Emergent Student Conceptions of Geologic Time and their Implications for Embodied Learning

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Introduction

An understanding of geologic time is critical for students in understanding many concepts within geology (Kortz and Murray, 2009) and may contribute to an understanding of concepts which occur on time intervals outside of human experience, such as evolution (Catley, & Novick, 2009) or climate change (Laughlin, 2010). Much of the much research on student understanding of geologic time has found that individuals generally place geologic events in correct relative order, however their ability to place the events in absolute order when given the age of the events is less accurate and often exhibits temporal compression for older events (Catley, & Novick, 2009; Cheek, 2012).

While a lack of explicit declarative knowledge contributes to insufficient understandings of geologic time, students' difficulties in understanding geologic time are due to several factors (Cheek, 2010). Research in psychology has indicated that individuals generally use events to measure time (Resnick, Atit, & Shipley, 2012). In this vein, several studies have focused on students' geologic content knowledge underlying their conceptions of geologic time (Delgado, 2013). For example, Delgado (2013) found that students have a limited number of "collective landmarks" with which to reason about geologic time.

Other studies have focused on students' understanding of large numbers as an impediment to understanding time on a geologic scale (Cheek, 2012; Hidalgo, & Otero, 2004; Trend, 1998). This study proposes that student conceptions of geologic time are due to the interaction of declarative knowledge and understandings with explicit and implicit visual models held by students. This study addresses two questions. First, how do undergraduates understand and make sense of large numbers when reasoning about time? Second, how do students draw upon this informal reasoning when asked to create a formal geologic timeline?

There has been much debate about whether students scientific conceptions exist as misconceptions, or intuitive fragments of knowledge (Brown, 2014; diSessa, 1993). These two positions can be reconciled by adopting a perspective where students' conceptions are viewed as dynamically emergent structures. This perspective allows one to view student conceptions as both wrong ideas that are common and robust and as ideas that arise out of more elemental intuitions (Brown, 2014). A frame work consistent with this perspective views student conceptions through four different lenses -- verbal-symbolic knowledge, conscious models, implicit models, and core intuitions, which aligns with (Brown, 1992).

Cheng and Brown (2010) provide definitions of the four categories which are useful to highlight the way in which these categories can be conceptualized. Verbal-symbolic knowledge is intentionally employed and discrete. As such, it consists primarily of verbal information that can be consciously recalled from memory. Conscious models are employed when students consciously employ imagery to make sense of, or explain, their reasoning. The use of gestures, drawings, or verbal descriptions of their imagery is indicative of the use of conscious models.

Implicit models are assumptions that are not consciously employed, but are drawn from imagery that is context specific. Core intuitions are "gut-level intuitions" that cut across domains.

Method

Participants

Thirteen undergraduate students enrolled in an Educational Psychology course at a large Midwestern University were interviewed for this preliminary qualitative study. The sample was non-representative (12 Female and 1 Male) and convenient. All participants were interviewed individually and given pseudonyms. Video recordings were transcribed to capture both verbal responses and gestures.

Interview Tasks and Procedure

This study employed task-based interviews where participants were asked to create an accurate representation of geologic time. While this meant a timeline for many of the participants, the participants had the freedom to construct the timeline using representations they constructed themselves. This allowed participants to construct visual images that more accurately reflect their conceptions of geologic time. Before construction, students were presented with geologic and historical events (see Table 1) and asked to explain how they thought about the intervals of time.

