TIMELINE AND TIME SCALE COGNITION EXPERIMENTS FOR A GEOLOGICAL INTERPRETATIVE EXHIBIT AT GRAND CANYON

Linear timelines are analogical models that are frequently used in formal and informal learning settings to teach about geologic time; nonetheless, their effectiveness in such contexts has not been fully assessed. We examined respondents' abilities to understand and interpret a logarithmically scaled walking timeline: the Million Year Trail (MYT). This is a prototype of a longer version that will soon be part of a major geoscience exhibit, "The Trail of Time", at Grand Canyon National Park. We asked 70 respondents to find precise points along our model timeline, each representing an event from recent times to 65 million years ago. We also tested their purely mathematical understanding of the timeline and its scale changes. Our results indicate that most Grand Canyon visitors should be able to understand the full-size MYT if each point on the timeline is clearly labeled, and if visitors are enabled to locate a few meaningful, contextualized events (e.g., one's own birth or a major historical event) along the timeline as they traverse it. Our findings have already informed modifications to MYT design, and the design of on-site cognitive experiments to be conducted on the permanent Trail of Time exhibition at Grand Canyon upon its completion.

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Introduction

The "Trail of Time" exhibition (Figure 1), under construction at Grand Canyon National Park in northern Arizona, will be the world's largest interpretative geoscience exhibit at one of the world's signature geological landscapes (Karlstrom et al., 2008), visited by about five million people annually (Littlejohn & Hollenhorst, 2004). The heart of the exhibition is a 4.5-km accessible timeline trail along the popular South Rim of Grand Canyon, each meter of which will be marked to represent the passage of one million years.

Figure 1. Map of the Trail of Time exhibition at Grand Canyon National Park.

Interpretative signage and displays on Grand Canyon geology and culture will be deployed along its entire length. The goal is to enable Grand Canyon visitors to construct an accurate understanding of and a visceral sense for geologic or "deep" time (Carlyle, 1832, cited in Dodick, 2007; McPhee, 1981), learning both cognitively and kinesthetically (Gyllenhaal, 2006; Perry, 2002) as they traverse the Trail. Many such analogical models have been created to teach about geologic time (e.g., Rowland, 1983; Ritger & Cummins, 1991; Brandt et al., 2007), but none with the scale and scope of the Trail of Time exhibition. Moreover, the Trail is intimately linked with the geological surroundings it models, giving it greater cognitive impact than typical teaching models.

A key objective of the Trail of Time is to enable visitors to adjust their own temporal frames of reference from personal time scales (years to decades), through historic and archaeological time scales (centuries to millennia) to deep time (millions of years). Toward this objective, visitors will begin their trek on a 136-meter "Million Year Trail" (MYT), along which the time scale will exponentially increase in stages from one year per meter at the start to 100,000 years per meter at the end. Here the MYT dovetails with the principal segment of the Trail of Time, the "Deep Time Trail," with its fixed scale of one million years per meter. The MYT segment of the exhibition is intended to help visitors understand how long a million years truly is, whereas the Deep Time Trail shows how many millions of years are encompassed by the geologic history of Grand Canyon and Earth.

The effectiveness of linear timelines in teaching about geologic time in formal and informal learning settings has not been fully assessed, although such analogical models are common features of high school and university courses. The MYT introduces another level of complexity because of its multiple, changes in scale, specifically designed in order to accustom Grand Canyon visitors to the massive scale of geological time. In advance of the scheduled construction of a permanent MYT at Grand Canyon during 2009-2010, we conducted two off-site studies (in Arizona and Israel) of visitor responses to, and comprehension of the proposed MYT design. Our research tested whether respondents understood the purpose of the MYT, and if they could easily navigate and interpret it (i.e., recognize scale changes and correctly identify the time represented at any point). The results of our studies have informed MYT design modifications and the design of on-site cognitive experiments to be conducted on the permanent Trail of Time exhibition at Grand Canyon upon its completion.

Materials and Methods

We used a scaled simulation of the proposed MYT referred to as the "Time Accelerator Trail Experiment" (TATEx): a 74-m by 0.7-m strip of durable plastic-backed white paper, on which realistic Trail of Time markers were placed at 1-m intervals. Every 10 m along the TATEx, the time scale increases by a factor of 10, from 1 year per meter at the start to 100 million years per meter at the end. We intentionally exceeded the scale range of the actual MYT by three orders of magnitude to allow us to examine responses over a longer time expanse. Each respondent participated in the experiment individually, accompanied by an interviewer and another researcher who video recorded the respondent's reaction to the timeline. At the start, respondents were told only that the trail was a "walking timeline" being tested for use at Grand Canyon and other National Parks.

