A Study On How The Public Uses The Landscape To Understand Principles Of Geologic Time While Experiencing The Trail Of Time Interpretative Exhibit In Grand Canyon National Park

by

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ABSTRACT

The spectacular geological panoramas of Grand Canyon National Park (GCNP) motivate the curiosity of visitors about geology. However, there is little research on how well these visitors understand the basic geologic principles on display in the Canyon walls. The new Trail of Time (ToT) interpretative exhibit along the South Rim uses Grand Canyon vistas to teach these principles. Now being visited by thousands daily, the ToT is a uniquely valuable setting for research on informal learning of geologic time and other basic geologic concepts. At the ToT, visitors are not only asked to comprehend a linear timeline, but to associate it with the strata exposed in the walls of the Canyon. The research addressed two primary questions: (1) how do visitors of the National Park use elements of the geologic landscape of the Grand Canyon to explain fundamental principles of relative geologic time? and (2) how do visitors reconcile the relationship between the horizontal ToT timeline and the vertical encoding of time in the strata exposed in the Canyon walls?

Semi-structured interviews tracked participants' understanding of the ToT exhibit and of basic principles of geologic time. Administering the verbal analysis method of Chi (1997) to the interview transcripts, the researcher identified emergent themes related to how the respondents utilized the landscape to answer interview questions. Results indicate that a majority of respondents are able to understand principles of relative geologic time by utilizing both the observed and inferred landscape of Grand Canyon. Results also show that by applying the same integrated approach to the landscape, a majority of respondents are able to reconcile stratigraphic time with the horizontal ToT timeline.

To gain deeper insight into the cognitive skills activated to correctly understand geologic principles the researcher used Dodick and Orion's application of Montangero's (1996) diachronic thinking model to code responses into three schemes: (1) transformation, (2) temporal organization, and (3) interstage linkage. Results show that correct responses required activation of the temporal organization scheme or the more advanced interstage linkage scheme. Appropriate application of these results can help inform the development of future outdoor interpretive geoscience exhibits.

DEDICATION

I would like to dedicate this thesis first to my father and mother, Wilvan W Mathews and Rosemary D Mathews. They have been tremendous examples throughout my life, always encouraging me and setting high standards of excellence. I also dedicate this to my daughter Elizabeth Jane Frus. I entered school to be an example to my future children and now that she is here I hope she sees the value of higher education. And to my husband Adam Frus who has been my field partner since the beginning.

ACKNOWLEDGMENTS

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Besides my advisor, I would also like to thank the rest of my committee, Dr. Dale Baker and Dr. Jack Farmer, for their thoughtful questions and expert knowledge. I also give thanks for Dr. Jeff Dodick whose knowledge helped guide the path to completion.

I would also like to thank Dr. Karl Karlstrom and Dr. Laura Crossey for their hard work and love of the Grand Canyon. As well I am grateful to the National Park staff at Grand Canyon National Park and to the wonderful visitors for allowing me to do this study.

I would like to acknowledge my husband Adam Frus. He was my lab and field partner for all of my undergraduate geology courses and he continued to be my field assistant throughout life. I also appreciate all of the research assistants and office mates who helped to get this project completed including Jennifer McNeil, Leah Pettis, Brenda Willis, Deb Williams and Heather Pacheco.

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Chapter 1

INTRODUCTION

The Trail of Time (ToT) is a new exhibition at Grand Canyon National Park (GCNP) that uses the scenery of the Canyon walls to teach about principles related to geologic time. The rocks found in the walls of the Canyon are a record of a long history of geologic processes and provide an ideal setting for research.

To investigate how visitors use the landscape to understand principles of geologic time, semi-structured interviews were performed at the ToT in the summer of 2009. A collection of visitor interviews (n=166) were audio recorded and later coded into emergent themes using the verbal analysis method of Chi (1997). The interview protocol went through a rigorous content validation process and interrater reliability between researcher and assistant was recorded as Cohen's kappa K=0.8999.

Results show that a majority of visitors were able to understand principles of geologic time including superposition, lateral continuity and relative geologic time. To understand these principles the temporal organization scheme of Montangero's (1996) diachronic thinking model was activated. Results also indicated that understanding of these principles was constructed not only by using the observed landscape, but also by drawing on prior knowledge of geologic processes such as deposition and erosion.

Understanding these processes was also necessary to understanding the specific functions of the ToT. Results indicate that visitors to the ToT were able to walk the horizontal, linear timeline and understand that it represented time encoded vertically in the strata.

Chapter 2

BACKGROUND

Geology of Grand Canyon

The immensity of the Grand Canyon has been described by many; well-known author Wayne Ranney (2005) writes of the vastness of the sheer rock walls and the silence found when floating down the Colorado River. Upon seeing the Canyon's view for the first time, one visitor to the National Park stated that "it is so awesome!", and another proclaimed it to be "the most wonderful view." The grandeur of the scenery also leads viewers to contemplate events that have happened in Earth's past; for example: one visitor asked, "where did all of the source material come from for these rocks?" and another stated "there must have been an ocean here before".

Research shows that the rocks of the Canyon provide evidence of gradual changes to the environment, over a vast interval of geologic time, with rapid events periodically happening in localized regions. Examining the rock record of Grand Canyon provides ideal examples of principles such as tectonics, island-arc accretion, unconformities, sedimentary deposition due to eustatic sea-level changes, superposition, and lateral continuity (*Figure 1*).

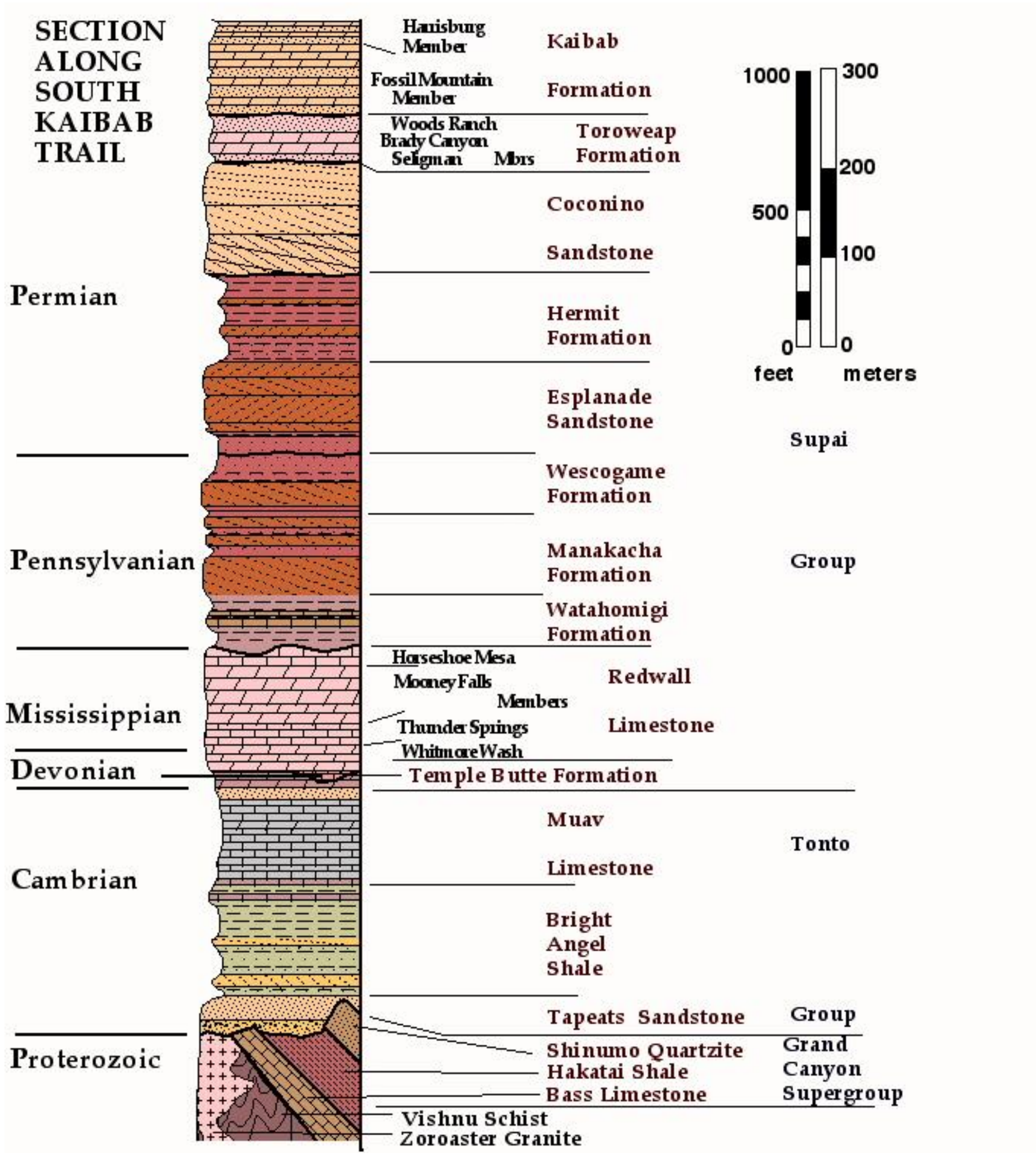


Figure 1. Stratigraphic column for Grand Canyon. (Blakey, 2008)

Proterozoic Eon.

The oldest rock found at the Grand Canyon is the Elves Chasm Gneiss (1.84 Ga), which is part of the Vishnu Metamorphic Complex (Trail of Time Project, personal communication 2010). This complex was formed as magmatic arcs developed above subduction zones were later welded onto the Archean craton from the southeast (Price, 1999; Karlstrom, Ilg, Williams, Hawkins, Bowring, & Seaman, 2003; Blakey & Ranney, 2008, Trail of Time Project, personal communication 2010). These rocks were then intruded by igneous material in three different episodes. The first two intrusive episodes occurred during the formation of the Vishnu Mountains from 1.75 to 1.73 Ga (Karlstrom et al., 2003).

As a result of island-arc collisions and igneous intrusions, the metamorphic and igneous rocks were uplifted. Exposed at the surface, these Proterozoic crystalline rocks were leveled by erosion. Later (1.5 Ga), the last episode of igneous intrusion began, accompanied by a series of north- and south-striking faults (Karlstrom et al., 2003). These faults are believed to be associated with rifting of the continental crust (Blakey & Ranney, 2008).

During the time of rifting in the Mesoproterozoic and Neoproterozoic (1,100 – 740 Ma), down-dropped basins were flooded by eustatic sea level rise. Within this warm marine environment sedimentary rocks were deposited onto the previously eroded surface of the Paleoproterozoic crystalline rocks, causing an unconformity (Price, 1999; Karlstrom et al., 2003; Blakey & Ranney, 2008, Trail of Time Project, personal communication 2010). This suite of sedimentary rocks is the Grand Canyon Supergroup. The Supergroup comprises the Unkar and Chuar Groups, which are exposed at isolated outcrops along the Colorado River.

Research indicates that during the rifting the rate of subsidence of the basins somewhat equaled the rate of deposition for both groups. This caused the area to have both marine and subaerial sediment deposition. The sediments were later tilted as the basins continued to subside (Hendrix & Stevenson, 2003).

Paleozoic Era.

The rocks from the Cambrian Period at Grand Canyon, dating back to 525 Ma, are a classic transgressive depositional sequence. The rocks of the Tapeats Sandstone, Bright Angel Shale and Muav Limestone perfectly preserve the record of a transgression with similar sequence of sedimentary rocks preserved around the globe (Middleton & Elliott, 2003; Blakey & Ranney, 2008). With this sedimentary deposit on the mostly flat erosional surface of the Precambrian crystalline rocks the Great Unconformity was created. A huge gap in the rock record spans some 1.2 billion years of time (Blakey & Ranney, 2008). Also noteworthy is the Cambrian explosion of life where multicellular life rapidly diversified around the world. The Cambrian rocks of the Grand Canyon hold fossils of marine invertebrates and trace fossils (Middleton & Elliott, 2003).

Rocks of Devonian age are limited to the Temple Butte Formation (370 Ma), a limestone deposited in a shallow marine environment. The lower contact of Temple Butte Formation with the upper Muav Limestone is identified as an unconformity where whatever Ordovician and Silurian rocks may have been deposited were eroded away. Erosional patterns on the top of Temple Butte Formation contact also indicate an unconformity with the lower Mississippian Redwall Limestone (Beus, 2003a; 2003b).

A prominent feature of the Canyon, the Redwall Limestone forms a 500-800 ft. (150 – 250m) cliff (Beus, 2003b). It was deposited on a low-lying continental shelf, as the global oceans of the Mississippian Period (340 Ma) transgressed to form large shallow seas over most of Northern Arizona (Blakey & Ranney, 2008). The Redwall Limestone records variations to the ocean sediments with limy muds and sands in thin layers of different members.

