteria (cyanobacteria). However, an image of a tree may limit or skew the way learners' thought or planned to use the card.

Trace fossil/first evidence of life had an image of a trace from an organism on the card. The intent was first evidence of life, but by giving an image of a bacteria associated with early life, the learner would be given a direction by which they needed to think and discuss. However, the trace fossil image might be associated with organisms that came later in Earth's history (e.g. closer to *present day* and representing more developed organisms). As it was a qualitative study, learners were able to discuss how they used the event card and their reasoning for placement. The card was still challenging to learners because of the image and name, and was interpreted differently by each learner. In the future, images and names of event cards would be made clearer to reduce the discrepancy of their use.

Scale cards. A limitation to scale card use was the lack of intended use. During the pilot study, novice learners were displayed anxiety when prompted to assign values to the model. As the assigned values provided a clear idea of the values that learners thought of in terms of time, the researcher didn't want to lose that. Scale cards were created to ease learners' after having provided their own values. Providing a range of scale cards was also intended to assist learners with the scaling and rescaling of their models. However, instead of being used to rescale the model, scale cards were used to match the values or scale learners had already established. This was not a problem with the expert learners as much as it was the novice learners. Expert learners had already created a scale and reasoning for its use. Novice learners tried to align their assigned values to the scale cards values, but did not provide detailed reasoning for use and placement of the scale cards. Scale cards were irrelevant to the model, because of the alignment to the assigned values. In addition, none of the novice learners expressed using the distances on the scale cards to assist them in thinking about the lengths or durations of time.

This study has opened the door to understanding expert and novice learners' representations of geologic time, but increased the number of questions about novice learners' understandings of scale and duration. It was unclear whether learners attributed a better understanding of scale based on the distance images provided on the scale cards. Further, it has established areas that need development in terms of wording and images on the event and scale cards for future work. As the sample size was low, the results are not adequate to represent the entire population of introductory students entering the university. Additionally, as intermediary learners did not participate in the study, it was unclear how learners developed successful practices for understanding time. However, it does indicate the wide range of knowledge learners possess that educators will need to acknowledge in order to address alternate conceptions or assigned values from various funds of knowledge.

Generalizability

Participants: Convenient samples and volunteer basis. As the samples were convenient samples, results of the study may not be representative of a population (Marshall, 1996). However, learners that participated in the study aligned with the type of learners the research focus was intended to examine. Additionally, selection of participants was on a volunteer basis. Participants that volunteered may not represent the entire population, but possibly the extremes of the class. The term *extremes* refer to the learners that always participate in class and are confident in the material, or may be students that hoped to get extra help to boost their grades. As was seen in the demographic survey, all of the novice learners participating in the study were obtaining extra credit for completing the study.

Additionally, very few expert learners participated in the study. Many expert learners did not have time to allocate to the study outside of their research and teaching responsibilities, and therefore were unable to participate. Although similarities and differences in the strategies presented by the expert learners, the ability to generalize results of the expert population would be difficult. Furthermore, the study lacked representation of learners that were in the intermediary category of their learning. In other words, the study had novices and experts only, but learners transitioning between novice and experts, such as undergraduate majors, were not represented. The intermediary group is important as it would have allowed the researcher to gain an understanding regarding ways of knowing and doing in terms of content and scale knowledge, as well as discourse improvement with practices and language. This could provide information on geoscience skill development with regard to learning and teaching geologic time.

As research was conducted at one university in one state in the U.S., it would be difficult to generalize the novice and expert populations from this university to represent students across the country. The research foci of large research universities vary and therefore, experts research experiences and teaching foci would also vary. Although experts are expected to have particular knowledge and discourses to be part of the geoscience affinity group, expert learners' specific interests by discipline shape the depth of knowledge they convey, as evident by this study.

Sample size. Non-major undergraduate learners were from one of the introductory geoscience courses offered at a private university. There was not enough time to examine students from all of the introductory courses. Introductory course at this particular university can contain 80-200 undergraduate students. As the activity took approximately one-hour minimum to complete, there was not enough time to gain representations, conceptions, and discourses from a range of students from each introductory-level course. There would have been far too many factors to control for, such as if one course goes more in depth about time than another, laboratory activities that focus on events in time more than one another or emphasizes the relationships between events more than another course.

As the sample size was low, there are issues with generalizability of the study. For a very detailed study, such as this one, a small sample size was appropriate as it provided rich data and answered the research questions in depth. Focusing on the representations and conceptions of a single student as representative of an entire group would not be meaningful, as that is a “complex and multifaceted endeavor” (Chick, 2013, p. 27). What is meaningful from this study regardless of generalizability, is the wide range of conceptions that learners have about the events in time and their relationship to one another, learners’ ideas about when these events occur in geologic time, and the disconnections learners had about scale, that could be revealed through a study with a smaller samples size and more time with each learner. A study with more learners would have resulted in gathering information from surveys about their conceptions, where data may be incomplete, lacking detail, or ambiguity in the text that the researcher would need to decipher without any context or clarification (Chick, 2013).

This research has four main strengths: 1) insight has been provided into the similarities and variations in learners’ thinking across a continuum from novice toward building expertise; 2) the implications of the similarities and variations in learners’ thinking brings awareness to geoscience educators about the types of conceptions (e.g. specific events that appear to challenge learners, the funds of knowledge that affect student learning, the range of assigned values attributed to events, and the way that learners’ think about scale); 3) the influence that funds of knowledge has on learners has been presented, and will hopefully be incorporated into practice by educators to make learning meaningful to the range of diverse students in their classrooms; and 4) both novice and expert learners can be viewed in as possessing competent ideas and logical reasoning.

Points one and two are important because awareness means that pedagogical approaches can be developed to further delve into learners' ideas about geologic time, reveal their thinking processes and schema, and hopefully, to assist learners to construct or reconstruct their representations. This is easier said than done as learners across a range of ages hold conceptions about geoscience topics that instruction has been unable to address thus far (Cheek, 2010). Additionally, problems with spatial and temporal scales are seen across disciplines, not just the geosciences (Cheek, 2010). Points three and four are important because the literature has often focused on what students do not know, rather than what they do know. The ability to address particular funds of knowledge learners draw on can improve understanding of conceptual thinking in the geosciences (Cheek, 2010), and across disciplines, by improving the links between funds of knowledge and classroom discourses.