Respondents were asked to walk to several selected places along the TATEx timeline, while responding to questions and tasks posed enroute by the interviewer. In other words, our research strategy extensively employed "think aloud protocols." Each respondent was given eight placards (Table 1); the first represented the respondent's own age, and each of the others depicted an event or phenomenon in Grand Canyon or Arizona history. Respondents were asked to place each placard on the TATEx timeline at the corresponding point in time.

Table 1
Placards Used in the TATEx

Placard designation	Event represented	Time of event (years before 2007)
Age	Respondent's own age	Varies
SR27	Major flood of the Salt River	27
AZ95	Arizona becomes 49th state	95
SC942	Sunset Crater volcano erupts	942
BW1500	Petroglyph panel engraved by Ancestral Puebloan people	1,500
MC50k	Impact forms Meteor Crater	50,000
GC6M	Grand Canyon begins to form	6,000,000
TR65M	Deposition of a *Tyrannosaurus rex* skull found in regional strata	65,000,000

At the marker representing 10,000 years ago, respondents were asked to indicate whether they thought that the marker spacing had changed since the start (correct response: "no"); and if not, what if anything was changing (correct response: "the time scale only"). At the end of the TATEx timeline, an unnumbered marker representing 200 million years ago, respondents were asked how far backward along the timeline they would need to walk to cover 200 million years (correct response: "all the way back to the start"). After they finished walking the TATEx timeline, respondents were given a brief description of the Trail of Time exhibition and the purpose of the MYT, and were invited to offer additional comments or recommendations.

Experiments were conducted in 2007-2008 at two large research universities in Arizona, USA, and Israel, respectively. Respondents (n=40 in Arizona and n=30 in Israel) were recruited locally. Most, but not all, were university students; the mean age was 23 ± 6.9 years and the median age was 21 years. The aggregate group self-identified as 38.8% White, 29.9% Israeli secular, 14.9% Israeli religious, 7.5% Latino, 4.5% Asian, 3.0% American Indian, and 1.5% African American; this sample was more ethnically diverse than that of recent visitors to National Parks in the southwest USA (93% White; National Park Service, 2002).

Initially, the TATEx was modeled closely on the design for the MYT as it existed in 2004, part of an integrated plan for the Trail of Time tested in a front-end evaluation at Grand Canyon by Gyllenhaal and Perry (2004). However, during experimentation in Arizona in 2007, TATEx designs were modified in response to respondent behaviors. The initial MYT design called for the use of calendar years to mark time from the present (set at 2010 CE) to 2,000 years ago. We immediately abandoned this design element when several geoscience graduate students found it difficult to negotiate the change of units at the "year zero" marker in pre-experimental runs.

TATEx version 1.0 (abbreviated *v.1.0*), still largely concordant with the initial MYT design, marked time with unlabeled 2-cm diameter blue squares every 1 m, circular labeled time markers (medallions) every 10 m, and signs indicating the change of scale also at every 10 m. This design was tested with 30 respondents in Arizona. In the second iteration, *TATEx version 2.0* (*v.2.0*), labeled medallions were used at every meter (replacing blue squares between multiples of 10 m), and all scale-change signs were removed. *TATEx v.2.0* was tested with 10 respondents in Arizona and with 30 respondents in Israel in 2008.

Findings/Analyses

We focused on behaviors and comments we deemed indicative of a respondent's understanding of, and ability to navigate and interpret, the MYT. Our protocol can be subdivided into two parts. The first part asks respondents to locate eight events along the timeline, from the respondent's own age to 65 million years ago, by placing placards. We measured their ability in terms of the errors they made in placard placement, as well as the certainty they showed in their original placement along the timeline.

Error in placard placement

The distance (in marker spacings) between a respondent's placement of a placard and the correct point on the timeline indicates the respondent's understanding of the time represented at any point on the timeline. We totaled placement errors for each of the eight placards in the two TATEx iterations and averaged these over the number of respondents (N = 30 for *v.1.0* and N = 40 for *v.2.0*). These values are shown in Figure 2.