The erosional surface of the Redwall Limestone is locally incised by channel fills of the Surprise Canyon Formation, which was formed in a dendritic drainage system (Beus, 2003b). This network of drainages is the indication that the contact between the Redwall Limestone and the overlying Supai Group is an unconformity (Beus, 2003b).

Beginning in the Early Pennsylvanian Period (318 Ma), the Supai Group was deposited as four different formations, separated by unconformities. The Supai Group and the Early Permian Hermit Formation record swift environmental changes that impacted both the type of sediment as well as the depth of sedimentation. These formations are interbedded with sea and wind-blown deposits. This evidence indicates the regional depositional environment was a large flood plain and delta (Blakey, 2003; Blakey & Ranney, 2008).

The Coconino Sandstone, deposited on top of the Hermit Formation, is an indication of environmental changes from the flood plain to a vast desert of wind-blown sand dunes (Middleton, Elliott, & Morales, 2003; Blakey & Ranney, 2008). The rocks from the latter half of the Permian Period are witness to another global transgression. Transitioning from the desert to a sea deposit, the Toroweap Formation is a record of sea-level and subaerial deposits. The end of the Permian

(270 Ma) has Northern Arizona in the vicinity of Grand Canyon under a warm shallow sea in which the Kaibab Limestone was deposited (Hopkins & Thompson, 2003).

Mesozoic Era.

The rock record of the Mesozoic Era is missing from Grand Canyon. Although found higher up on the Colorado Plateau Mesozoic rocks have been eroded away from the area of Grand Canyon. At the beginning of the Cenozoic the area was uplifted. This tectonic action led to the erosion of the Mesozoic rock record (Morales, 2003).

Cenozoic Era.

The story of the Cenozoic at Grand Canyon is of mountain building and erosion. In the Early Cenozoic the subducting Farallon plate changed its descent angle (Huntoon, 2003). Still hotly debated, some researchers indicate that this change activated the Proterozoic faults below the Colorado Plateau and activated the Laramide Orogeny which uplifted the western North American Continent (Huntoon, 2003; Trail of Time Project, personal communication 2010). Later in the Cenozoic there were two extensional events. The first dating 30-20 Ma formed metamorphic core complexes of the southwest and around 10 Ma the crust was slowly pulled apart, creating the Basin and Range Province. The Colorado Plateau remains a relatively undeformed and elevated part of the continent flanked by highly extended crust (Price, 1999; Hutton, 2003).

The most recent major geomorphic process at Grand Canyon is the carving of the Canyon by the Colorado River. Due to the tectonic setting and uplift of the Colorado Plateau, the Colorado River began to erode the layers of the Canyon approximately 6 million years ago (Trail of Time Project, personal communication 2010). Carving through the layers the Colorado River has exposed the Paleozoic and Proterozoic rocks now on display in the Canyon walls (Price, 1999; Hutton, 2003; Lucchitta, 2003; Ranney, 2005; Blakey & Ranney, 2008, Trail of Time Project, personal communication 2010).

Trail of Time at Grand Canyon National Park

The layers exposed in Grand Canyon, and their relationship to one another, offer us evidence on how and in what order environments have changed. The Trail of Time Exhibition along the South Rim at Grand Canyon National Park utilizes this spectacular natural view to help visitors connect to the landscape and to grasp the immensity of deep time (Appendix C).

Using this geologic panorama, the Trail of Time teaches visitors about the timing of major geologic events in Grand Canyon's history as represented by walking along a timeline. The 4.5 km timeline is permanently marked at intervals of 1 meter (each representing 1 million years) and is the world's longest geologic timeline exhibition. Incorporating many types of displays, the exhibition includes seventeen waysides that use pictures, graphs, text and parts of the landscape of the Canyon to teach about the Earth's systems. Now being visited by thousands daily, the Trail of Time is a uniquely valuable setting for research on informal learning of geologic time and other geological concepts (*Figure 2 & 3*).

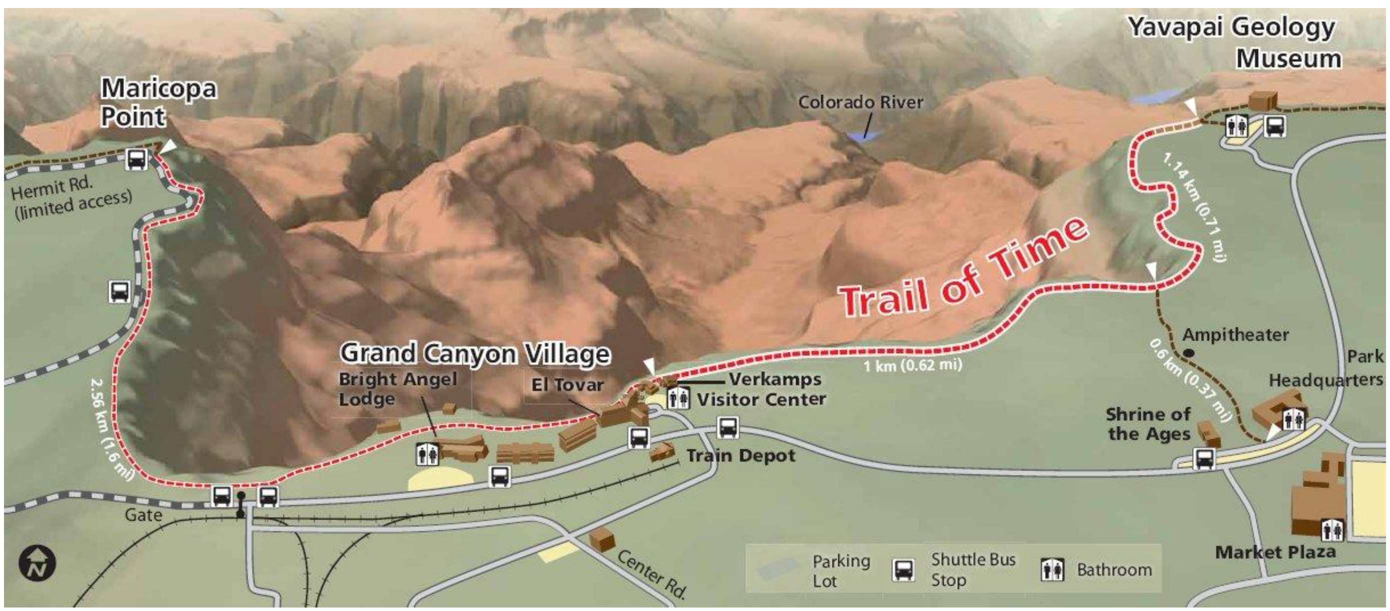


Figure 2. Map of Trail of Time Exhibition location at Grand Canyon's South Rim. (Trail of Time).

Figure 3. Using the Trail of Time. Photo by M. Quinn, 2010.

Understanding Geologic Time

Geologic time is a benchmark scientific principle. The influence of deep time has impacted many scientific disciplines and enables us to understand environmental changes and the preciousness of nonrenewable natural resources. And yet, a 27-year summary and analysis of geoscience conceptions research (Cheek, 2010) indicated that geoscience understanding is lacking in many areas, including understanding the duration of geologic events (Dodick & Orion, 2003a; 2003b) and the length of time between geologic events (Libarkin, 2007). Earth science courses at the high school level are scarce (Barstow, 2002) and most secondary school systems do not consider geology a core science discipline. There is very little research on the "relationship between teacher preparation programs, teacher implementation and student learning" (Lewis, 2008, p. 446). Informal education in the National Park Service has until recently focused on biological and social sciences (National Park Service Advisory Board, 2001). There is also a sociopolitical (religious fundamentalist) opposition to the idea of processes related to geologic time such as evolution (National Center for Science Education, 2011; National Science Teachers Association, 2011).

Geologic time is hard to comprehend because it is so different from most people's ordinary experiences. The scale of geologic time is so immense it is unfathomable (Trend, 1998; 2001b). People are generally able to understand the passing of decades but comprehending millions or billions of years remains a stumbling block to understanding geologic principles related to deep time (Gould, 1987; Trend, 1998). Current research with university populations indicates that many students lack an effective conceptual framework to comprehend very large time frames (Cheek, 2010; Catley & Novick, 2009; Libarkin, 2007).

Today educational research on student comprehension of geologic time remains limited. Currently most research on how students understand deep time is conducted in classrooms (Ault, 1981; Trend, 1998; Dodick & Orion, 2003a; 2003b; Libarkin, 2007; Catley & Novick, 2009) and focused on sequential ordering of major Earth events (Cheek, 2010).

Cognitive and education researchers Jeff Dodick and Nir Orion proposed that understanding of geologic time can be divided into two modes; absolute (event-based) and relative (logic-based) time (Dodick & Orion, 2003a; 2003b).

The first mode, event-based, is that in which major events in geologic history are assigned an absolute age and a sequence of events is established (Dodick & Orion, 2003a; 2003b). In looking at the major events of Earth's history, students are able to understand that the Earth is very old and has a long history of slow changes with high impact events (Kastens, 2009). Even though people are able to create a correct sequence of events in Earth's history, the scale of time between these events is poorly understood (Ault, 1982; Trend, 1998; 2001a; 2001b; Dodick & Orion, 2003a; Libarkin, 2007).

Ault (1981) tested second through sixth graders to determine if they could give a relative order to major geological and biological events in Earth's history. He found that children are able to solve puzzles that use the same skills necessary to gaining an understanding of geologic time. While Ault's findings were positive, he was not able to translate these findings to the field. His students struggled replicating the same skills while in the field (Ault, 1981).

Trend (1998) tested 10 and 11-year-old children in the United Kingdom in a classroom setting. He determined that students were aware of major geologic events (e.g., Ice Ages), but there was no clear understanding by the students on the chronology of events in Earth's history (Trend, 1998). In contrast, research on university students' understanding of time based on macroevolutionary themes shows that students have a strong tendency to underestimate how long ago events occurred and how much time passed between events (Catley & Novick, 2009; Libarkin, 2007).

The second mode used to understand geologic time, logic-based, is that in which relative spatial relationships are used to determine the ordering of events (Dodick & Orion; 2003a; 2003b; 2006). Here the logical geologic principles are based on temporal organization. Geologic principles such as superposition, biostratigraphic correlation, and original horizontality are used to determine the relative ages of geologic features.

To gain a full understanding of geologic time, one must recognize that the rock layers are a record of environmental changes over geologic time. Logic-based cognition describes how students are able to reconstruct geologic time using the natural (but largely static rock and fossil record). Students understand this relationship between different strata and the transformations that they represent by diachronically thinking.

Diachronic Thinking

Jacques Montangero's (1996) model of diachronic thinking is a knowledge perspective that identifies how people use their acquired temporal knowledge to improve their understanding. The diachronic thinking perspective provides a way to determine if one's understanding is simply quantitative, or if the respondent has developed a way to look at problems in a qualitative perspective (Macar, Pouthas, & Friedman, 1992). Diachronic thinking shows respondents' organizational knowledge as well as their abilities relating to causal explanations. It allows one to view an object over time to consider how that object has changed from what we see today. Therefore, using the diachronic thinking perspective allows researchers to understand "aspects of cognition which plays a crucial role in the acquisition and restructuring of knowledge" (Montangero, 1996, p. 184).

Dodick and Orion (2003a; 2003b) applied Montangero's model of diachronic thinking based on the understanding that "temporal understanding in geology has a basis in more generalized cognitive principles" (Dodick & Orion, 2003a, p. 415). Although not directly related to geologic time, Montangero's diachronic thinking is based on the idea that all things are situated in time whether it is a specific time or a sequential ordering of events (Montangero, 1996).

Translating Montangero's diachronic thinking into principles of geologic time, Dodick and Orion (2003a; 2003b) described the cognitive skills needed to understand geologic time. The three schemes of the diachronic thinking model associated with geologic principles of time include: (1) Transformation, which provides the means for understanding that a change has happened; (2) Temporal organization, which gives a sequential ordering to the transformations; and (3) Interstage linkage, in which a connection between transformations is applied for full comprehension of the problem.

To evaluate logic-based cognition, Dodick and Orion (2003a; 2003b) devised and validated an instrument; they named the Geological Time Aptitude Test or

GeoTAT. Using the GeoTAT the researchers explored how middle and high school students understand geologic time based on the temporal relationship among strata in a geologic column. Dodick and Orion found that students from around eighth grade could activate the basic diachronic schemes to solve problems dealing with relative time.

Timelines

Linear timelines have been used in formal and informal settings alike to teach principles of geologic time. Timelines help learners to conceptualize different temporal scales. Trend (2006) suggests that timelines can be successful teaching tools but *conceptual anchors* are required for the timeline to be understood. Conceptual anchors are defined as concepts that are generally agreed upon by the scientific community, such as when life appears on Earth, or when the Grand Canyon was carved by the Colorado River. Different types of models have been created to teach about geologic time, but research is lacking on their pedagogical and cognitive effectiveness (Semken et al., 2009; Dodick & Orion, 2007).