Interview biases and questions. Although richness of data is a strength of interview data, there is "always a danger of bias of inconsistency and bias" with the interpretation of interview transcripts (Cheek, 2010, p. 363). All of the data was analysis was conducted by the researcher on the project, which could result in questioning the significance of the interpretation. Data and interpretation of data was discussed with various members of the researcher's department and committee members in an attempt to alleviate interpretation biases.

Further, follow-up questions into student thinking during the task-based interview may not have gained as in-depth information as the researcher had wanted. The researcher contacted learners after participating in the activity for clarification after the task-based interview, however, the reasoning provided was not as descriptive as it had been during the activity. For example, novice learners' ideas about scale were pretty open. They explained that there was a certain point where they did not know how to rescale the activity, but didn't describe further why they felt they would be unable to scale the model or what they felt they need to be able to rescale the model. Additionally, there is the added danger of creating leading questions (Cheek, 2010; Johnson & Gott, 1996). Although the researcher attempted to ask broad questions or would state that they were trying to clarify, the learner could try to adjust their response to what they thought would prompt a *correct* answer.

Discourse analysis

There is not one single science identity that learners need to achieve. Identity is fluid and not fixed, meaning that a person's identity can cross time and contexts, as well as the ability to change and develop (Carlone & Johnson, 2007). This study catches a glimpse of novice and expert learners at a single point in their academic careers related to the geosciences. Their ability to think about and represent geologic time can change. Their discourses and identity associated with the geosciences can change. Therefore, the findings of this study represent the novices as they enter the classroom and the expert learners at the end of their graduate career. As both novices and experts progress in their education, jobs, and daily life, their discourses, practices, and identities will also evolve as they establish a "sense of who they are and who they want to become" (Carlone & Johnson, 2007, p. 1189).

Additionally, there are many ways of doing and ways of knowing in the sciences. Therefore, "there are many ways of being a "science person"" (p. 1212). However, as there are certain discourses, specifically, certain practices and language that Earth scientists use, this study worked to identify and examine the ways in which novice and expert learners used these discourses. Thus, the arguments made toward discourses and identities was defined by the ways in which the novices and experts employed these discourses.

Future Research

The questions raised by this study and its limitations suggest avenues for further research. First, the timescale activity could be modified in various ways. The event cards for *trace fossil/first evidence of life* and *photosynthesis begins on Earth* could be adjusted to be clearer for learners to understand. As stated in the limitations section, the images for these two cards made it difficult for learners to associate with different parts of the timescale. Additionally, the timescale activity was based on discussions with faculty in a geoscience department to gather information about the events they expected novice learners to know entering their classrooms. The view of Earth's history was very Phanerozoic-focused. However, novice and expert learners demonstrated a better understanding of events deeper in time. Although this assisted with identification of the events learners had difficulty with, experts expressed that these are not the primary events covered in their courses, teaching, or research. Therefore, although conceptions about the scale and temporal ordering of Phanerozoic-focused events were gained, novices working toward gaining expertise in the geosciences at this particular university would not be experiencing the same material as expert learners, making it difficult to compare the knowledge what they know about the topics and how they know this material. Therefore, more events in deep time could be added to compare how novice and expert learners' ideas regarding deep time relate.

Second, questions about learners' views of their identity could have been added into the interview. Learners' identities were analyzed based on their practices, language, use of hedges, and funds of knowledge. Although these aspects can be used to reflect group affiliation and membership (Brown, 2004), it would have been beneficial to ask novice and expert learners how they viewed their relationship or membership with the geoscience community.

In addition to research on university-aged learners' conceptions about scientific phenomena and their spatial thinking, this dissertation has led me to think about the discourses and identities associated with scientific classrooms and communities. As a result of this study, I have a better understanding of the ideas learners enter the classroom with after leaving the K-12 system and the ways in which learners negotiate their participation and identities associated with the geoscience community.

The combination of discourse analysis and phenomenography were complementary for this study. These approaches would be useful to gain more insight into learners' understanding of other geologic processes, as well as use in curricular and instructional improvement and advancement. Phenomenography is rarely used in geoscience education research (Stokes, 2011). However, as it is an approach that allows research to gain insight into learners' perceptions and conceptions regarding phenomena, as well as strategies employed during learning, it has implications for curriculum design and instruction (Stokes, 2011). Understanding "not only the *what* students know, but the different *ways* in which they know or understand" (p. 23), can assist with design and development of teaching practices, learning activities, and changes in curriculum to meet learners' needs, as well as to gain insight into conceptual change during a course or an academic degree (Stokes, 2011). The approach is flexible and would be well-suited for application to a wide range of geoscience inquiries in the higher education setting (Stokes, 2011).

To further this research, I would like to apply certain aspects of this project (e.g. discourse analysis of practices and language) of the intermediate group of learners between novices and experts. Although novices and experts provide the two extremes of the spectrum for learning in the geosciences, there was a missing link between development of practices to support learning geologic time, which was the learners that are building toward expertise in the geosciences. Additionally, it would be beneficial to extend this study to other aspects of the geosciences that require spatial thinking to understand how we can better support novice learners to develop practices to work with abstract ideas in the geosciences. Identity and funds of knowledge "open a new way of viewing teaching and the science learning environment" (Carlone & Johnson, 2007, p. 1189). The ability to actively engage and involve learners' identities and funds of knowledge learners has the potential to develop more equitable and inclusive approaches to instruction, and meaningful learning.

Appendix A

Sample questionnaire

1. Name _
2. Age _
3. Department _

   Major(s)_

   Minor _

4. Gender _

5. What science course(s) have you previously taken?

High School:

College:

6. What mathematics course(s) have you previously taken?

7. Have you ever had any experience or exposure to the geologic timescale?
8. If yes, when? And how did you learn about it?

9. Why are you participating in the study?/What do you hope to gain from this study?

Appendix B

Sample interview questions

Most of the questions were on the spot and geared toward learners' strategies for event and scale card placement on the model, how they used the scale cards, and how they assigned values to the model, as well as their reasoning for these strategies. The first question leads the entire interview. The rest of the questions were dependent upon how the learners ordered their models and the reasoning provided (i.e. what the learner brought up in discussion about how the events relate (or do not relate) to one another). Learners typically began discussing how they ordered the event cards on the model and relationships between events. Questions 2, 3 and 4 are repeated to keep the participant talking about event ordering and relationships. Below are the sample questions that were discussed during the first part of the activity. Questions 4-8 may be used at the end of the interview to gain a better understanding of how participants think the geologic timescale is structured.

