Title: Progressive Alignment of Geologic Time
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How do animals become extinct? How likely is it for another mass extinction to occur? How long have humans been on the Earth, and how does this compare with the presence of other animals?

What is global warming, and is it real? If global warming is real, how are humans influencing it? How am I influencing global warming?

Having an understanding of geologic time is required in order to answer the questions like these. Geologic time refers to the amount of time it has taken for objects like the Earth to form. It is the idea that time is unidirectional, moving from the very distant past through the present (Gradstein and Ogg, 2009). Geologic time is often represented spatially in the Geologic Time Scale (see fig. 1).

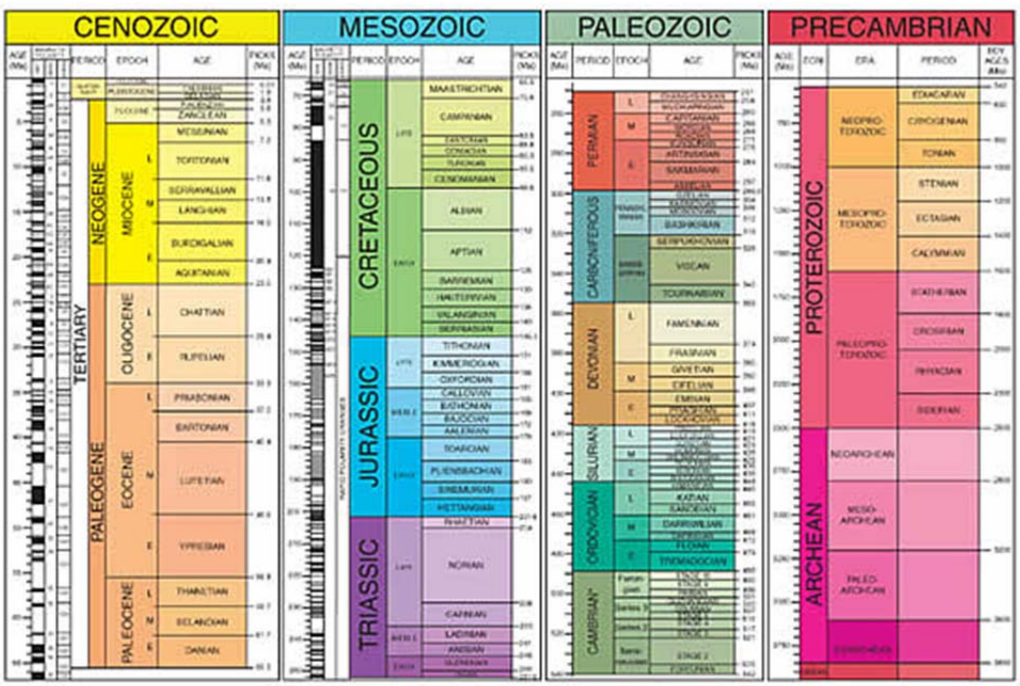

Figure 1. Geologic Society of America official Geologic Time Scale, ***from: http://www.geosociety.org/science/timescale/***

The Geologic Time Scale is an important foundational concept across scientific disciplines (Dodick & Orion, 2003), including geology, cosmology, astronomy, ecology, evolutionary biology, as well as in everyday life. Having a clear understanding of geologic time provides a framework for the understanding of current environmental crises (Trend, 2009), such as how rates of natural temperature and greenhouse gases change and how replenishment of renewable resources relate to human consumption (Zen, 2001).

Unfortunately, geologic time appears to be difficult to understand. People have persistent and consistent misconceptions regarding geologic time (e.g. Dodick & Orion, 2003; Libarkin, et al., 2005). While people are able to arrange well-known geologic events in the correct sequence, they struggle assigning absolute ages and relative magnitudes (Petcovic & Ruhf, 2008).

One reason people may have difficulty understanding geologic time is that geologic time may be so far removed from familiar human event scales that it is difficult to reason about and understand. People tend to think in terms of familiar events that range in magnitude, but are bounded by a human lifetime. The current study examines the role of magnitude in understanding geologic time and reasoning about events that extend beyond the range of familiar experience.