Table 1: Events and approximate times used in timeline construction

Event	Approx. Time
Invention of the phone	100 years
First Europeans to sail to America	1,000 years
First use of fire	1,000,000 years
Extinction of Dinosaurs	65,000,000 years
Dinosaurs Appeared	230,000,000 years
First Life Appeared	3,000,000,000 years
Formation of the Earth	5,000,000,000 years

Results

When the participants were asked to explain how they understood different units of time many referred to visual imagery, often placing themselves within their visualization or framing their answers in the context of human experience. Mandy was asked to explain how she understood how long 230 million years is as a time period. She indicated that, "people typically understand things when they are able to visualize it, perhaps either being able to draw it out or like a movie." In the visual imagery employed by many of the participants the ways in which the Earth was different from today was used to measure the amount of time which had passed. Amanda explicitly discussed her visualization for the time period between the first dinosaurs and the extinction of the dinosaurs by saying, "I'm thinking, way back in the past, but I don't like have a whole lot of knowledge supporting stuff that happened back there than like dinosaurs existed and then they didn't." In this statement we see that in Amanda's visual model of the Earth for this time period there are few, if any, differences. Similarly Kristie contrasted the time between the first dinosaurs and the extinction of the dinosaurs by saying, “you can't really like conceptualize 65 million years. If it was sometime that we had in like recorded history, like with people, it would be easier. Because we could be like they didn’t even have like technology, or this is what life was like.”

In the imagery that 10 of the 13 individuals employed, much of their thinking was connected to human experience, specifically visual differences. Their use of imagery suggests that they employed an implicit model of placing themselves within the timeline. They imagined themselves located in time, at present, and peering from their location in time to different times to see how different they are from today. For example, Xia used her hands to demonstrate that one thousand years was larger than one hundred years. When asked how she determined what distance to hold her hands apart she indicated that it was “just like the feeling, cause 1000 years, I feel, is very far away from me, but 100 years I can still think about it. Like, its closer to me.” This implicit placement of oneself within the timeline and located at the present day has consequences for how one reasons with time. If we visualize ourselves physically being located on a timeline, then the actual distances between objects which are located far away from our location are much larger than our perception of those distances. Imagine viewing two mountain peaks from a distance away. These peaks appear to be much closer together than the distance they really are from each other.

Verbal-Symbolic Knowledge about Large Numbers

Several aspects of verbal-symbolic knowledge were employed by individuals when constructing a timeline. One aspect that was frequently drawn upon is the idea that leading digits are important when comparing numbers. This is useful when comparing numbers of the same order of magnitude, but can be misleading if the orders of magnitude are not compared as well. Deanna indicated that she used the “units to determine the order,” but seemed to focus on the leading digits when placing the numbers in proportional relationship to each other. This led to a relatively disjointed time line where the numbers within the same “unit” were ordered somewhat proportionally according to a linear scale, but the spacing between units was not precisely determined. When placing the numbers 230 million, three billion, and five billion Deanna notes, “we went from million to billion so it has to be a big space, and then, like three to five, it’s like nothing.” Six of the 13 timelines exhibited a “disjointed” property which is consistent with not utilizing the magnitude as numerical information. Deanna’s timeline (Fig. 1) has large gaps that mark the transition between “units” and smaller spaces for differences between the leading digits. In explaining her process Deanna indicated that she focused on the leading digits consistently across the timeline. She noted that the space between 65 million years and one million years is about the same size as the space between today and one hundred years ago because, “Sixty-five is about the same as one hundred.”

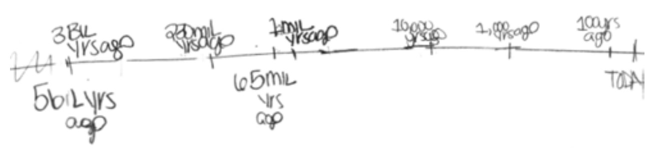

Figure 1: Deanna’s Timeline

Does Context Matter?

The context of time seemed to inhibit the ability of many of the students to transfer their mathematical understandings to the context of reasoning about large periods of time or creating a geologic time line. Many of the students indicated their experience with large numbers in mathematics classes, but were uncertain about applying their knowledge. Carrie expressed her uncertainty about how applicable her mathematical experiences were to the context of time when asked how she made sense of one thousand years.

> *Carrie:* I'm picturing like in elementary school like they first started teaching you about counting there was like little bars {pause} yeah like little bars, they had like little lines [gesturing as if manipulating unifix cubes]. That's how I'm picturing it. But I am feeling like that would be really tedious and a lot of work. And it wouldn't be relevant to, to, 1000 years because I am showing like a figure as opposed to time. Because it's like a lot different.