Questions to guide the event card sorting task:

1. What was your strategy for placing the event cards in this order?
2. How did you decide to place this card first?/How did you decide to place this card (name of the card) next to this one (name the card)?
3. What prompted you to place these cards near each other?
4. Ask clarifying questions to learners' reasoning based on questions 2 and 3.
5. How do you feel about the way the event cards are currently ordered? If learner indicates they are okay with their model as is, move to 6. If no, have participant adjust the event cards they are concerned about and begin questions one through four again.

During the second part of the activity, participants will be asked to explain their strategy for their choice of values placed on the model

6. What was your strategy for establishing these values of time?
7. What made you choose (value of time) for (specific event)?
8. How did you decide your next value?
9. How much time is represented in these intervals between events?
10. Are all of the intervals of this size the same value?
11. After going through all of the values, are you satisfied with your times as they are right now? If yes, move to question 16. If no, participant will rearrange or write new values of time.
12. Would it be easier for you [learner] if I provided a value of time? (participant usually says yes), research assistant places "0 Years" at the end of the timescale with *present day* marker and "4.6 Billion Years" at the end of the timescale with *Earth's formation*.
13. How do you feel about your current values of time? If learner indicates they are okay with their model as is, move to 18. If no, have participant redo the values of time and begin questions 6-13 again.

Questions to guide the final card-sorting task where cards represent scale

14. What was your strategy for placing the scale cards in these particular places?
15. How did you decide to place this particular value here on the timescale? (go down the timescale and ask this and follow-up question until the timescale is finished)
16. How do these cards measure up to the values of time you previously used?
17. What was your experience using the scale cards versus writing out your own values of time?

Appendix C

Discourse analysis symbols

Symbol	**Meaning of the symbol**
Name	Pseudonym
wor-	Truncated; self-interruption; break in the intonational unit
.	Terminative; end of intonation unit; falling intonation
,	Continuative, pause less than 0.5 seconds; end of intonation unit; fall-rise intonation
…	Pause for greater than 0.5 seconds
[ ]	clarification from the researcher; filling in a statement or description for clarity
(…)	break in the statement that removes information not pertinent to the explanation
(Numbers)	Timestamp; Example (20:01)
(*italicized word*)	Movement, gesture, or body language; Example: (*laughs*)
(non-italicized word)	Researcher's comment indicated by OC
OC	Observer comment (in this case, the researcher)

Appendix D

Individual learners' models

Key to the model:

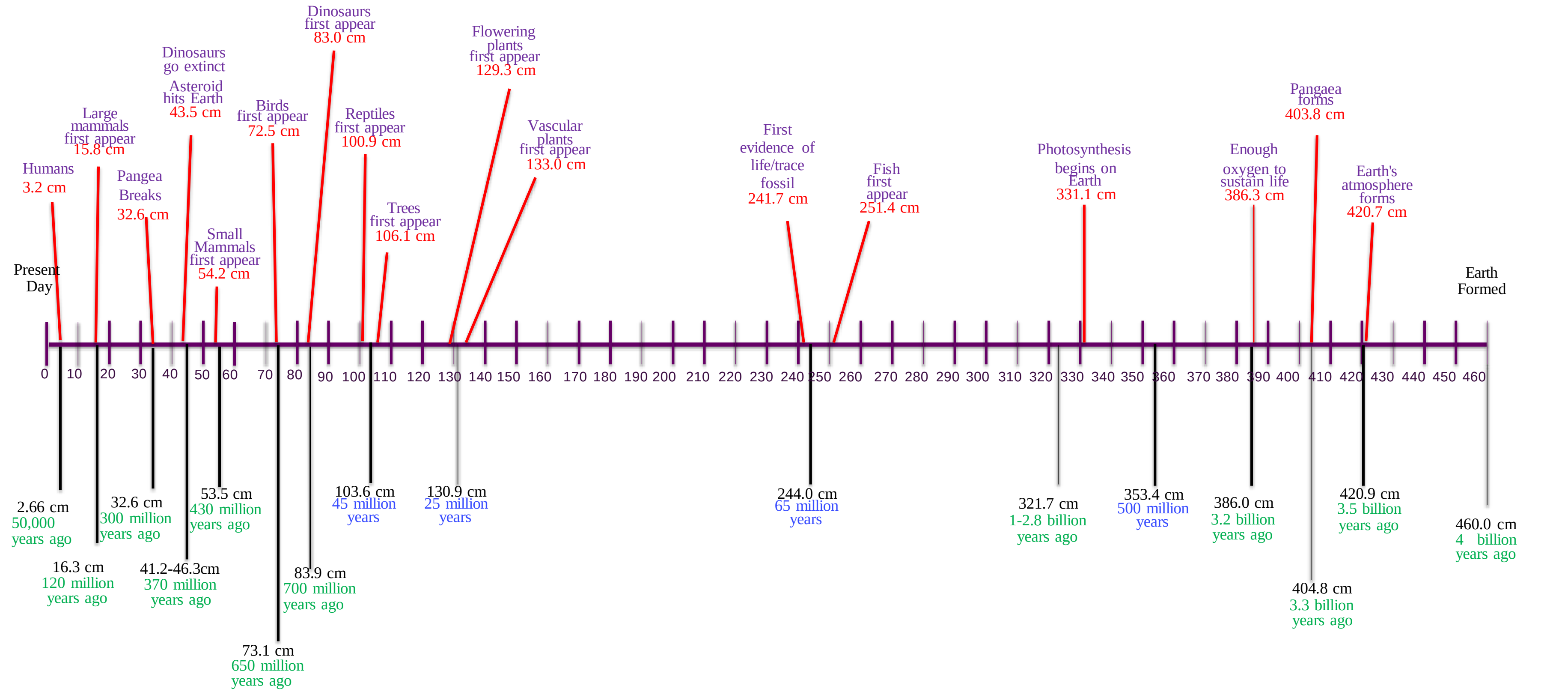
Purple = Event cards
Red = Measurements of learners' event card placement
Green = Learners' original numerical values
Orange = Secondary numerical values
Blue = Scale card values
Black = Measurements of scale card placement