An intervention was designed based on the common classroom exercise of aligning time to a spatial representation. The intervention was designed using progressive alignment to give students practice aligning time to space. Progressive alignment is an effective analogical teaching technique that begins with the comparison of two highly similar items then moving to increasingly dissimilar items (Kotovsky & Gentner, 1996; Thompson & Opfer, 2010). Commonalities between the similar items make the corresponding relations salient. Thus, comparing two very similar items will help extend the analogy to the subsequent unfamiliar items (Gentner & Namy, 2006).

Students aligned time to space beginning with a familiar personal time scale, working through different historic and geologic timelines, up to the Geologic Time Scale. For each timeline, students were required to indicate the timeline's length, locate specific events, and locate where all previous timelines would begin on the current timeline (see fig. 2). Half of an undergraduate introductory-level geology class participated in the intervention activity after a stratigraphy lab (the intervention group), and the other half completed only the stratigraphy lab (the control group). All students completed outcome measures one month later after learning about geologic time in regular class instruction.

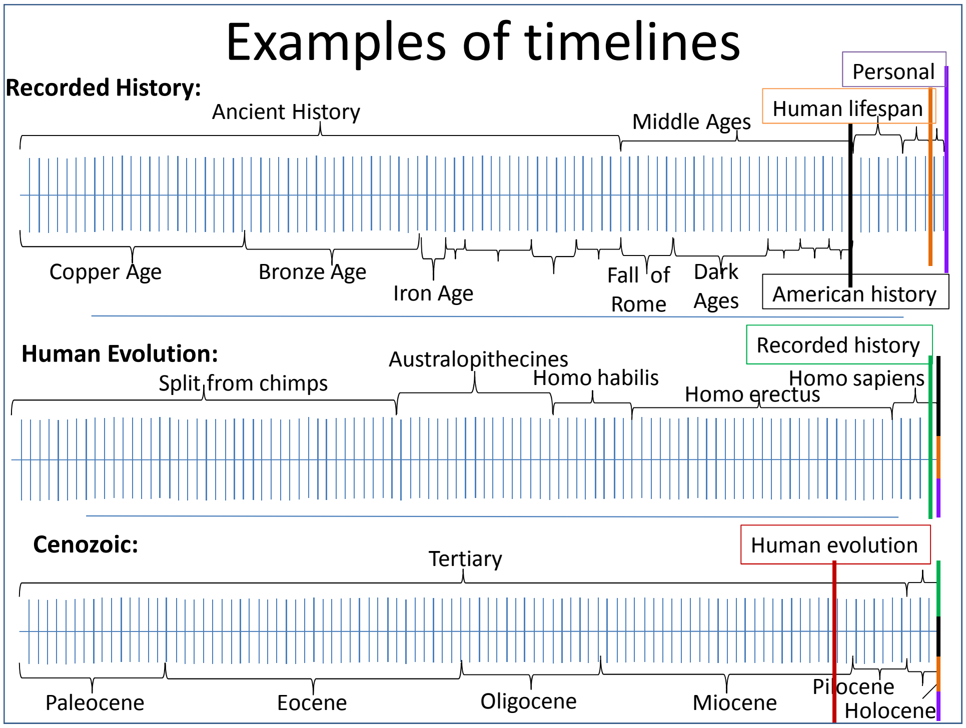

Figure 2. Example of 3 timelines in the progressive alignment intervention

The intervention group demonstrated a more accurate sense of the relative proportions of geological events than the control group. On an item from the Geoscience Concept Inventory on geologic time (see fig. 3), students were presented with different geologic timelines and asked to choose the most correct one. The intervention group was significantly less likely than the control group to choose the mostly common error. Further, the intervention group was more likely to choose response options that presented dinosaurs appearing, dinosaurs going extinct, and humans appearing appropriately clustered together at the end of the time line. The control group was just as likely to choose the clustered options as the non-clustered options. Thus, the intervention group showed a reduction in the magnitude of temporal location errors compared to the control group (see fig. 3).