The ToT is a linear, horizontal timeline that leverages views of the exposed strata to teach about geologic time. The ToT therefore utilizes both the event-based and logic-based modes of learning about geologic time. An event-based mode of learning is employed in the representation of specific timing of large events of Earth's history along the timeline. Being situated in a setting where the strata (a record of events) are exposed provides an opportunity for logic-based learning by identifying the relationships among layers and understanding that time is represented in these layers. This horizontal/vertical relationship is a key characteristic of the ToT and this research is directed at the effectiveness of the ToT in teaching about geologic time using a horizontal timeline and the vertical encoding of time that it represents.

Chapter 3

METHODS

Research Project Design

In April of 2009 the research team made their initial visit to the South Rim of Grand Canyon National Park. Participants included the researcher, advisor Dr. Steve Semken, Dr. Jeff Dodick, and research assistant, Adam Frus. During this trip the researchers determined the breadth of the research questions, the logistics requirements, and protocol for interviews.

It was determined that data collection would come from specific sites along the ToT. Researchers would be stationary and only observe the interactions of visitors to the ToT within a limited space. The marker representing 270 million years ago (270 Ma) was initially selected based on the panoramic views of both the north and south Canyon walls and the presence of a ToT wayside panel. (A second location at 540 Ma was later selected for the second data collection trip.)

In May 2009 a second trip to the Grand Canyon was made with ToT principal investigators and designers from the University of New Mexico (UNM; Dr. Karl Karlstrom and Dr. Laura Crossey et al.), NPS interpretive personnel (Judy Hellmich-Bryan et al.), and the external evaluators for the project (Dr. Deborah Perry and Dr. Eric Gyllenhaal of Selinda Research Associates). This trip familiarized the researcher with the ToT Exhibition in its interim condition. The researcher had the opportunity to assess the ToT content and observe visitor interactions with the exhibition.

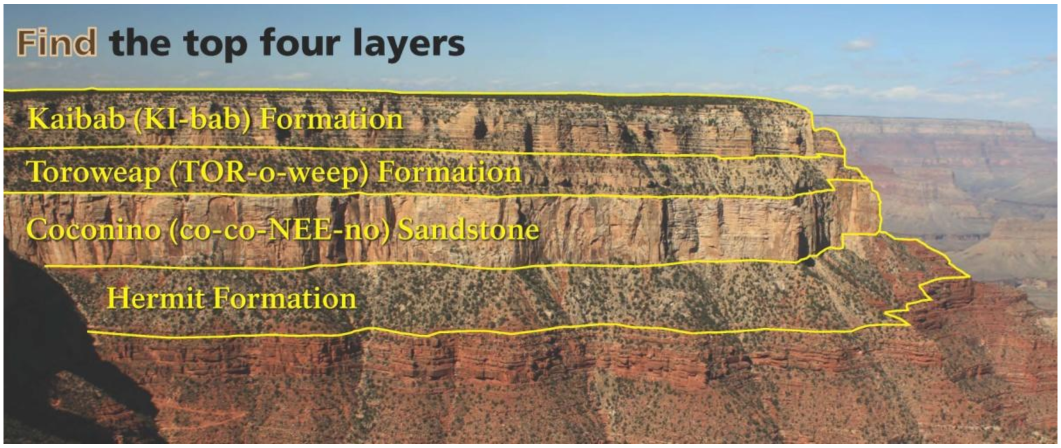
While the timeline medallions and markers had by that time been permanently installed on the South Rim Trail for the Deep Time Trail segment of the ToT, the other elements of the exhibit were still being manufactured. The medallions for the Million Year Trail (changing scales) segment had not yet been installed. It was decided that this portion of the ToT, having been previously studied off-site (Semken et al., 2009), would not be used for this research.

The interview protocol was initially developed in April 2009 from a preliminary script developed by the advisor. The researcher proposed changes based on observations made during the May 2009 evaluation and concurrent discussions. Further discussions among the researcher, advisor and Dr. Jeff Dodick led to a finalized interview script (see Appendix B for Interview Protocols).

Questions 1 and 2 (referred to as Q1 and Q2) were designed to determine that the participant(s) understood the logistics of the timeline by pointing at the timeline medallions and indicating which direction is west. These are binary questions that test whether participant(s) understand that in a westward direction, the numbers were increasing and represented going backwards in geologic time.

Question 3 (Q3) is a multiple-choice question that tests the respondents' understanding of superposition and relative dating. Standing on the edge of the South Rim, respondents were introduced to the different geologic layers that make up the Canyon walls. Using the layers on display in the Canyon walls as well as a hand-held image that identified contacts and named the formations, visitors are asked, "which layer is the youngest?" (*Figure 4*).

(A)



(B)

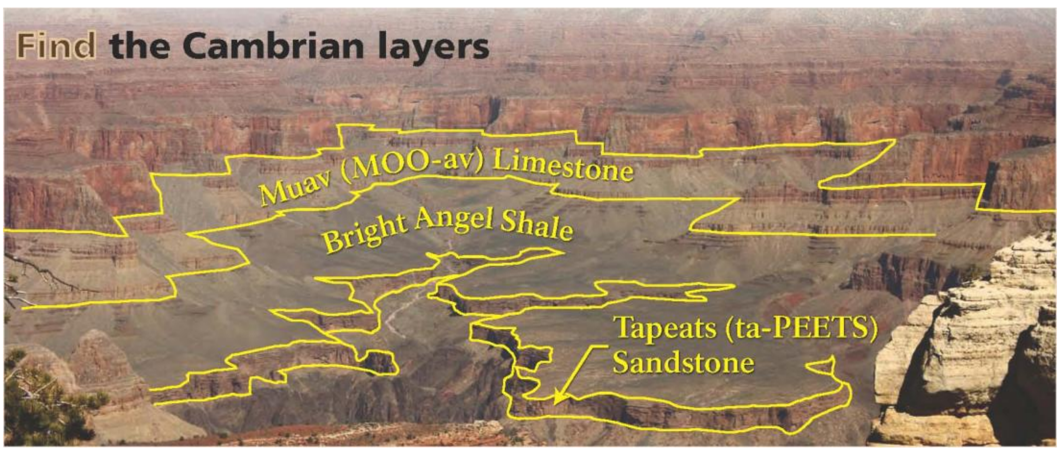


Figure 4. Hand-held images used with interview Q3. Photo (A) was used at location 1 and photo (B) was used at location 2. Photos provided by R. Crow, UNM.

Question 4 (Q4) tests the respondents' ability to reconcile time encoded vertically in the strata with the horizontal representation of time in the Trail of Time timeline. Related to the answers given by the respondent to the previous three questions, visitors are asked to determine which direction along the Deep Time Trail one would have to walk to find the time in which an older or younger rock unit was deposited. The researcher would point to the Canyon wall, use the hand-held photos (*Figure 4*), point to the exhibit medallions and wayside (see Appendix C), and point east and west, to help respondents understand the question.

Question 5 (Q5) tests the respondents' ability to recognize lateral continuity when viewing the Rims of the Canyon. With clear views of both the South and North Rims, the researcher would point out obvious landforms on both Rims and again use hand-held labeled images similar to those used with Q3 (*Figure 5*).

Figure 5. Hand-held image used for interview Q5. Photos provided by R. Crow, UNM.

Question 6 (Q6), which was only asked at the 540 Ma location, tests respondents' capacities to explain the larger picture of environmental changes over geologic time as envisioned while viewing all of the exposed layers visible in the Canyon. Researcher would point out layers that had already been introduced as well as point to the entire Canyon wall.

Question 7 (Q7), also used only at the 540 Ma location, asks respondents to suggest a quantitative age for the oldest rocks found in Grand Canyon.

Data Collection

Two separate periods were designated for data collection in the summer of 2009. A total of 191 interviews were completed. The interviews were with groups varying in size from individuals to seven or more. To collect data in the National Park permits were obtained: NPS Scientific Research and Collecting Permit GRCA-2009-SCI-003 for Study Number GRCA-00530, start date July 01, 2009 and expiration date November 30, 2009. (NPS has the original copy of the permit on file, and research advisor retains an unsigned secured copy of the permit. The ASU Institutional Review Board granted this study exempt research status (Protocol number 0905004046; see Appendix A).

As noted above, the final wayside panels, rock displays, and viewing tubes for the entire ToT were not installed at the time of research. Temporary versions of the wayside panels and viewing tubes were used to simulate the final ToT Exhibition as closely as possible (*Figure* 6). The ToT design team provided up-to-date digital versions of eight Deep Time Trail waysides that were printed as 3'x4' posters and laminated (Appendix C). These temporary waysides where mounted on wooden saw-horses to provide the respondents and other visitors with realistic ToT content.

(A)

(B)

Figure 6. Photographs of temporary displays at 6 Ma medallion marker. (A) Front view of panel: Grand Canyon is 6 million years old (B) Back view. Photos by J. McNeil.

The initial data collection period was July 24, 2009 through August 2, 2009. Research was conducted at the 270 Ma marker and accompanying wayside titled "The top layer is 270 million years old" (Appendix C). The text further explains the principles of superposition and lateral continuity using the views from both the south and north Canyon walls which can be seen from this location. These views prominently displayed the exposed Kaibab Formation, Toroweap Formation, Coconino Sandstone and Hermit Formation.

The second location, at 540 Ma, was used for the second collection period, August 12, 2009 through August 18, 2009. Moving the location allows for results to be applied to the entire ToT timeline, rather than to just one view of the Canyon or one portion of the timeline. The second location required the visitor to look across from the South Rim to the North Rim to view the lower Paleozoic layers. This location was near the wayside panel (titled "Animal Life appears about 630 Ma") at which visitors are taught about the Cambrian explosion and given the names and ages of the four rock units regionally deposited within this time frame (Appendix C). Here visitors were able to look into the Canyon and see the Muav Limestone, the Bright Angel Shale and the Tapeats Sandstone exposed beneath the North Rim. The younger Paleozoic layers of the Grand Canyon are also visible below the North and South Rims from this location.

Preliminary results from the 270 Ma location indicated that interview questions were not drawing out explicit answers to the idea of environmental changes over geologic time as represented in the strata. The review of research results also indicated a need for the visitors to offer a quantitative number on the age of the oldest rocks. At this time Q6 and Q7 were added to the protocol to probe for richer descriptions of visitor understanding (see Appendix B for full script).

Semi-structured interviews were conducted using a random sampling of Park visitors (n=191). The first day of each data collection period (July 24 and August 12) was not included in the research results due to changes to the interview protocol on each of those days. On July 31 there were also two interviews that were not included due to audio recording difficulties and transcripts were not able to be produced. Therefore the total number of interviews used for results is n=166.

Visitor interaction with the ToT has been previously studied by Selinda Research Associates (Gyllenhaal & Perry, 2004), who found that visitor participation includes physical engagement, intellectual engagement, social engagement and emotional engagement. In this study, this researcher also observed that some visitors engage by reading and discussing the waysides, while others would take note of the medallions and continue walking. Others appeared to ignore the exhibition. Visitors were asked to participate if the researcher observed any interaction with the location wayside and/or medallions.

Researcher and assistant were stationed at the designated medallion and wayside. The researcher asked questions and audio recorded the interviews after obtaining permission from the respondent(s). The assistant, stationed slightly off to the side, noted group comments, recorded general demographics of the respondents and tracked answers on an observation form that was used for preliminary analysis of the interview data (*Figure 7*).

TRAIL OF TIME Research Log

DATE: ____________________

RECORDER: ____________________

ID Number		
Data collected on participant through **observation only**		
Age	Gender M / F	Race/Ethnicity

Data collected on participant through **open-ended questions**	Data collected on participant through **research questions**
State/Country	**Walking west,** 1. Increasing or decreasing
Visited GC before?	2. Forward or backward
1st Language?	3. Superposition I II III
Who are you here with today?	4. Which direction to find Toroweap time East or West
Visit Yavapai Museum?	5. Lateral correlation I II III
Reading the ToT signs?	
NOTES/COMMENTS	

Page Number__________

Figure 7. Research observation log for preliminary results.

During each interview, the researcher used the labeled images of Canyon vistas described above (*Figure 4* and *Figure 5*). These hand-held pictures helped the researcher to point out the different formations and to clarify the interview questions. Participants were also allowed to reference the waysides, although the researcher never pointed directly to the wayside portion of the exhibit.