Novice learners will be presented first, followed by the experts

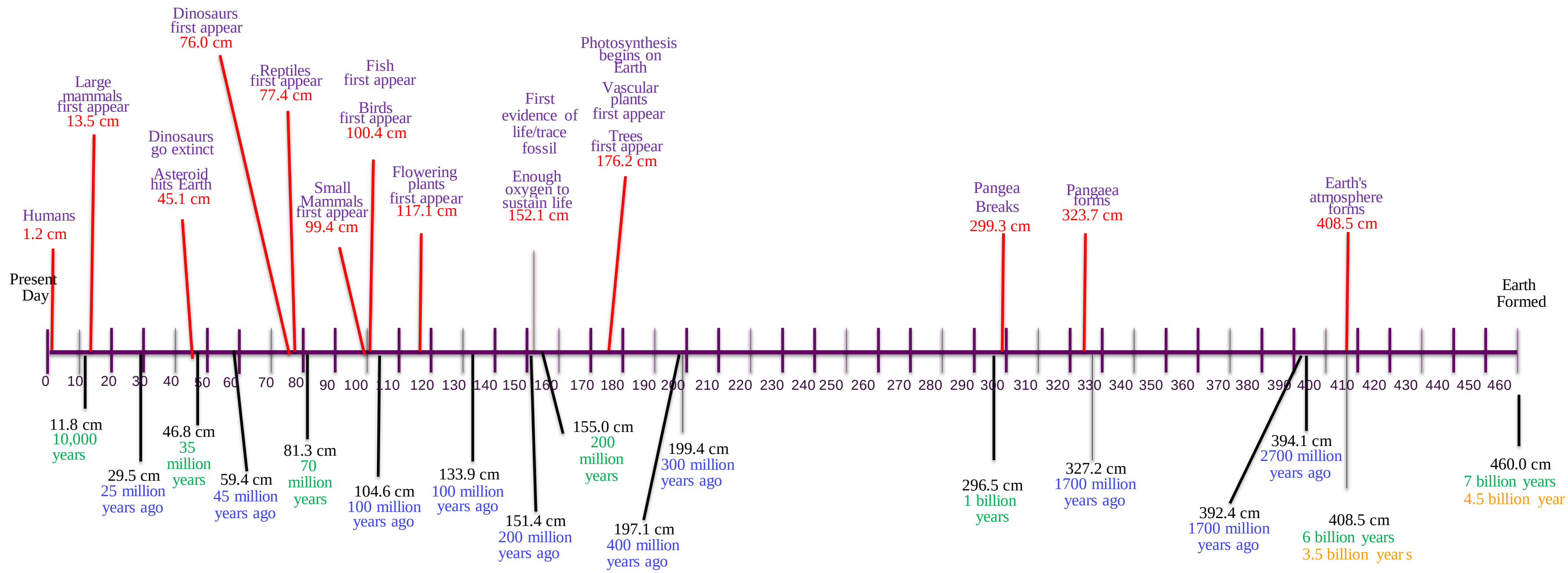
Novice learners: Harper, Taylor, Frankie, Cameron, and Mica