While Carrie did not provide an explanation of how they were different, Deanna talked explicitly about the difference between her visualization of time and objects. When she was asked how she made sense of five billion years, she explained that when she thinks about five billion years she thinks about "how different the world was then compared to now" and how many changes have occurred. "But if I think about an object, like a pen or something, then I would picture how many times it would circle the Earth. Or 5 billion dollars… I'm thinking someone in the penthouse, sitting on their money. Physically I would think about like, stacks of it."

The difference in her implicit model can be thought of as the position she takes when conceptualizing the same large number in different contexts. When she reasons about large numbers in the context of time she places herself inside time as if she was on the timeline. She views changes in time as changes in the perceptual experience that she would have at different times. However, when she is reasoning about objects she visualizes herself looking at the objects. Here she places herself outside of the objects and uses comparative distances or sizes when she thinks about numbers of objects. Before she was asked to draw the timeline Deanna is asked to compare large numbers of grains of sand since she indicated that she viewed objects differently than time. Using gestures Deanna placed three billion approximately halfway between five billion and zero. She further indicates the 200 million would be less than one-fourth that of three billion. In comparing the same numbers in two different contexts, Deanna arrives at two different number lines. In the context of time she conceives of five billion and three billion as essentially the same amount. However in the context of comparing objects, her gesturing indicate that three billion is just over half of five billion. By implicitly placing herself externally to the objects she is able to visualize the difference between these numbers more accurately, than when she visualizes time.

An interesting interaction between visual models and verbal-symbolic knowledge of proportion, was found in two of the participants. In her interview Amanda describes how she views a fixed period of time differently depending on how recent this time period occurred relative to today.

> *Amanda*: If you said the hundred years between today and a hundred years ago that would almost appear larger to me, than if you said between like 1600 and 1700, even though it's the same amount of time, because I have less life experience, less education of that time period, just all those things it seems like it might be less.

In this comment we observe the interaction between Amanda's implicit model of placing herself on the timeline and her conscious model that the number of events that one can recall is indicative of the amount of time that has passed. Again, Amanda discusses her understanding of numbers as consistent in size when she mentions that the two time intervals are the same amount of time. Her visual model, however, is inconsistent with this knowledge. In her informal reasoning about geologic time the visual model seems to contribute more to her reasoning than her verbal-symbolic knowledge.

Conclusion

Resnick, Atit, and Shipley (2012) discuss how science conceives of time as "single metric" used to measure events. The implicit framing is that of time being external to the human experience which is different than how humans generally conceive of time as a series of events. In this study, participants used both visual differences and the number of events they could recall to measure time. While the number of events that occur is related to the extent of the visual difference between the two time periods, the level of processing is different. The former strategy is at a verbal-symbolic level, while the later strategy is at a more intuitive level.

This suggests that in addition to emphasizing the hierarchical relationships between geological events as Resnick, Atit, and Shipley (2012) recommend, rich descriptive description of the environment, biota, and geology of the different geologic times should be presented to students with an emphasis on similarities and differences to other time periods. Similarly the use of temporal benchmarks (Schwartz 2009), or landmarks (Delgado, 2013) seem to be productive ways in building richer visual models of geologic time. In addition, methods which promote the coordination of visual models in which the individual views time externally and internally may be warranted. The use of embodied experiences appears promising for coordinating visual models. In one example, Hester (2008) found that having students walk a geologic timeline while listening to descriptions of the events was useful in developing richer understandings of geologic time. Finally students may need additional instruction on comparing numbers of differing magnitudes. One promising avenue of future research concerns embodied technologies, which present opportunities for students to construct productive conceptual models. This is especially true for context that involve both large and small numbers (e.g. Nanoseconds in computing to billions of years in geologic time) which are difficult or impossible to experience in reality. Future research should investigate the types of conceptual change and transfer across these and other crosscutting concepts using embodied computerized simulations.

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