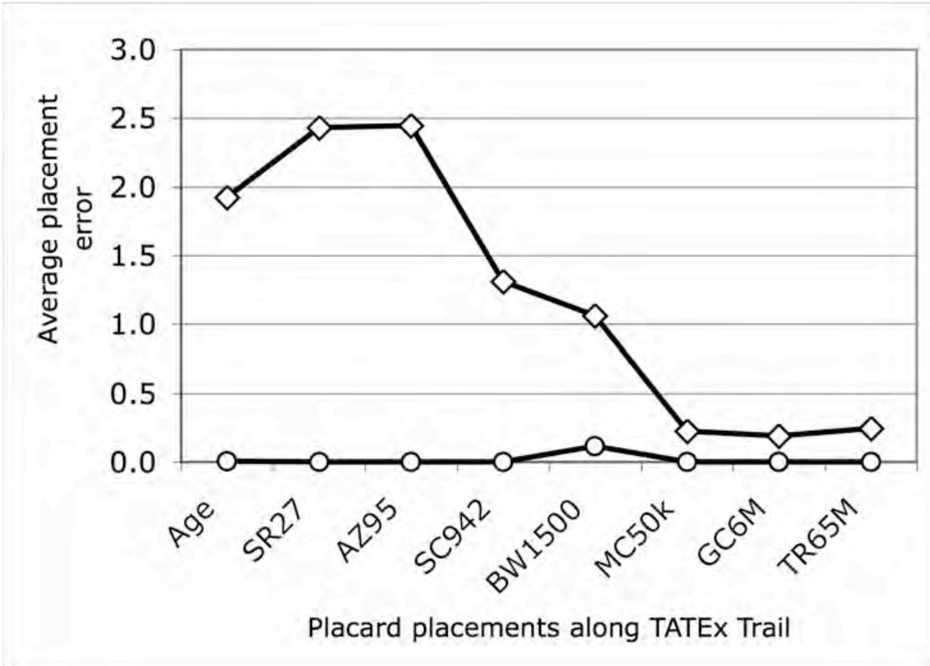

Figure 2. Average respondent error in placard placement (in marker spacings) versus placard position, for TATEx *v.1.0* (open diamonds) and *v.2.0* (open circles). See Table 1 for explanation of placard designations.

We initially hypothesized that respondents would have more difficulty in locating events that involved greater expanses of time but in fact in v.1.0 the opposite result occured. In part, this is due to the non-rounded time figures for the early placard figures which lie between tick marks and make these locations harder to find. However, more importantly in *v.1.0* we observe a learning phenomenon in which respondents gradually grasp the idea of the MYT about halfway along its length, and thus their errors decrease. On TATEx *v.2.0,* along which time was explicitly labeled at every marker but scale changes were not, respondents made essentially no placement errors, which suggests that they immediately understood the nature of the scaled timeline.

Uncertainty in placard placement

This is defined as the situation in which a respondent believes he or she has erred, and moves the placard to a different place. The less often this occurs, the more certain the respondent is in his or her understanding of the timeline. We totaled and averaged replacements for each of the eight placard placements in the two TATEx iterations, and plotted each average against placard placement on the experimental trail (Figure 3).

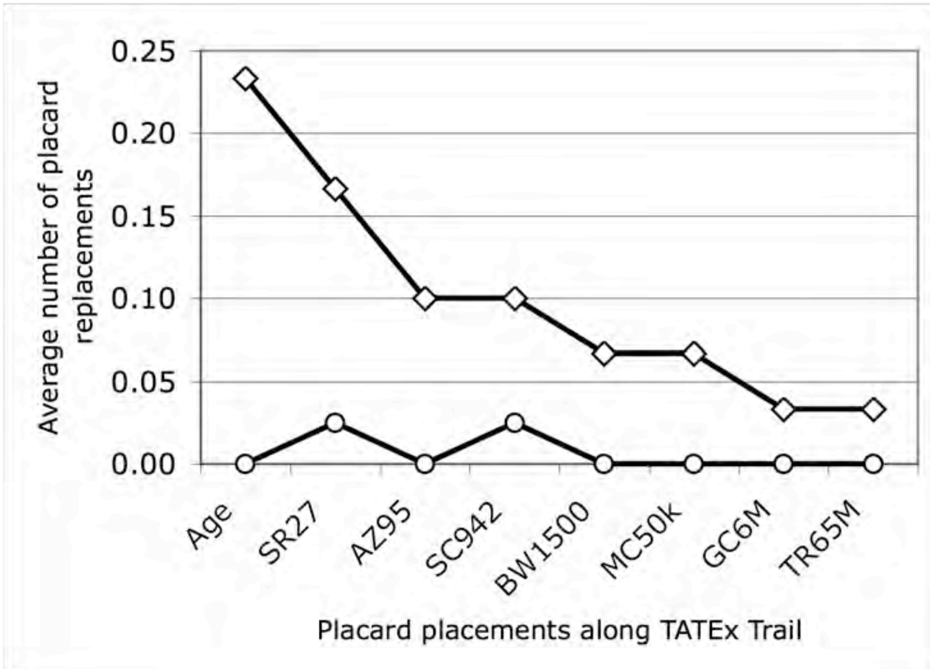

Figure 3. Average respondent uncertainty in placard placement, represented by average number of placard replacements, versus placard placement, for TATEx *v.1.0* (open diamonds) and *v.2.0* (open circles).