Expert learners: Alex and Jayden

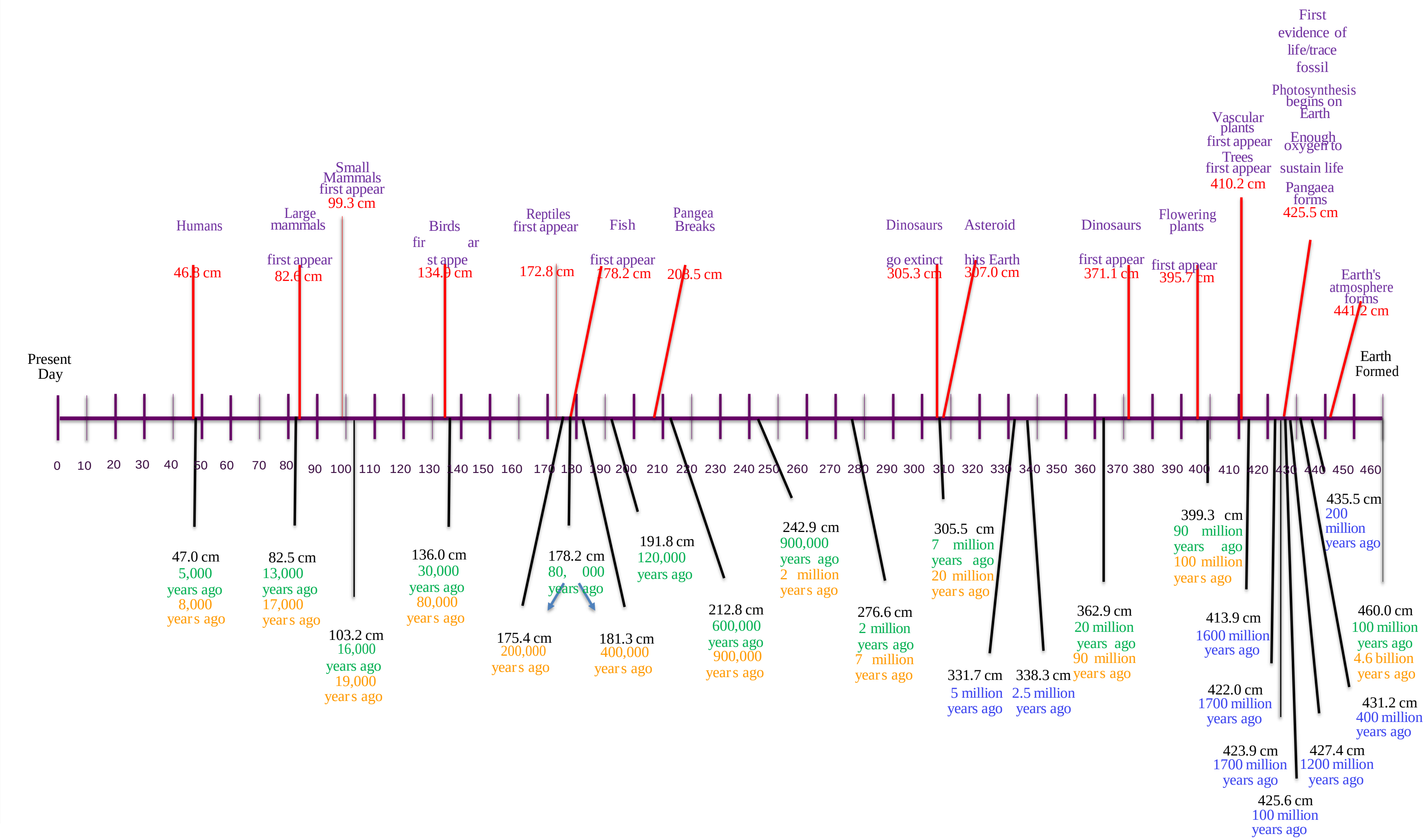
Harper, novice learner



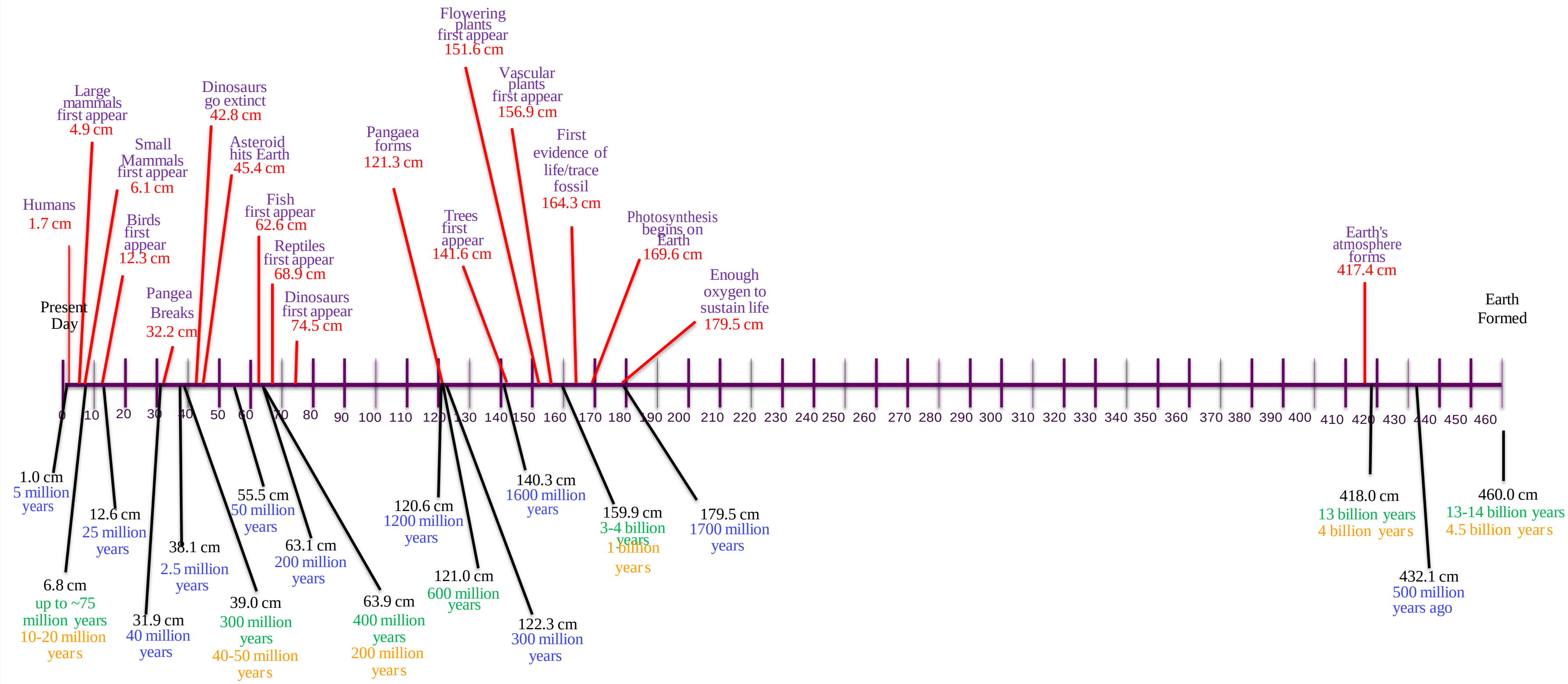
Taylor, novice learner



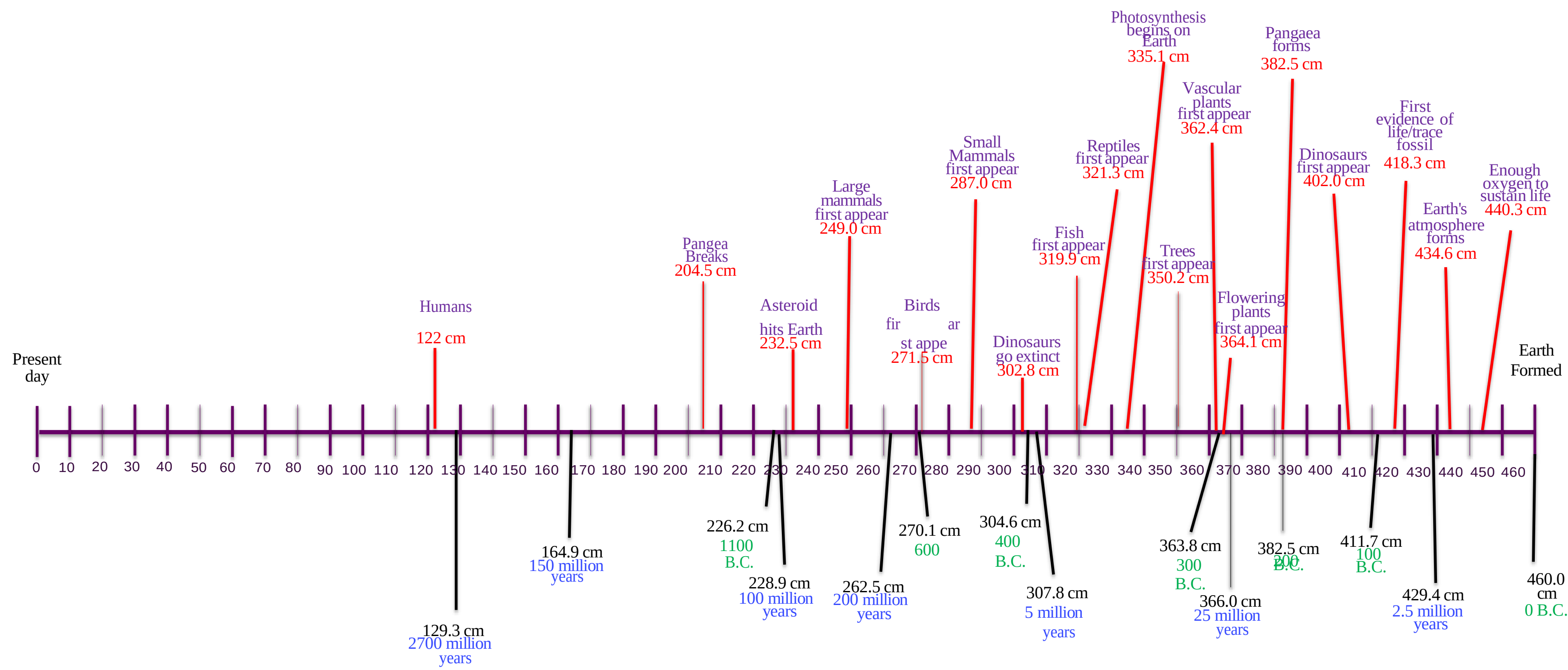
Frankie, novice learner



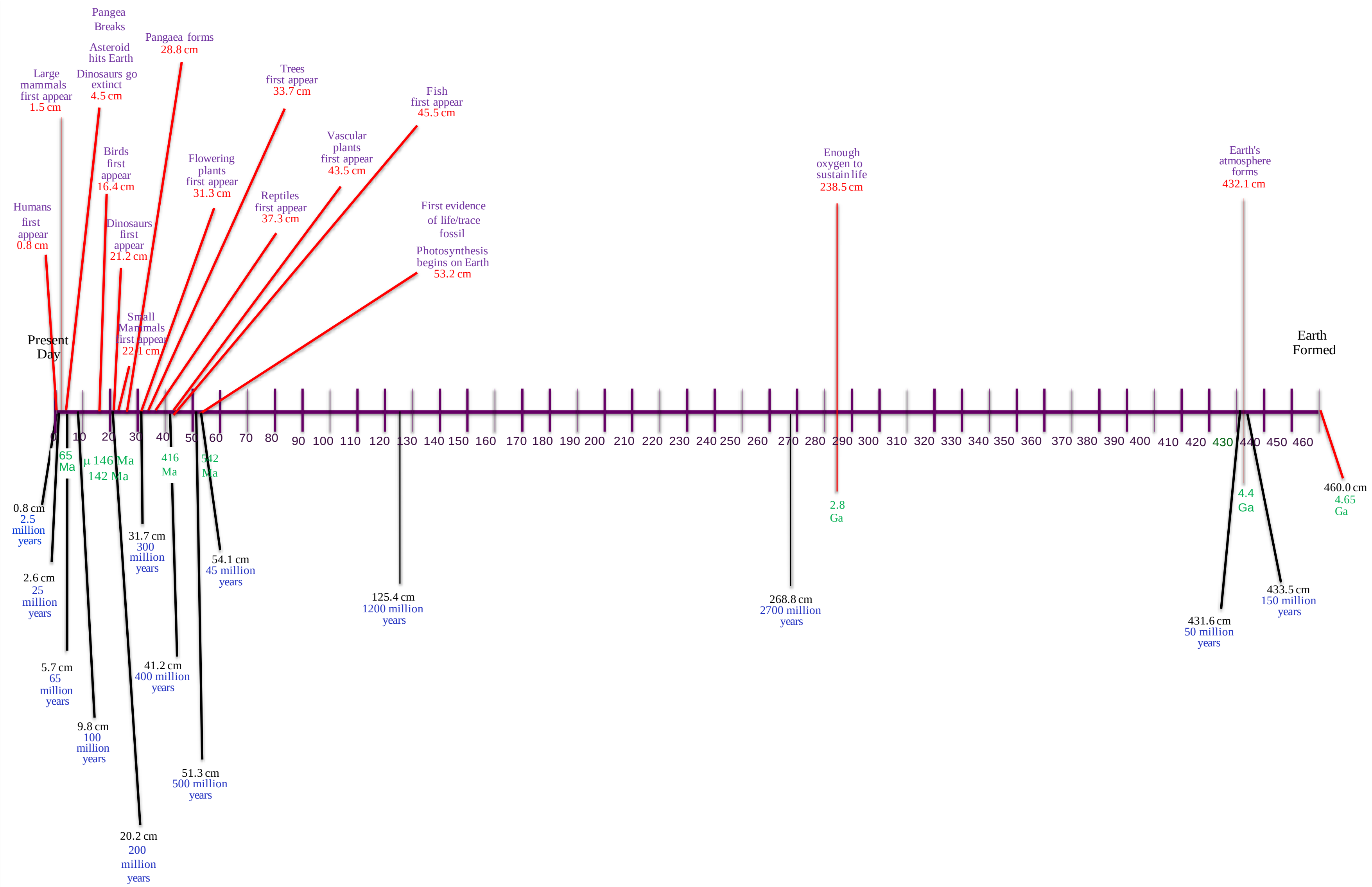
Cameron, novice learner



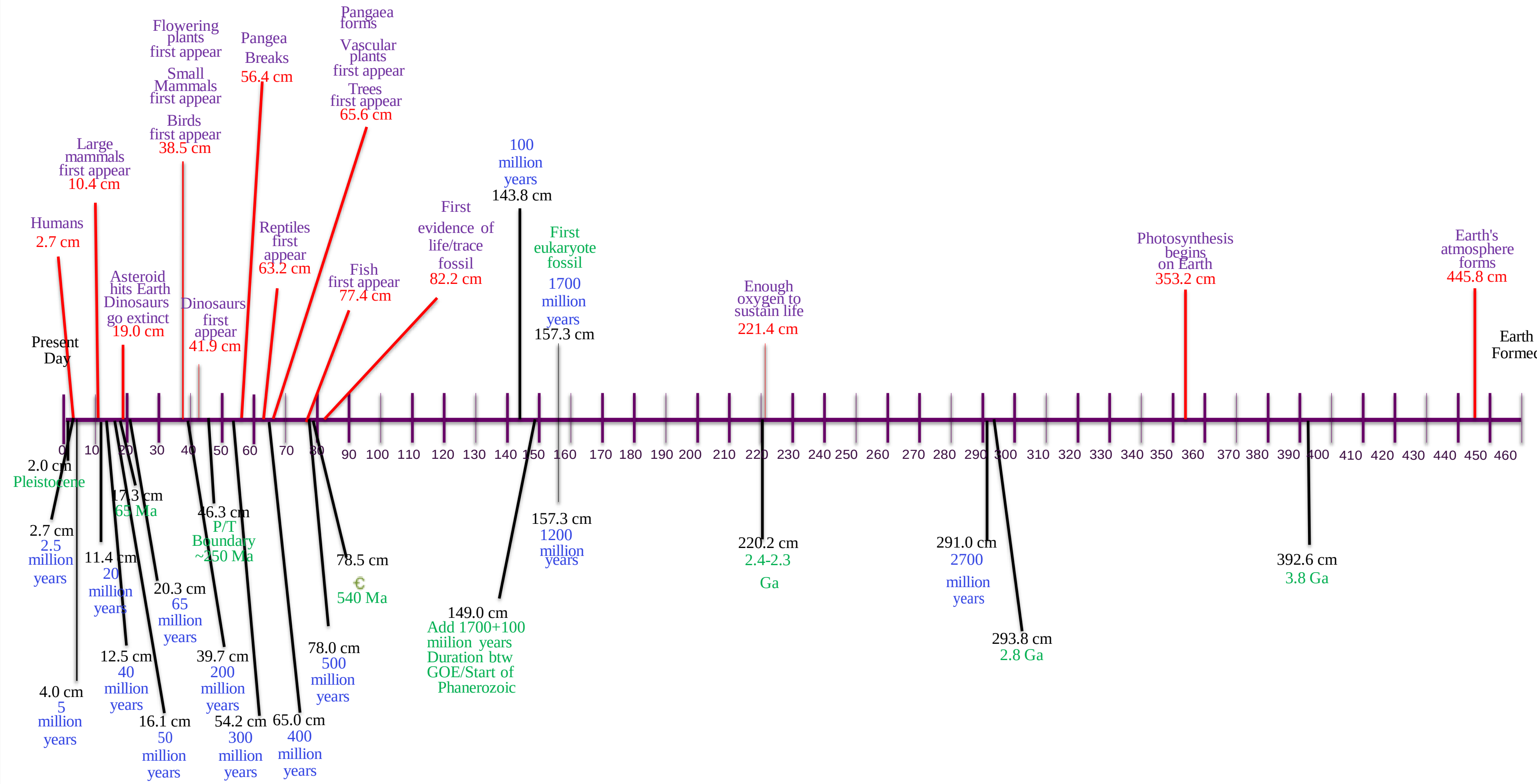
Mica, novice learner



Alex, expert learner



Jayden, expert learner



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EDUCATION AND EMPLOYMENT

Syracuse University, Syracuse, NY 13244
Doctoral Candidate, College Science Teaching (expected graduation: May 2017) — August 2013-Present
Master of Arts in Earth Sciences — August 2011-May 2013

Columbia University, School of Continuing Education, New York, NY
Post-Baccalaureate Program — September 2010-May 2011

Gemological Institute of America (GIA), New York, NY
Diamond Research Associate — September 2008-August 2011
Safety Committee Officer — June 2010-August 2011
Graduate Gemologist Program — October 2008-January 2010
Graduate Gemologist Certificate
Graduate Pearls Certificate
Accredited Jewelry Professional Certificate

Royal Holloway, University of London, United Kingdom TW20 0EX
Junior year study abroad: Joint Honors Program: Geology and Geography — September 2006-June 2007

Mount Holyoke College, South Hadley, MA