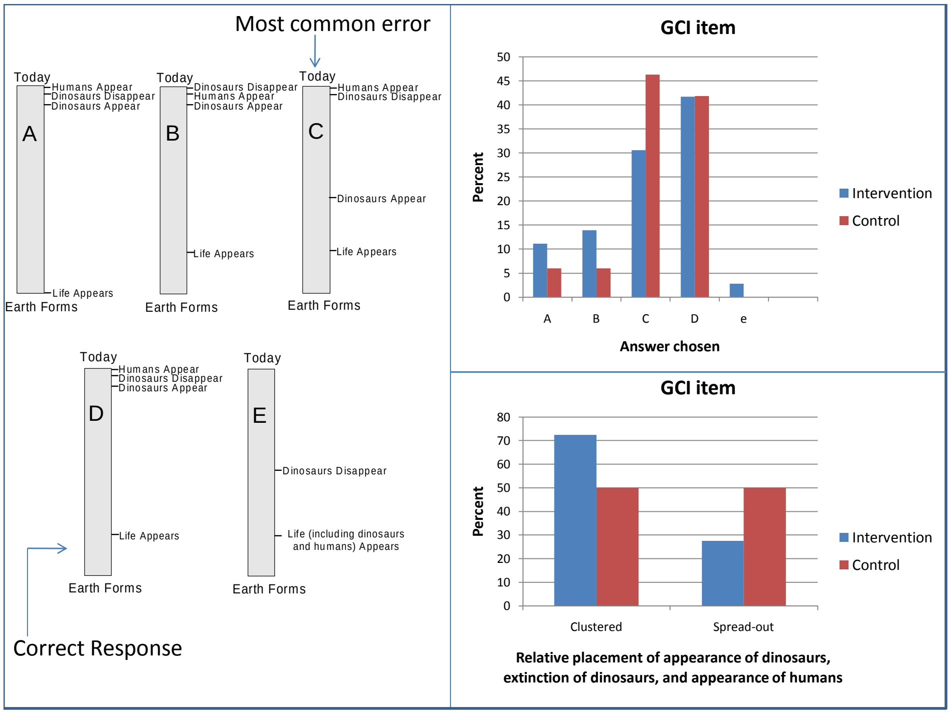

Figure 2. Item from the Geoscience Concept Inventory (left) and student responses (right). The graph in the top right-hand corner shows student responses for each response option. The graph in the bottom right-hand corner shows student responses for items where the appearance of dinosaurs, extinction of dinosaurs, and appearance of humans are clustered together at the end of the timeline (clustered) compared to those response items where they are not (spread-out).

The intervention group was also more accurate on a multiple-choice item that required students to identify which duration-based statement was true using a conventional diagram of the Geologic Time Scale. The correct choice is the statement: *The Proterozoic Eon lasted much longer than the Phanerozoic Eon*. While numerical information is provided in the diagram, the correct choice was hard to see in the diagram because the spatial intervals of the eons do npot match their temporal lengths. The most commonly chosen incorrect response was a statement that is consistent with the visible spatial interval (*The Phanerozoic lasted much longer than the Proterozic*). This item is a new measure of geologic time developed for use with middle school students. The intervention group was significantly more likely than the control group to choose the correct response.

Importantly, the intervention and control groups did not differ significantly on a third test item that was knowledge-based and did not require an understanding of magnitude. This suggests the intervention affected understanding magnitude of geologic time, and did not merely increase effort or motivation in the intervention group.

In sum, this study found that the progressive alignment of geologic time is an effective way to reduce problems that arise from unfamiliar magnitudes in understanding geologic time. Students who received the progressive alignment intervention were still making some errors. This suggests there are multiple components involved in understanding geologic time. Currently, we are examining the role of qualitative encoding, particularly hierarchical organization of events, in understanding geologic time.

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