We find a pattern similar to that for error in placard placement: with *v.1.0* respondents become increasingly confident in their placements after some early uncertainty, whereas with *v.2.0* they exhibit limited uncertainty with the first few placements but none in the second half of the timeline. This suggests that in using a timeline to accustom people to the idea of geological time, it is helpful to start them at magnitudes that they are more familiar with: tens, hundreds, and thousands, before proceeding to millions. This supports the use of the MYT as a tool for cognitively preparing visitors for the Deep Time Trail and its million-year per meter scale.

The second part of our protocol (Table 2) involves a more complex set of tasks; rather than locating a series of events, respondents compare parts of the timeline and reflect on how it changes. The results are opposite to those we saw in the first part of the protocol when we asked respondents to locate specific events; respondents found it easier to decipher changes in the timeline at smaller rather than larger time scales. Here, the questions are not contextualized within events, but are based on pure mathematical reasoning, and larger numbers are harder to conceptualize. Another difference is that fewer respondents were able to decipher the final marker and the symmetry of the timeline with *v.2.0* than with *v.1.0,* even though the former was much better labeled. It may be that this better labeling imparts something of a false confidence in some respondents: as they proceed, they notice that the scale changes, but they pay less attention to the magnitudes of the changes.

Table 2
Responses to Questions Asked in Second Part of TATEx Protocol

	Question Asked	Typical Correct Response	% Correct	
			v.1.0	*v.2.0*
1	How is the timeline changing? (Asked at the 10,000-ya marker)	"The spacing between the markers is not changing, but the time scale is increasing."	86.7	95.0
2	Note that the final marker on the timeline is not labeled. What time does it represent?	"200 million years." (*Note:* The marker immediately prior is labeled as 100 million years ago.)	86.7	72.5
3	What is the time difference between the last two markers?	"100 million years."	86.7	72.5
4	How far *backward* along the timeline would you need to walk, to travel an equivalent amount of time?	"All the way back to the start." (*Note:* The Hebrew version of the question differed slightly from the English version.)	66.7	72.5

In the 2008 Israeli experiments (all with *v.2.0* only), respondent errors in question 2 were almost evenly divided between overestimation (e.g., "The final marker represents 1 billion years") and underestimation (e.g., "The final marker represents 110 million years."). It should also be noted that the Hebrew version of question 4 was cognitively easier than the English version, but still, nearly a quarter of the Israeli respondents found it challenging. It should also be kept in mind that the Israeli sample is weighted towards science students (93% of the total), and amongst them 16 were in strongly quantitative disciplines (chemistry, physics, computer science, geology, and engineering). This represents an upper bound on the expertise of potential Grand Canyon visitors; thus, if nearly 25% of this group experienced difficulties, we would expect greater cognitive difficulties on the actual MYT if it were to be presented only as a decontextualized mathematical model. This problem will be overcome at the Grand Canyon in part by contextualizing chronology within actual events as well as signage and exhibits that focus specifically on time cognition. This strategy of contextualizing chronology within concrete / visual events has support within the literature. In their research on history education among grade 5 children, Barton and Levstik (1996) and Levstik and Barton (1996) concluded that using visual images with a variety of chronological clues stimulated a greater depth of historical understanding than mere verbal description attached to dates. So, too, the rocks and fossil materials of the Grand Canyon, representing key events in earth's history, should act as a concrete organizer to bridge over some of the abstract difficulties of geological time's massive, and intimidating scale.

Conclusion

Although there are many analogical models used to teach geologic time (see Dodick & Orion, 2006, for a review), this is the first time that one has been tested in a rigorous pedagogical fashion; thus, these findings inform future pedagogical practice. Our results indicate that most

Grand Canyon visitors should be able to understand and interpret the full-size Million Year Trail if each point on the timeline is clearly labeled, and if visitors are enabled and encouraged to locate a few meaningful, contextualized events (such as their own birthdate or a major historical geological event) along the timeline as they traverse it.

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