Initially the interview would start out conversational. Unstructured, open ended questions were asked about the respondent's visit to the Grand Canyon. The goal for these icebreaking questions was to learn as much as possible about visitors in a casual, friendly and not overly intrusive manner. Not all questions were asked of every respondent. Such opening questions included:

- Have you been to the Grand Canyon before?
- What language do you usually speak? (ask only if respondent appears to not speak English)
- Who are you here with today?
- Have you had the chance to visit the Yavapai Geologic museum?
- Have you been reading the temporary waysides that have been displayed along this trail?

Once the respondents seemed comfortable with the interview, the researcher would begin with the scripted questionnaire (see Appendix B for full script). For the different questions, the researcher would draw the participants' attention to different parts of the landscape or ToT Exhibition.

Protocol Changes

Researcher's initial field notes demonstrated that Q5 was worded awkwardly and that respondents were not able to understand the question. Researcher and advisor agreed to changes to the protocol which included asking "what was missing" or "what did it look like before". Field analysis indicated that this was leading the respondents to the answers. Further field discussions led to a finalized text for Q5: "Can you explain how we get the same rocks on both sides of the Canyon?"

In-the-field changes to Q4 helped to clarify how the question was relating the stratigraphy to the horizontal timeline. Initially it was perceived as vague by respondents because they did not understand it was directly related to the ToT exhibition. Changes to the interview protocol included bringing the respondent back to the Deep Time Trail, placing him or her right at the 270 Ma or 540 Ma medallion, and asking "In which direction along this exhibit would I walk to find…."

Q6 asked respondents to explain the different environments represented in the walls of Grand Canyon. Field observations indicated that this was a leading question and the text was changed to: "Now you have been introduced to three sedimentary rock types. When we look at all of the layers in the Grand Canyon, what story do those layers tell?"

Data Collection Limitations

There were some limitations to the data collection. Both field locations at the South Rim of Grand Canyon were very windy with often uncomfortably warm days (above 90˚F and strongly sunny). Technology limitations also restricted results. Interviews were audio recorded making it impossible to later identify individual respondents in a group.

Participant group size also made observations difficult. Hand gestures or other physical interactions during the interviews could not be recorded. Researchers also noted that in many interviews several people from the group would answer some but not all of the questions. In this study, groups were reduced to a single response. If the group did not agree on an answer to any of the questions the researcher identified a primary speaker by looking at the transcripts and counting the number of times each person spoke. The person who spoke the most was then identified as the primary speaker and his or her responses were counted as the group response.

Data Analysis

Qualitative social science methods are used in situations where research is being conducted in a natural setting. In this project, the researcher is responsible for data collection and data analysis, which can be more subjective (Chi, 1997).

Verbal analysis method. Verbal analysis (Chi, 1997) is a method of quantifying qualitative data to reduce the subjectivity inherent in using the spoken or written word as data. Quantifying qualitative data is a way to control and manipulate variables to test specific hypotheses. Although this approach has been used by many researchers, it is difficult to generalize findings to other settings.

Chi (1997) states that the goal of verbal analysis method is to identify what a learner knows by what they say. The verbal analysis method allows researchers to understand how knowledge affects the way the learner reasons and solves problems. This method outlines a way for researchers to both quantify what is said and dig deeper underneath to establish relationships in thinking behind the words. This combination leads to improved instruction design to add to the subject's knowledge.

Verbal analysis categories for coding emerge from the data rather than pre-determined (*a priori*) data coding categories. This method allows for a fuller variation in understanding to be expressed and evaluated. Categories are coded, counted and analyzed quantitatively as well as qualitatively.

Verbal analysis technique. Data are collected, transcribed and read several times as a corpus. Chi (1997) gives a breakdown of the technique into eight steps.

1. Decide whether to analyze the entire body of protocols or only selected samples;
2. Break the protocols chosen for analysis into units called *segments;*
3. Develop a coding scheme, bearing the hypothesis to be tested in mind;
4. Code each segment separately;
5. Display the data in a table or graph for analysis;
6. Seek patterns in the data;
7. Interpret the pattern;
8. Repeat the process.

Coding in *NVivo* software. Interview data were downloaded into *NVivo* software tracking system (NVivo 9, 2010) to allow for ease of coding. *NVivo* software allows the researcher to see the number of times a source is coded as well as the number of sources in a code. Data were analyzed based on the number of different ideas each group expressed per interview. *NVivo* compiles the categories that were present in each interview and identifies the distribution of categories over entire data set

Respondent answers to each of the seven questions were coded separately as the first segment. Respondents' comments were the only part of the interview to be coded. Interviewer's comments and questions were disregarded. Using *NVivo* the segments were then coded into a coarse grain size based on the correctness of the respondent's answer (Appendix D shows coding scheme based on correctness).

In order to identify how the respondents used the landscape, a second coding scheme was created from the interviews themselves. This detailed scheme was created by listening to the audio recording and reading along with transcripts.

The fine-grained analysis was based on an idea, with some ideas being expressed as a single word. Specific codes were created as new ideas were found that did not fit pre-existing codes. Using *NVivo* the transcripts were coded for the use of landscape. (Appendix D shows transcripts of respondents' answers and the coding assigned to those answers.)

Upon review of the fine-grained coding, it was found that there were similarities among the codes. A new coding scheme was created by the researcher to consolidate like words and comments that were similar expressions. (Appendix D shows the consolidation of landscape coding).

After this consolidated list was reviewed, an additional coding scheme was identified. This third scheme was based on what respondents expressed about the *physical landscape* or the *inferred landscape* as defined in Table 1.

Inferred landscape. The inferred theme is used when the respondents were explaining processes and physical changes that were not visible from the location today at the Grand Canyon. Processes such as the passage of geologic time, tectonics and deposition are not directly experienced from the Canyon's Rim, but instead must be inferred.

Observed landscape. The observed theme identifies respondents' use of the landscape they could observe from the Canyon's Rim. Objects seen today such as layers, vegetation, cliffs, and the river and layer thickness were used by respondents to explain their answers to the interview questions.

Q5 regarding lateral continuity (Respondent, 080209_13)

> "Because they were both formed at the same time and the river went through and went down in between them. At one point they were all the same plane, except where the river went through."
>
> Coded into:
>
> Inferred Landscape
>
> Observed Landscape

Table 1

Coding Scheme for Inferred and Observed Landscape Usage

Inferred Landscape Usage	**Observed Landscape Usage**
Environment	Elevation (vertical)
Erosion	Direction (horizontal)
Geologic Time	River
Means of Sedimentary Deposition	Use of exhibit
Previous Landscape	
Tectonics	
Water	

Diachronic Thinking

Using the Dodick and Orion (2003a; 2003b) translation of Montangero's diachronic thinking onto principles of geologic time, an additional coding scheme was created. In a personal communication with Dr. Dodick in May 2011, it was determined that applying the diachronic coding scheme would be appropriate for Q5 and Q6 as they were open ended questions and had partially correct answers (APPENDIX D).

Transformation. Montangero defines the transformational scheme as a "principle of change" (Montangero, 1997, p166). He goes on further to explain that this change can be either qualitative or quantitative. The transformational scheme is activated when a respondent identifies either (or both) a quantitative increase or decrease in the number of elements comprising an object or a qualitative change to the physical appearance (shape) such as a growing tree. Dodick and Orion use the principle of actualism or actualistic thinking where "the present is key to the past" to correlate geological knowledge with Montangero's transformational thinking. Geologic transformational thinking is represented by the understanding that many of the processes that shape contemporary depositional environments are representative of past geological environments (Dodick & Orion, 2003a; 2003b). Applying Dodick and Orion's interpretation to this research leads to the inference that transformational thinking occurs when visitors to the ToT understand that the environment of today could be different than the environments of the geologic past (by modeling the environment of the past on processes operating in the present) (J. Dodick, personal communication, June 3, 2011).

> "Originally the formation was like under the sea and the Kaibab Formation was like silt on the bottom of the sea"

Here the respondent is activating the transformational scheme of diachronic thinking. The respondent implies his understanding of sedimentary deposition where "the Kaibab Formation was like silt on the bottom of the sea". He further explains the transformation of the environment by stating that "originally the formation was under the sea", inferring his knowledge that the dry, arid environment of today's Grand Canyon is different from the environment during which the Kaibab was deposited.

Temporal Organization. The temporal organization scheme of diachronic thinking permits a subject to "identify the temporal links between stages of an evolutive process" (Montangero, 1996, p. 167). The geological principles that correlate to the temporal organization scheme are the logical principles of superposition, original horizontality, lateral continuity, cross-cutting relationships and the "rule of inclusions". In other words, geological principles that permit one to logically order the three-dimensional relationships of the strata and thus determine the temporal direction of events (Dodick & Orion, 2003a; 2003b). Based on this interpretation, the temporal organizational scheme is activated on the ToT when visitors understand that the top layer is youngest (superposition) or that the Canyon's layers were originally deposited continuously and horizontally over an area (J. Dodick, personal communication, June 3, 2011).

> "Well because the older one was first to be distributed by whatever means, and then the next layer isn't going to go under it. It will go on top of it. "

In describing the logic behind the principle of superposition, the respondent is utilizing the temporal organizational scheme of diachronic thinking. Describing the three-dimensional strata by the process of what was first, next and last gives an order to the depositional sequence.

"Well you would think that before it was the rim would have kept going across that space there and you'd have the formations that are here on the south rim and on the north rim would continue through that gap there."

Here the respondent is activating the temporal organization scheme of diachronic thinking as represented in geology as the principle of lateral continuity. When asked "how does the Canyon have the same rocks on both sides?" the respondent understood that "before it was the rim" the land "kept going across" and that the "formations…would continue through the gap". Activating the temporal organization scheme, the respondent is able order the sequence of events. Initially the layers were connected but today, due to the cutting process of the river, we have the Grand Canyon.

Interstage Linkage. The interstage linkage scheme is activated when a connection between the transformations over time and the succession of the transformative states are part of an evolutive process. Utilizing the interstage linkage scheme a respondent understands the passing of time and the progression of a process are connected but not necessarily linked (Montangero, 1996). Dodick and Orion (2003a; 2003b) relate this scheme to geology by indicating that "such stages are reconstructed through the combination of actualism as well as through the use of (scientific) causal reasoning" (Dodick & Orion, 2003a; 2003b). Applying this scheme to the Trail of Time research, respondents were utilizing the interstage linkage scheme when they indicated that each layer represents moments in the passing of time but also represents steps of the depositional process (J. Dodick, personal communication, June 3, 2011).

> "This was the sea floor at one point all of it was much lower and much flatter and it was uplifted as one unit…..and then eroded away, in the center, so these are the same rocks at different elevations."

Indicating that "this was the sea floor" implies that the respondent understood the process of sedimentary deposition and has activated the transformational scheme of diachronic thinking through actualism. Expressing that there was a temporal order starting with "the sea floor at one point" and "then erosion" indicates the use of temporal organizational scheme. The respondent utilizes the interstage linkage scheme because not only did she imply her knowledge of sedimentary deposition as well as the sequence of events, but she also was able to link together a series of independent events "this was the sea floor", "it was uplifted" and "then eroded away".

Interrater Reliability

Social science model indicates that verbal responses contain multiple meanings (Chi, 1997). Word meanings can differ across participants, and words have multiple meanings. The setting for data collection can narrow the frame of interpretation. Individual respondents come with multiple world views and paradigm.

To help ensure reliability, the researcher enlisted the help of an assistant to compare coding outcomes. Researcher coded all materials allowing emergent themes to come from the data. An undergraduate assistant (a secondary Earth science education major with minor in geology) initially coded three days-worth of data *a priori* using categories established from previously coded emergent themes. The process included discussions between researcher and undergraduate on specific questions of clarity. The coding process was then cross-compared in *NVivo* and determined to have interrater reliability Cohen's Kappa statistic of K=0.8999. Interrater reliability is a correlation based measure, where scores close to 1.0 indicate high levels of reliability for the coding of transcripts into a scheme (Cohen, Cohen, West, & Aiken, 2003; Green, Camilli, & Elmore; 2006; Coladarci, Cobb, Minium, & Clarke, 2008). Once the interrater reliability was shown to be satisfactory both the researcher and undergraduate assistant recoded all data under the consolidated *a priori* categories.

Validity

To ensure that the interview questions were "relevant and representative" (Green, Camilli, & Elmore, 2006) in identifying if visitors to the Grand Canyon were able to understand geologic principles by using the layers found in the walls of the Canyon, the questions underwent a rigorous process of content validation. Initially the interview questions were reviewed by experts in the field of cognition, geosciences education and evaluation, including research advisor Dr. Steve Semken, as well as Dr. Jeff Dodick and Dr. Deborah Perry. The interview questions, as well as the cognition that was to be measured, was discussed.

The advisor also joined the researcher on the first day of data collection, at each location, to again ensure content validity. He observed the interviews and gave critiques about the presentation of the questions. With these preparations and in-the-field changes, content validation was ensured for this research design.