Bachelor of Arts, with Honors; Double Major in Geology and Geography — September 2004-May 2008

GRANTS AND AWARDS

Outstanding Teaching Assistant Award — April 2016
G&G 2012 Dr. Edward J. Gübelin Most Valuable Article Award: First Place — April 2013
Royal Holloway, University of London: Award for the Best Fieldwork — June 2007
Mount Holyoke College: Leadership Award, S.M.A.R.T. Grant — September 2004

TEACHING

Instructor
College Teaching Workshops, EDCI 589, Curriculum and Instruction — September 2016-Present
Quests and Questions in Physical Phenomena I, SCI 104, Physics — September 2015-December 2015; September 2014-December 2014
Quests and Questions in Physical Phenomena II, SCI 105, Chemistry and Physics — January 2015-May 2015; January 2016-Present
Pedagogical Strategies in Teaching Undergraduates — January 2015
History of Earth and Life, EAR 102 — September 2012-December 2012

Teaching Assistant/Laboratory Instructor

Quests and Questions in Physical Phenomena II, SCI 105, Physics, Professor: Dr. Sharon Dotger	January 2014-May 2014
Environmental Geology, EAR 106, TA Coordinator, Professor: Dr. Laura Lautz	January 2013-May 2013
Introduction to Paleobiology, EAR 325, Professor: Dr. Linda Ivany	January 2012-May 2012
Dynamic Earth, EAR 101, Professor: Dr. Scott Samson	August 2011-December 2011
History of Life, Professor: Dr. Mark McMenamin	January 2008-May 2008 January 2006-May 2006
Planet Earth, Professor: Dr. Melinda Darby Dyar	January 2006-May 2006

Guest Lecturer

Mount Holyoke College, *Gem Identification and Spectroscopy*	July 2015
Mount Holyoke College, *Diamonds: Detecting Natural, Treated and Synthetic Stones*	October 2011

RESEARCH EXPERIENCE

Instructional Developer, Purdue University, West Lafayette, IN	July 2016-Present
NSF Robert Noyce Scholars Program Director, Syracuse University, Syracuse, NY	May 2014-December 2015
NSF Robert Noyce Scholars Program, Summer Research, Graduate Assistant, Syracuse University, Syracuse, NY	May 2014-August 2014
NSF Robert Noyce Scholars Program, Graduate Assistant, Syracuse University, Syracuse, NY	September 2013-May 2014
Research Associate and Pearl Gemologist, Gem Identification, GIA New York, NY	September 2008-August 2011
Safety Committee Officer, GIA New York, NY	June 2010-August 2011
Monograph Premium Service Member, GIA New York, NY	May 2009-August 2011
Mössbauer Research Laboratory, Mount Holyoke College	July 2007-August 2008
Keck Geology Consortium, Gore Mountain Garnet Study, Union College, NY	June 2007-July 2007
NSF Research Experience for Undergraduates, University of South Florida, Tampa, FL	May 2006-July 2006