Researcher reduced the data size to ensure that the interview methods were valid. The first day of data collection for each location was eliminated from the coded data due to changes in the interview protocol.

Chapter 4

RESULTS

Demographics

The observed data provided information on the demographics of the respondent groups. These results have varying numbers of participants because not everyone was asked the same question in the semi-structured part of the interview. Results indicated that of the observed respondents, 47% were male (n=189), 44% were female (n=177) and 9% were unidentified (n=38). Estimated age categories, were observed as follows; 19% (0-20), 17% (20-30), 13% (30-40), 23% (40-50), 8% (50-60), 6% (0+), and 14% unidentified.

Observations also included information on where the respondent was visiting from. It was recorded on the observation sheet if the respondent shared the information. Results for only those who shared their information show that 60% were from the United States (n=126) with the majority from Arizona and California. 35% were visitors from Europe (n=73) with visitors from England representing almost 40% of all the European countries. Visitors from other localities account for the remaining 3% with seven Canadians, four Israelis, and one Russian.

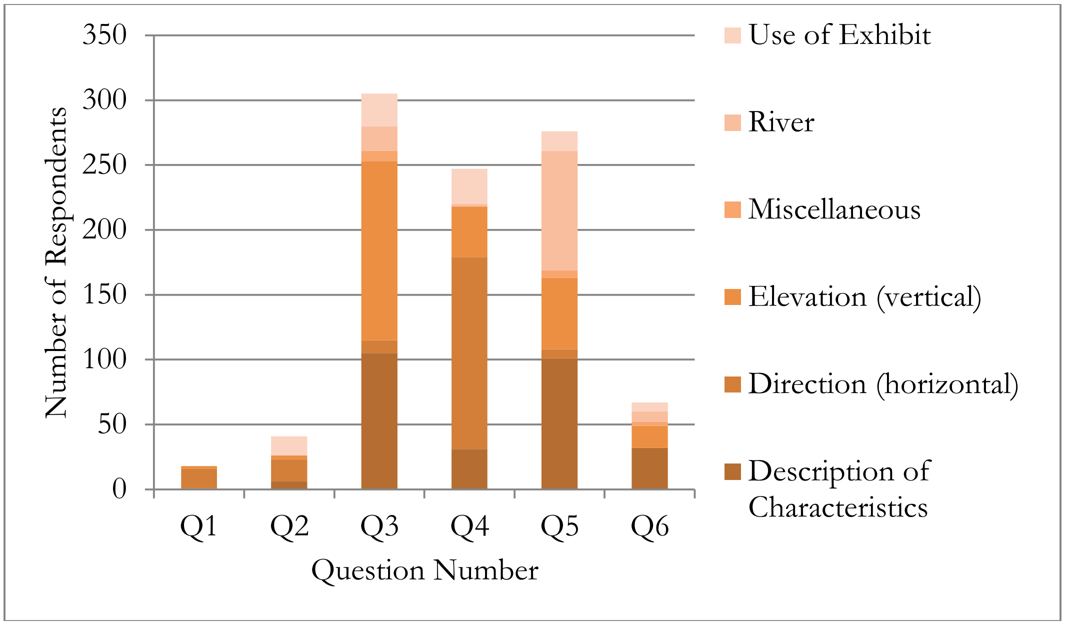
Inferred and Observed Landscape

The coding scheme for identifying how the landscape is used was applied to all seven questions. The total number of respondents who used the different landscape elements from each question was recorded. A total of n=2208 respondent expressions were coded. Results show that of the expressions coded, the respondents used the observable landscape 44% of the time. The most commonly referred element of the observed landscape was, *description of characteristics,* making up

29% of total uses (n=282). A close second and third most observed elements include *elevation* (27%) and the *river* (13%) (see *Figure 8*).

The inferred landscape was used by 56% of the respondents. The single inferred landscape element referred to in all of the questions was geologic time (36%). Tied for the second most commonly used landscape elements were erosion and means of sedimentary deposition each at 16% (see *Figure 9*).

(A)



(B)

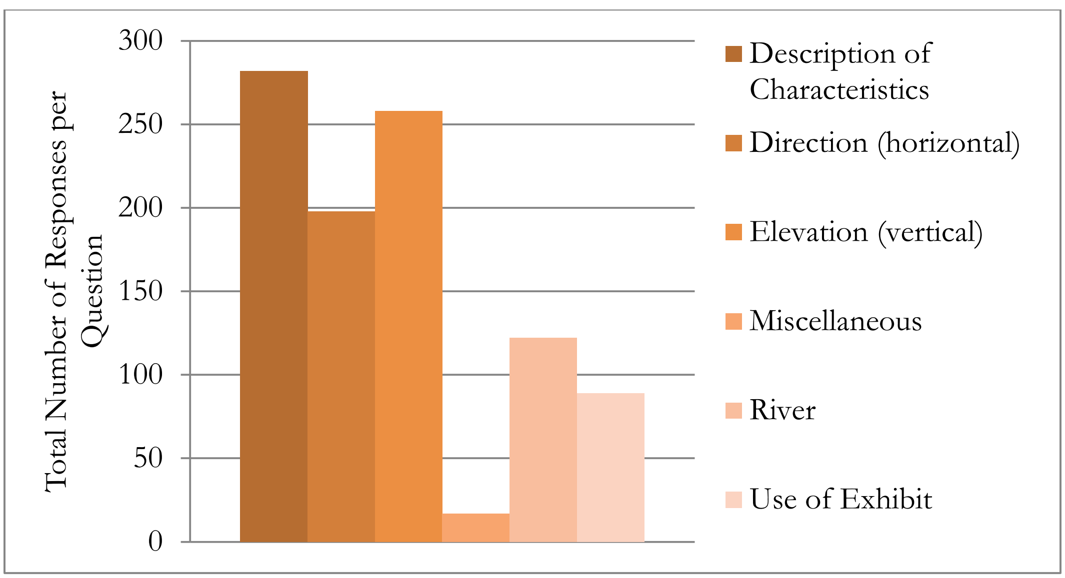
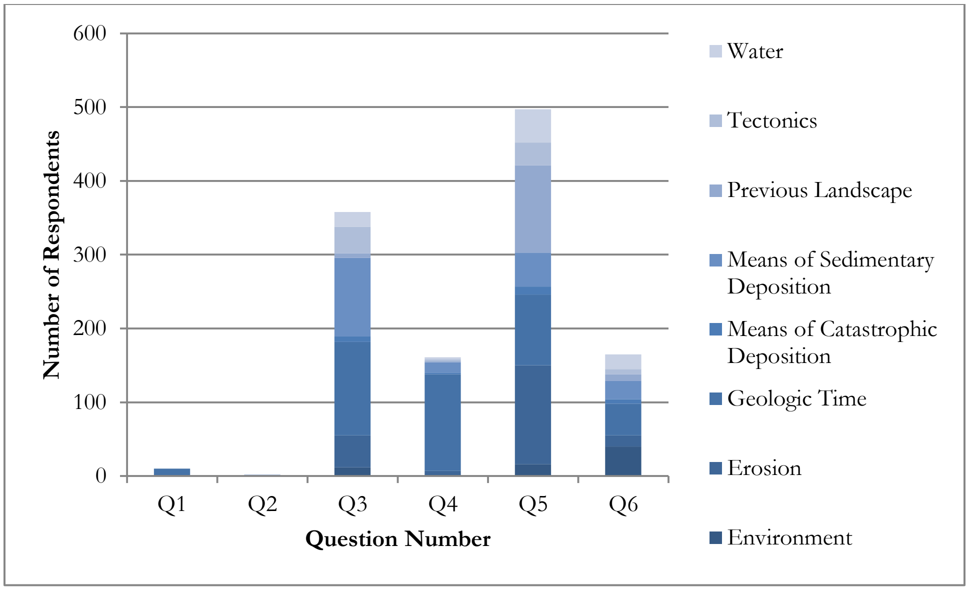


Figure 8. Observable landscape usage per coding scheme. (A) Column graph of the question number and the number of respondents' usage. (B) Column graph of total number of uses for all questions.

(A)



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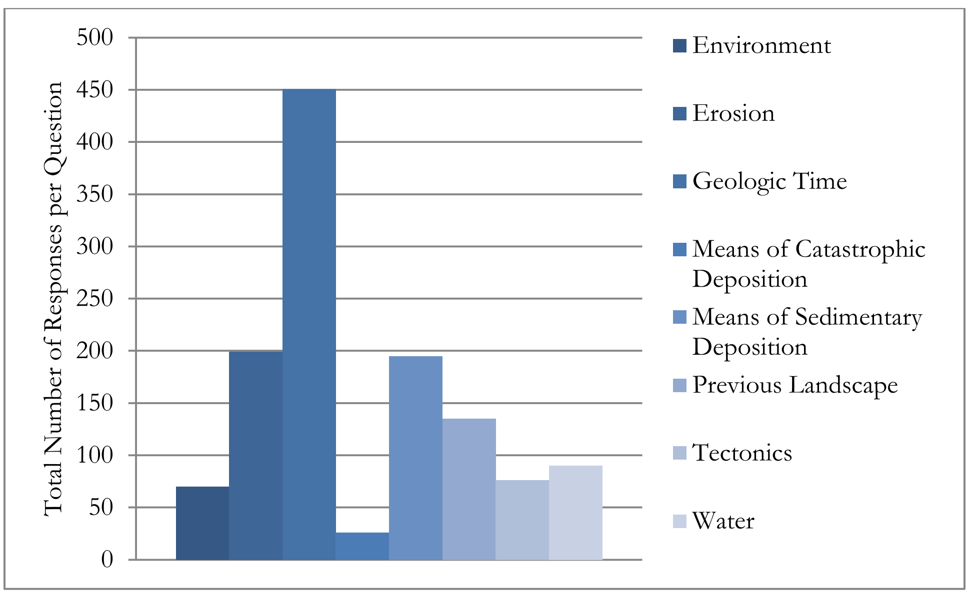

Figure 9. Inferred landscape usage per coding scheme. (A) Column graph of the question number and the number of respondents' usage. (B) Column graph of total number of uses for all questions.

Diachronic Thinking Scheme Activation

Applying the diachronic thinking model (Montangero, 1996) to this research helps to categorize the cognitive skills activated by the different respondents. Coding questions from the script that did not have multiple choice answers (Q5 and Q6, see Appendix B for full script) allows the researcher to understand what level of cognition is activated when trying to understand principles of geologic time.

Results indicate that of the coded responses (n=175) for the two questions, 33 responses (19%) activated the interstage linkage scheme, 105 responses (60%) activated the temporal organization scheme and 37 responses (21%) activated the transformation scheme (*Figure 10*).

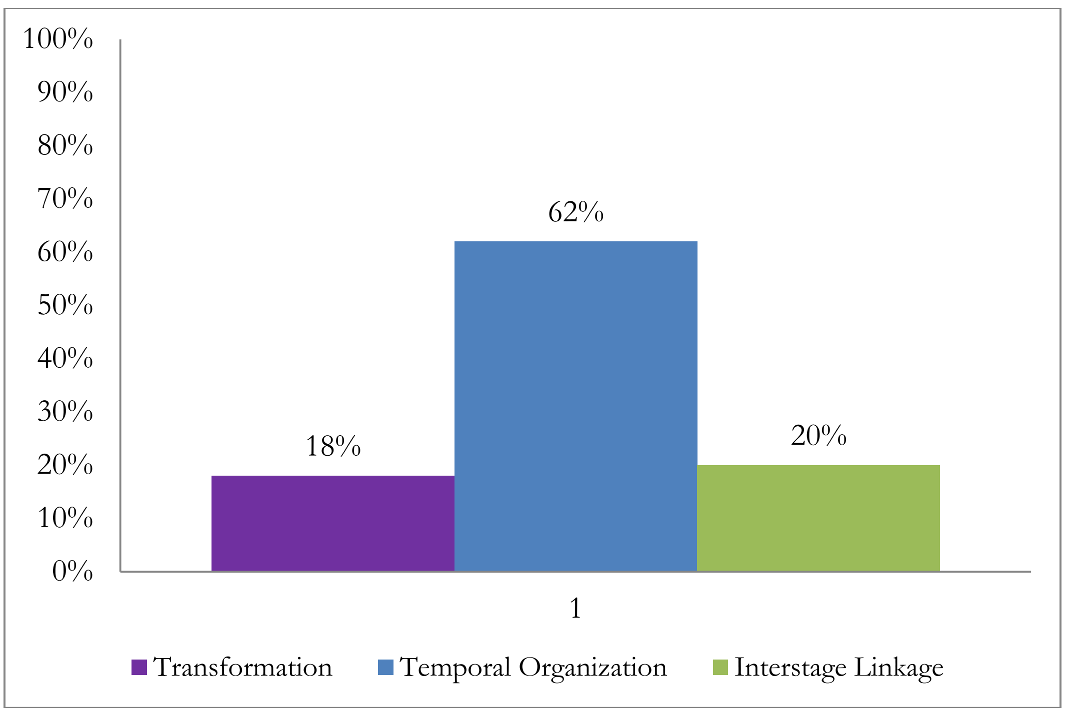

Figure 10. Activation of diachronic thinking schemes for all responses to Q5 & Q6. (n=175).

Closer inspection of results from location 2 identifies how respondents activated each scheme for Q5 and Q6. Results show that 4 respondents activated the interstage linkage scheme for both questions. 21 respondents activated the temporal organization scheme for both questions and 3 activated the transformation scheme for both questions (see *Figure 11*).

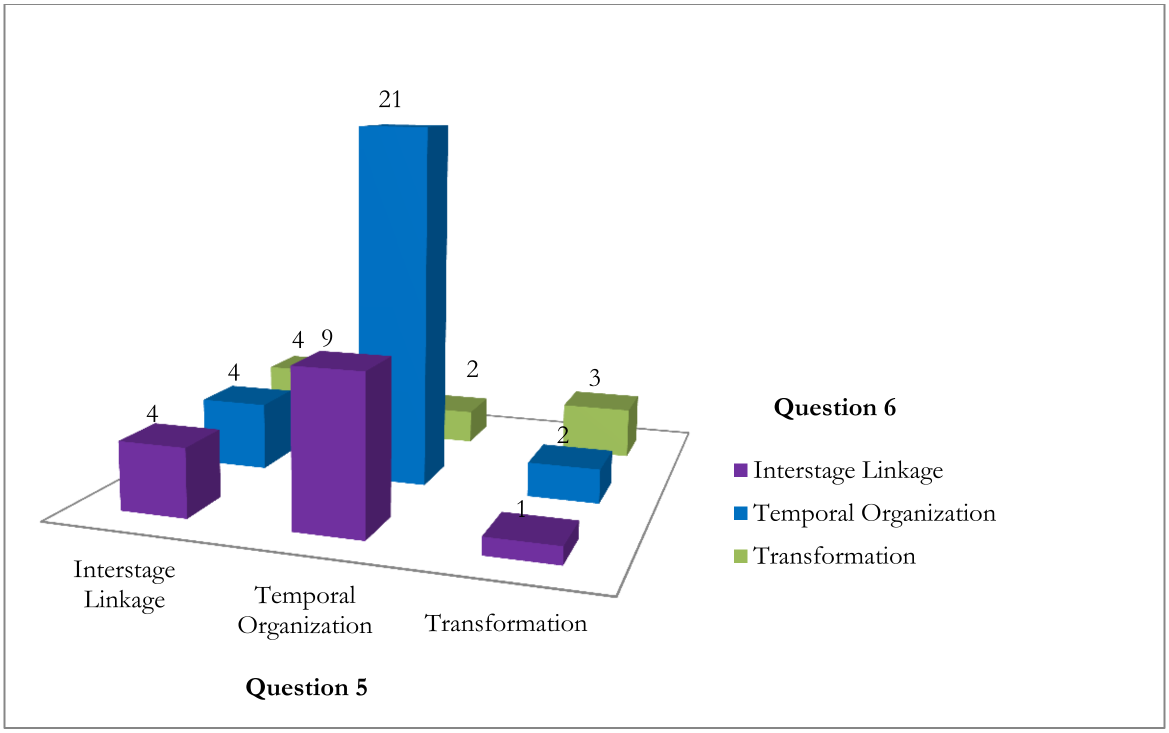

Figure 11. Activation of diachronic thinking schemes per respondent.

Interview Questions and Answers

Visitor respondents were asked to answer five (location 1) to seven (location 2) scripted questions (See Appendix B for full script).

Horizontal Trail of Time timeline logistics. Interview data, after coding for correctness, indicate that a majority of all respondents (n=165) were able to understand the logistics of the horizontal ToT timeline. 90% (149) of respondents correctly responded that the numbers on the timeline increase to the west and decrease to the east and that walking westward represented moving backwards in time (see *Figure 12*).

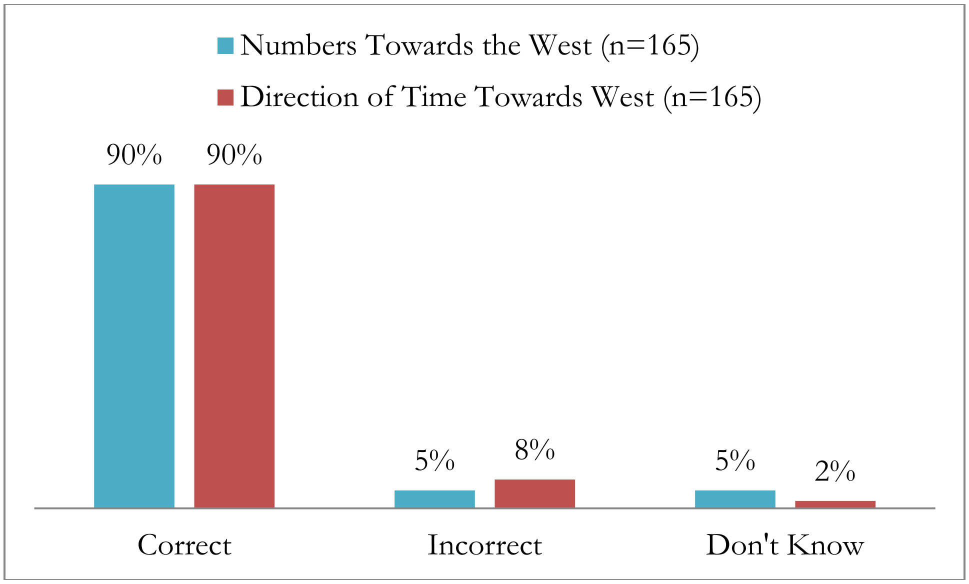

Figure 12. Horizontal timeline correctness.

Horizontal ToT timeline and vertical strata relationship. Not only were visitors able to understand the logistics of the horizontal ToT timeline, but of all responses (n=163), 69% (112) were also able to understand the relationship between the horizontal ToT timeline and the stratigraphically encoded time (see *Figure 13*). Interestingly, 7% (11) of the respondents indicated that they needed to go a different orientation, other than east or west along the timeline, in order to answer Q4. 10 respondents indicated that they would have to up or down in elevation; e.g., "looks like you would have to go to the lower elevation".

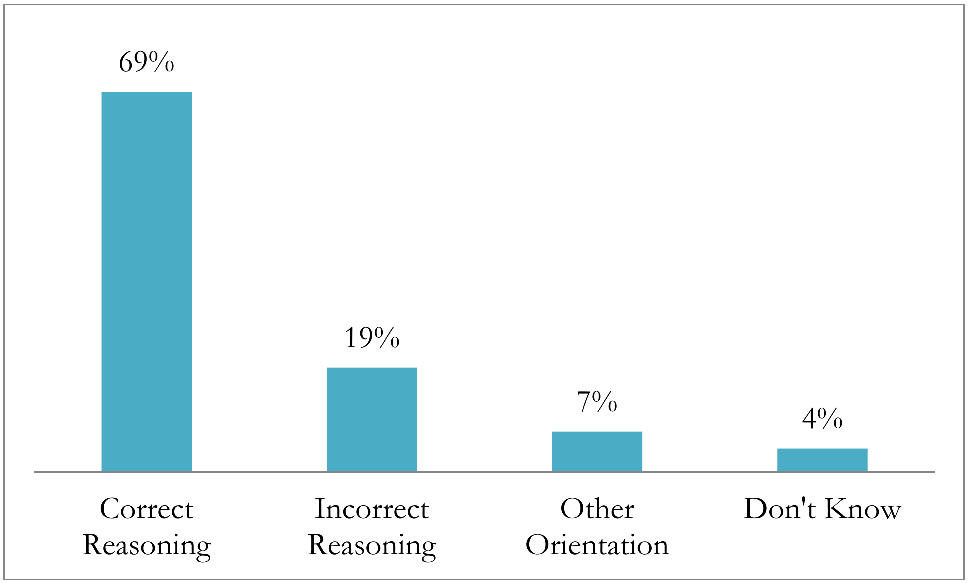

Figure 13. Horizontal Trail of Time timeline and stratigraphically encoded time correctness

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Coding results demonstrate how respondents utilize the landscape to correctly answer the question relating the horizontal ToT timeline and the vertical encoding of time in the strata. Data show that of the correct responses (n=113), 89 (79%) used an integrated approach using both the observable and inferred landscape to explain their answers. Of the remaining respondents who answered correctly, 24 (21%) used only the observable landscape. Of the 31 respondents who had incorrect reasoning, 48% (15) used both the observed and inferred landscape, while 52% (16) only used the observed landscape. Conversely, of those who offered other orientations (n=12), 5 (42%) used the integrated approach whereas 6 (58%) used only the observed landscape. Regardless of their answers, no one used the inferred landscape independently (see *Figure 14*).

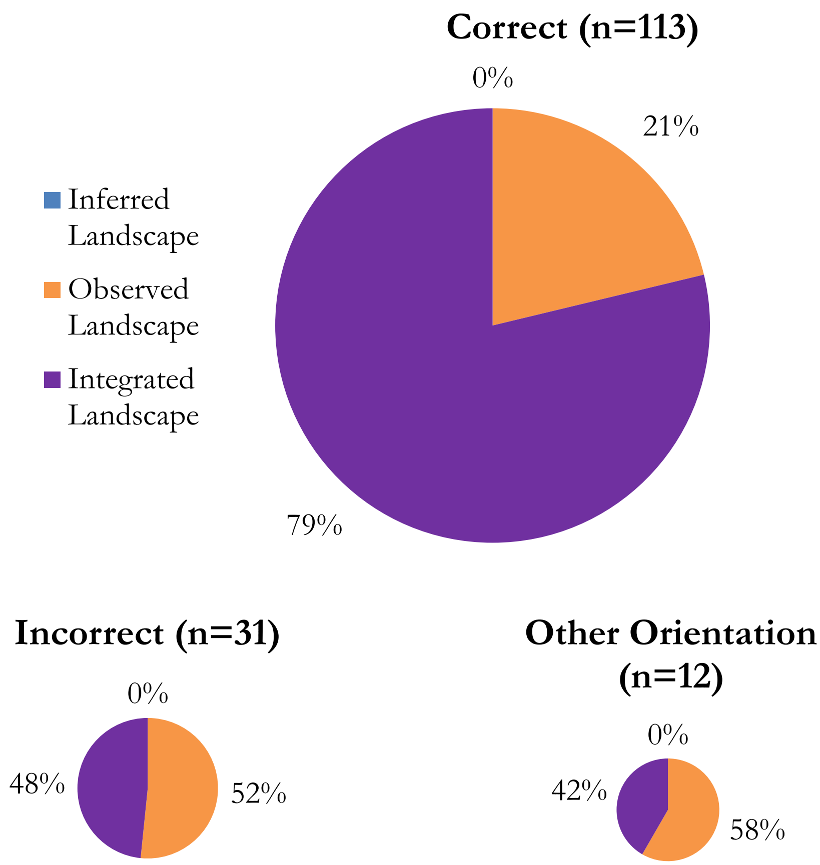


Figure 14. Use of landscape to comprehend horizontal Trail of Time timeline and stratigraphically encoded time by correctness.

Geologic principle of superposition. Coded data indicate that visitors to Grand Canyon National Park are able to understand the geologic principle of superposition when viewing the Canyon walls. When asked if the top layer is older, younger or the same age (Q3), 141 (85%) of all respondents (n=166) correctly answered that the top layer is younger than the layers below (see *Figure 15*).

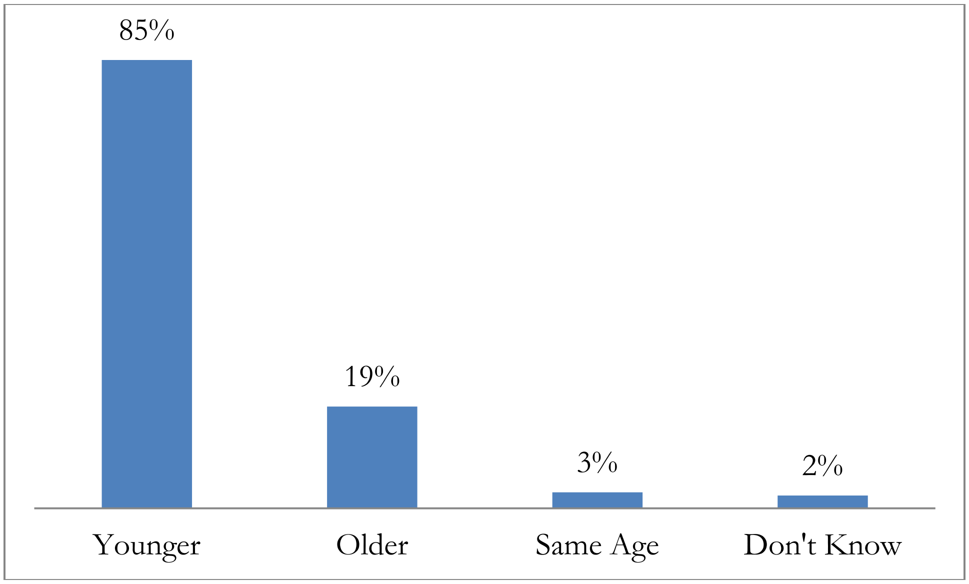


Figure 15. Understanding the principle of superposition by identifying that the top layer is the youngest.