DISSERTATION AND UNDERGRADUATE THESIS

Graduate Dissertation, *How do learners understand, represent, and discuss geologic time?*	September 2015-Present
Undergraduate Thesis, *Oxidation State of Iron in Garnets*, Honors	September 2007-May 2008

PUBLICATIONS

Dotger, S., Orado, G. & **Emerson, E.A.** (2016) Making Student Thinking about Magnetic Forces Visible in the Classroom: A Lesson Study Case. In preparation

Darby Dyar, M., Breves, E.A., **Emerson, E.A.**, Bell, S.W., Nelms, M., Ozanne, M.V., Peel, S.E., Carmosino, M.L., Tucker, J.M., Gunter, M.E., Delaney, J.S., Lanzirotti, A., & Woodland, A.B. (2012). Accurate determination of ferric iron in garnets by bulk Mossbauer spectroscopy and synchrotron micro-XANES. *American Mineralogist*, Vol. 97, pp. 1726-1740. (Thesis)

Wang, W. Doering, P. Tower, J. Lu, R. Eaton-Magana, S. Johnson, P. **Emerson, E.** & Moses, T. (2010) Strongly Colored Pink CVD Lab-Grown Diamonds. *Gems & Gemology*, Vol. XLVI, Spring 2010, pp. 4- 17.

Wang, W., D'Haenens-Johansson, U.F.S., Johnson, P., Moe, K.S., **Emerson, E.**, Newton, M.E., & Moses, T.M. (2012). CVD Synthetic Diamonds from Gemesis Corp. *Gems & Gemology*, Vol. 48, No. 2, Summer 2012, pp. 80-97.

Emerson, E., Johnson, P. & Win, W. (2009) Bicolor Diamond. *G&G*, Vol. 45, No. 2, pp. 134-135.

Emerson, E. (2009) Hydrogen Cloud with Etch Channels. *G&G*, Vol. 45, No. 3, pp. 209-210

Emerson, E., & Johnson, P. (2009) Colorless Petalite and Pollucite from Laghman, Afghanistan. *G&G*, Vol. 45, No. 2, pp. 150-151.

Darley, J. **Emerson, E.** & Johnson, P. (2009) Octahedral diamond with Stellate cloud

Emerson E., & Darley J. (2010) Chrysocolla chalcedony form Acari, Peru. *Gems & Gemology*, Vol. 46, No. 2, pp. 148-149.

Emerson E., & Darley J. (2010) Tsavorite and other green garnets reportedly from Afghanistan. *Gems & Gemology*, Vol. 46, No. 2, pp. 154-155.

Emerson E., & Wang W. (2010) Interesting Display of the H3 Defect in a Colorless Diamond. *Gems & Gemology*, Vol. 46, No. 2, pp. 142-143.

Emerson E., (2011) Coated Black Diamond. *Gems & Gemology*, Vol. 47, No. 3

Darley, J., & **Emerson, E.** (2011) Hemimorphite from China. *Gems & Gemology*, Gem News International

Hollocher, K., Stack, K., **Emerson, E.** & Denny, A. (2008) Petrology of Big Garnet Amphibolites, North Creek–Warrensburg Area, Adirondacks, NY. Geological Society of America *Abstracts with Programs*, Vol. 40, No. 2

Lavarreda, A. **Emerson, E.**, Herbert, G., Harries, P., Oches, R. & Portell, R. (2007) Developmental Basis of size decrease in *Turritella* gastropods during a regional mass extinction in the Plio-Plesitocene of Florida. Geological Society of America, *Abstracts with Programs*, Vol. 39, No. 2, p. 84.

Emerson, E. (2008). Analysis of Iron Oxidation in Garnets. Adirondack Project, Keck Geology Consortium Undergraduate Research Symposium, Vol. 21, p. 140-141.

RESEARCH CONFERENCE PRESENTATIONS

Tillotson, J.W. & **Layow, E.A.** Preparing Effective STEM Teachers for High-Needs Schools: Assessing the Impact of Noyce

Professional Development Experiences on Beginning Teachers' Beliefs and Practices. Paper accepted to the International Conference of the Association of Science Teacher Educators, Portland, OR, January, 2015.

PROFESSIONAL ASSOCIATIONS

Association of Science Teacher Educators (ASTE)	October 2014-Present
Sigma Xi	May 2008-Present
Sigma Delta Epsilon: Graduate Women in Science (GWIS) Kappa Chapter	November 2010-Present
Paleontological Society of America	November 2010-Present

UNIVERSITY SERVICE

Future Professoriate Program (FPP)	September 2014-April 2016
Certificate in University Teaching	September 2014-April 2016
Teaching Assistant Orientation Program (TAOP):	August 2014-Present
Teaching Mentor and Orientation Facilitator for Incoming Teaching Assistants	August 2014-Present
Seminar Series: Teaching to Non-Experts: Good Questions and Student Thinking	February 2016
Seminar Series: Teaching in the STEM Disciplines: Good Questions and Student Thinking	October 2014
Seminar Series: Passing Midterms and Racing towards the Finish Line: End of the Semester Issues Facing TAs	October 2014

Lesson Study, Research Lesson on Conservation of Mass September 2014-December 2014

SKILLS

Computer

- Software: Blackboard, Myslice, Windows Software, PC and Macintosh experience, Adobe Photoshop and Illustrator, MS-DOS, Microsoft Word, Excel, Power Point
- Mössbauer Software: Ghent, Mexfieldd and disd3e graph-fitting software
- XANES Software: X26A, PAN data processing program
- Grams data processing and graph fitting software
- Minitab
- Filemaker Pro

Equipment

- Spectrometers: Mössbauer, Fourier-transform infrared spectrometer (FTIR), Photoluminescence spectrometer, UV-visible spectrometer, High-Resolution UV-visible spectrometer, Perkin Elmer Lambda 950 UV-visible spectrometer, Thermo Spectronic Unicam UV-visible spectrometer with cryogenic accessory, ICP-MS, LA-ICP-MS
- X26A Synchrotron light source (Brookhaven National Laboratory – National Synchrotron Light Source)
- Microscopes: Petrographic microscope, Scanning Electron Microscope
- Thin section machines: slab saw, trim saw, drills, diamond polishing laps, grit wheels and polishing laps, steel jaw crusher, Rocklabs® hydraulic crusher/splitter
- Gemological equipment: refractometer, illuminator polariscope, calcite dichroscope, DTC DiamondView fluorescence imaging system, EDXRF Analyzer