Results show that of the 141 respondents who answered correctly, 125 (89%) of those respondents used the landscape in an integrated approach, utilizing both the inferred and observed landscape. Three (2%) used only the inferred landscape and 13 (8%) used only the observed landscape. Also noteworthy is that of the 25 respondents who did not answer correctly, 22 (88%) used both the inferred and observed landscape and 3 (4%) used only the observed landscape (*Figure 16*).

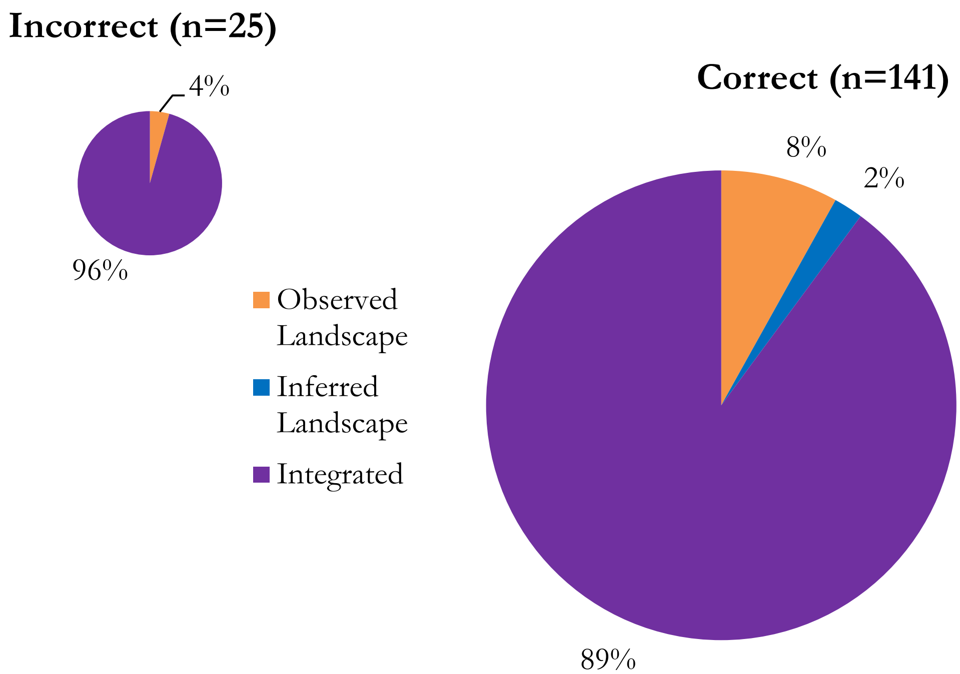


Figure 16. Landscape use by respondents in explaining the principle of superposition (Q3).

With respect to specific landscape elements (Appendix C), results show that a majority of all respondents used the inferred landscape elements of geologic time (127 or 77%) and mode of deposition (107 or 64%). Changes to elevation (138 or 83%) and visible landforms (105 or 63%) were the most-used observed landscape elements.

Respondents who were not able to understand the principle of superposition by looking at the Canyon walls incorrectly referred to erosion (9 or 36%): e.g., "the bottom stuff would be younger because stuff would erode from the top down"; tectonics (9 or 36%); e.g., "I think it's older too because of the stuff on the top is getting pushed up"; and the river (5 or 20%): e.g., "the water was going down right, and then created the layer going down".

Geologic principle of lateral continuity. Examination of the coded data for all respondents (n=164) answers to Q5 show that 97 (59%) were fully correct, 44 (27%) were partially correct, 16 (10%) were incorrect and 7 (4%) did not know (*Figure 17*). To get a fully correct answer, respondents had to reference two events in the geologic past of Grand Canyon, (1) mention of a previous landscape with an indication that the landscape has changed, e.g., "[the rims] were once connected"; "it was one plateau"; (2) identify that erosion created the Canyon, e.g., "the river carved it".

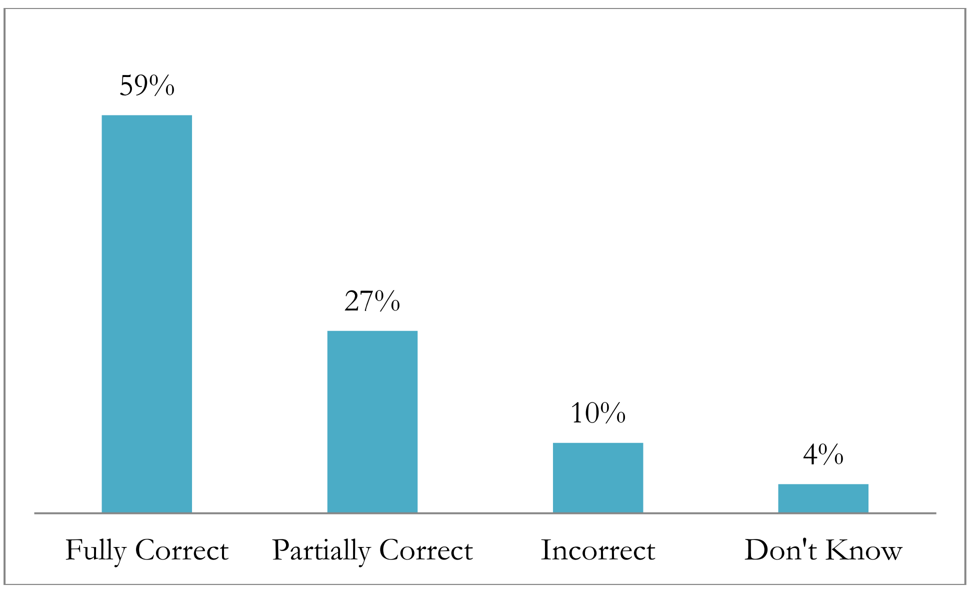


Figure 17. Respondent understanding of the principle of lateral continuity. Fully correct responses indicated the Grand Canyon's wall used to be connected and was later carved by the river. (Total number of respondents n=164)

Partially correct responses only identified one of the two elements. Of the respondents who were scored as partially correct 14 (32%) referred only to a previous landscape and 30 (68%) identified only erosion (see *Figure 18*).

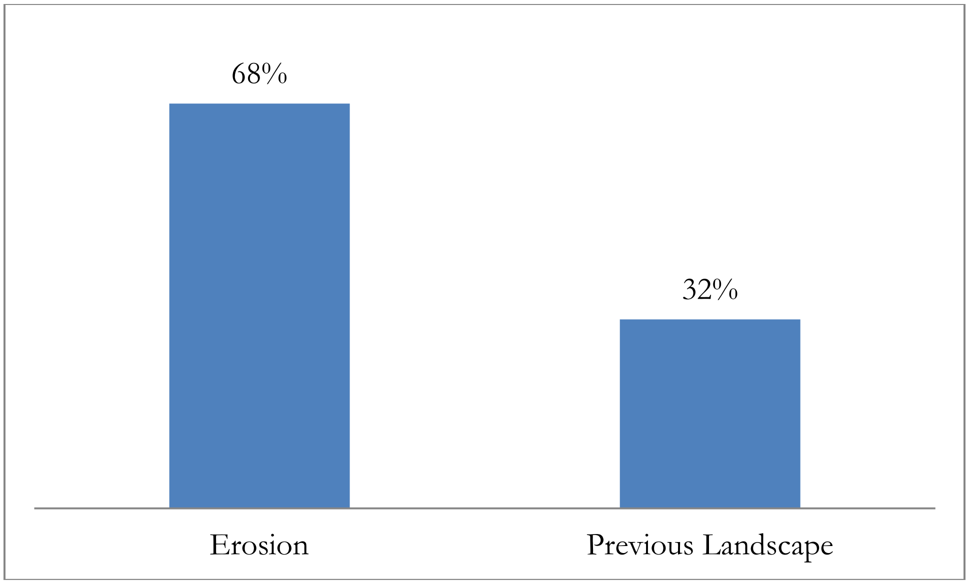


Figure 18. Percentage distribution of how elements were used from partially correct answers to lateral continuity Q5 (n=44).

Respondents' use of the landscape to understand the principle of lateral correlation show that respondents from the fully correct (n=96) and the partially correct (n=44) groups used an integrated approach, 89 (93%) and 39 (89%) respectively. Of these groups there was 7 (7%) and 4 (9%) who only used the inferred landscape while no one (0%) in either group used only the observed landscape. For the incorrect responses, 15(88%) utilized the integrated approach, while 2 (12%) used the inferred landscape only and no one (0%) used only the observable landscape (see *Figure 19*).

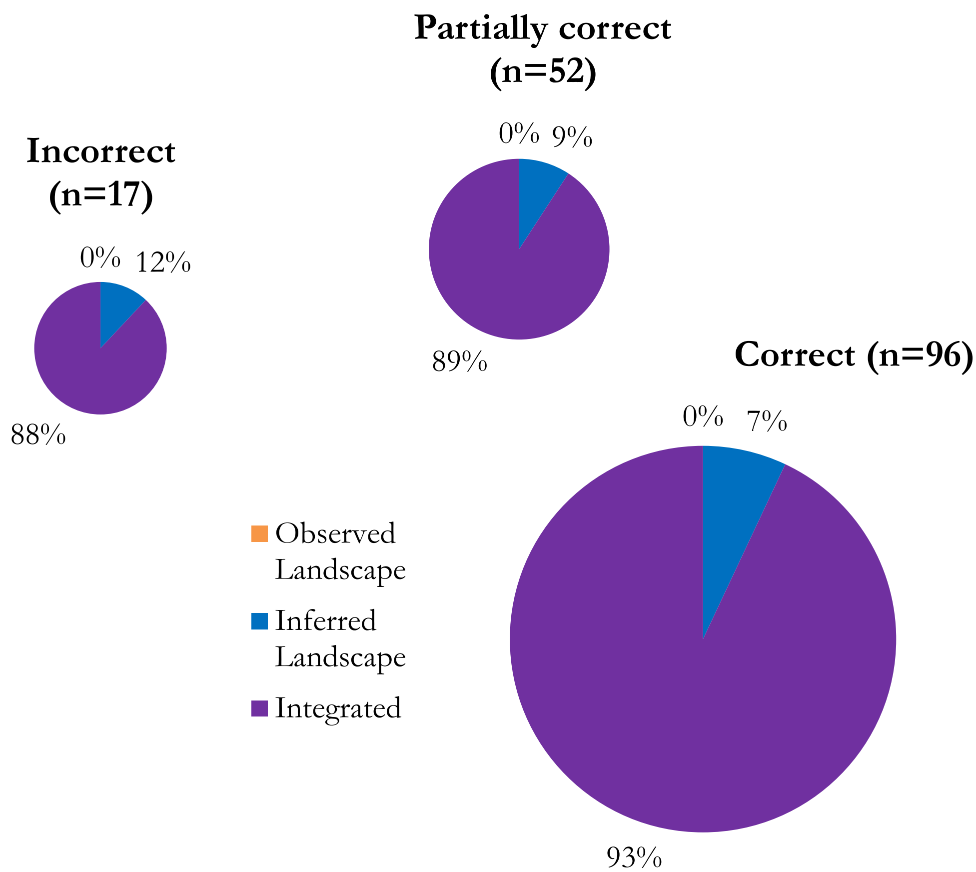


Figure 19. Landscape use by respondents explaining the principle of lateral continuity Q5.

Understanding the geologic principle of lateral continuity has been identified by Dodick and Orion (2003a; 2003b) as activating the temporal organization scheme of diachronic thinking. To activate this scheme, the respondent should recognize the "temporal links between an evolutive process" (Montangero, 1996, p. 167). In regards to lateral continuity at Grand Canyon, respondents should express that first the land was connected, and later the river carved the Canyon. Coded results show 66% of fully and partially correct answers (n=140) activated the temporal organization scheme. Additionally, 23 (16%) of the correct answers were able to activate the scheme of interstage linkage where additional processes (uplift) were described and placed in a correct temporal order; e.g., "this was the sea floor at one point all of it was much lower and much flatter and it was uplifted as one unit and then eroded away". Also noteworthy, of correct respondents, 21 (15%) were able to activate only the transformation scheme. Of this 15%, all of these responses were coded as partially correct as they were only able to identify a transformation, but were not able to indicate a temporal order to this change; e.g.; "some of it is gone, eroded out" (*Figure 20*).

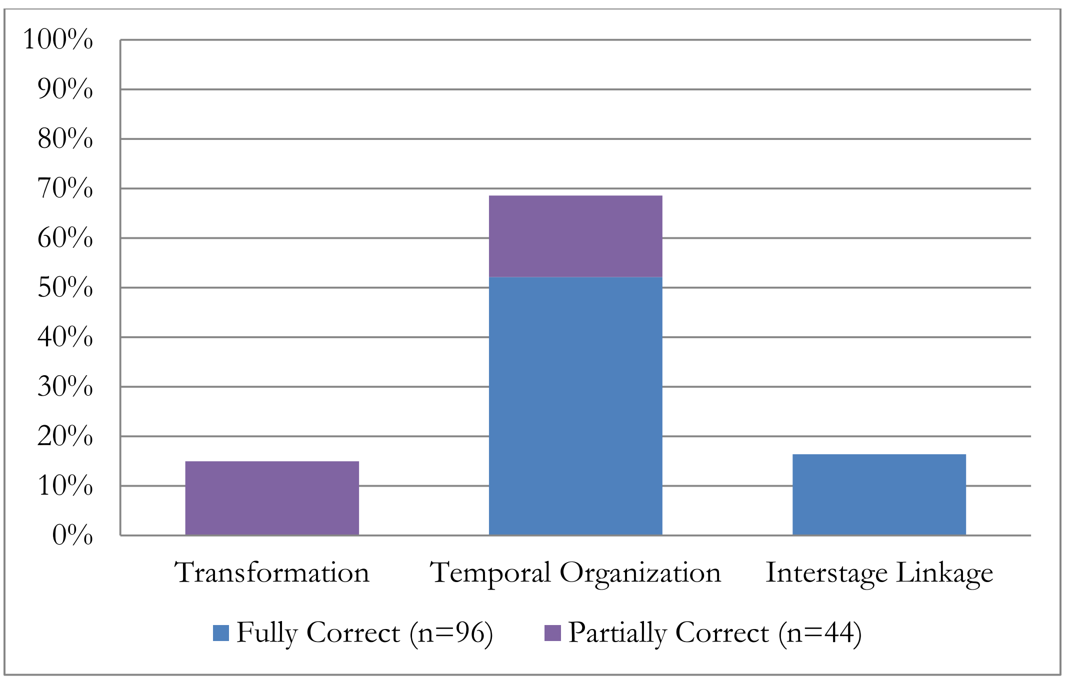


Figure 20. Diachronic thinking for fully and partially correct answers related to lateral continuity Q5.

Reviewing the incorrect answers (n=17) to the question on lateral continuity, 7 (41%) activated the temporal organization scheme. Respondents incorrectly identified a transformation and established a sequence of events. Of these respondents, four indicated a catastrophic tectonic event formed the Canyon; e.g.; "this used to be a big sea over the course of millions of years the whole structure has sunk, with the sides pushed up"; and one indicated a meteor hit; e.g.; "probably were together at one point and then maybe a meteor split it". While two respondents talked about a water source leaving rings around the Canyon; e.g.; "how the water is dropping because it is all level. How the water was decreasing, that is how it was marking the layers". Of note, only one of these two respondents identified themselves as creationists.

Of the incorrect responses, 10 (59%) activated only the transformational scheme: incorrectly identifying the changes that have happened at the Grand Canyon and giving no temporal order to these changes. Seven respondents indicated that it was the river that deposited the two Canyon walls; e.g.; "the same types of rock were traveling in the river and the river deposited them". Two spoke of catastrophic changes related to meteors; e.g., "it was some sort of meteor or crater formation"; or tectonics; e.g., "something got shifted".

Environmental changes over geologic time. Asked only to respondents at the second location (n=51), Q6 tested the respondents understanding that the layers of the Grand Canyon represent a combination of geologic time, environmental changes and sedimentary deposition. 31% (16) of the respondents were able to identify all three of the landscape elements (see *Figure 21*). One respondent answered succinctly with the layers representing "the story of the earth changing over the millions, hundreds of millions of years and things building up and breaking down and animals coming and going". Another said, "The build-up of all the sedimentation of rocks over millions of years, all that happened, how old it is, the weather and different changes in the environment".

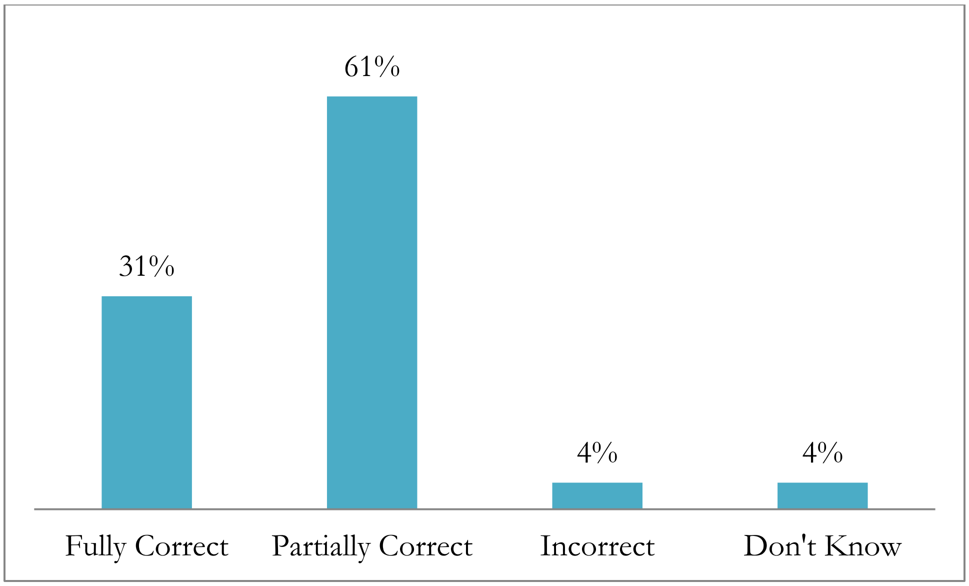


Figure 21. Respondent understanding that the layers of Grand Canyon represent environmental changes over geologic time.

Of the respondents, 31 (61%) were scored as partially correct because respondents were able to represent one or two of the three landscape element factors, either individually or in combination with one of the other two required elements. Geologic time was the most commonly referenced with 23 (72%) respondents identifying time as an element represented in the layers of the Canyon; e.g., "the formation of Earth through time"; "it took a really long time." 18 (56%) referred to environmental changes; e.g., "they [the layers] represent different types of climate and different types of seas and water and minerals," and 14 (44%) spoke about a mode of deposition for the layers; e.g., "more layers built on top of each other," (see Table 2 and *Figure 22* for breakdown).

Table 2

Partially Correct Answers (Q6) Use of Landscape Matrix

	Environmental changes	Geologic Time	Mode of Deposition
Environmental changes	18	11	6
Geologic Time	11	23	8
Mode of Deposition	6	8	14

Note. How landscape elements were used for partially correct responses (n=31) to Q6.

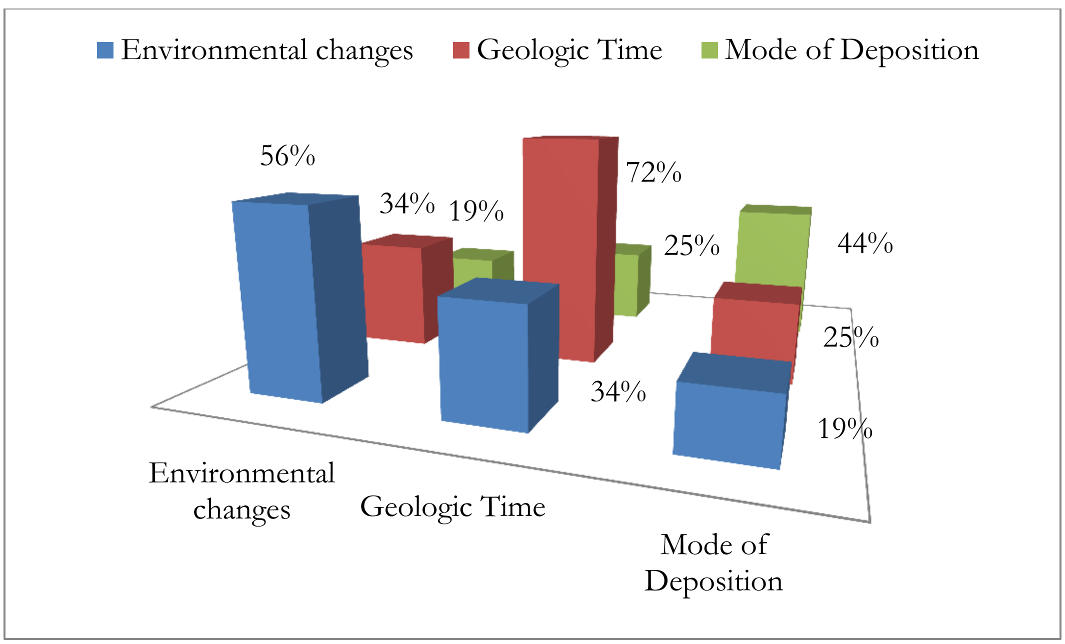


Figure 22. Use of landscape matrix for partially correct answers to Q6.

All three of the landscape elements used to determine correctness are variables of the inferred landscape coding and while all respondent (n=51) used the inferred landscape to answer the question, a majority (34:67%) used an integrated approach utilizing both the inferred and observed landscape (*Figure 23*). The majority of observed landscape was used in combination with the inferred landscape including visible landforms (32:63%) and referring to different elevations (17:33%).

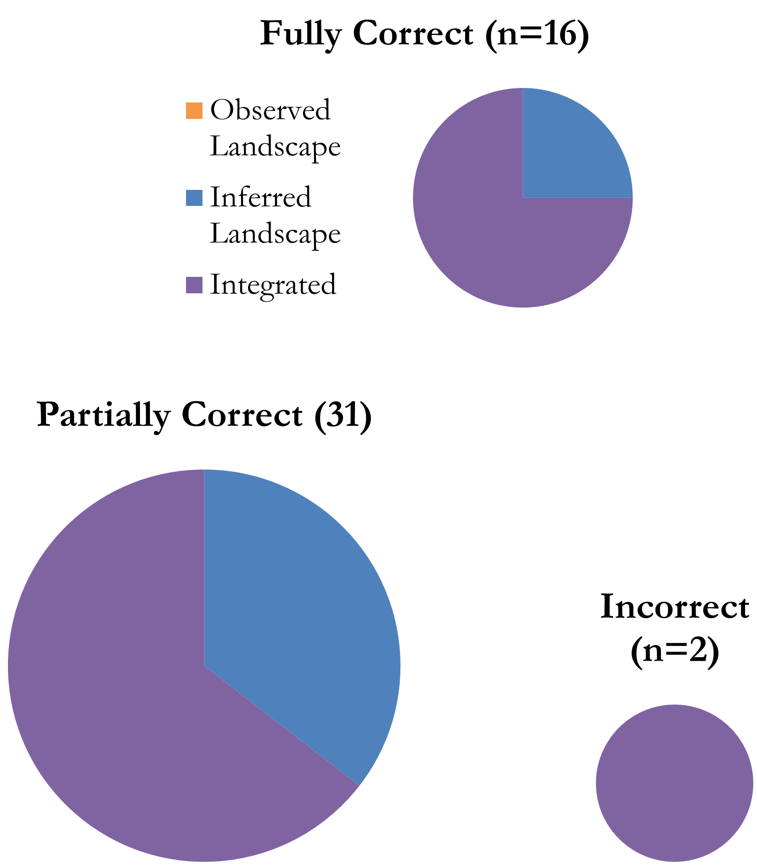


Figure 23. Landscape use by respondents explaining what the layers represent in answer to Q6.

Coded responses into the diachronic thinking scheme shows that the majority of fully correct answers activated the interstage linkage scheme (14:88%)

(*Figure 24*). These fully correct responses were able to identify a temporal order to an evolutive process.

> "The bottom was formed a long time ago from under the Earth, and everything was layered on top of it, through the oceans coming in and the continents changing. Just time."

While the majority of partially correct answers activated the temporal organization scheme (24:71%), being able to identify an order to the transformations, e.g., "each one was deposited at different time and afterwards was when the canyon was formed".

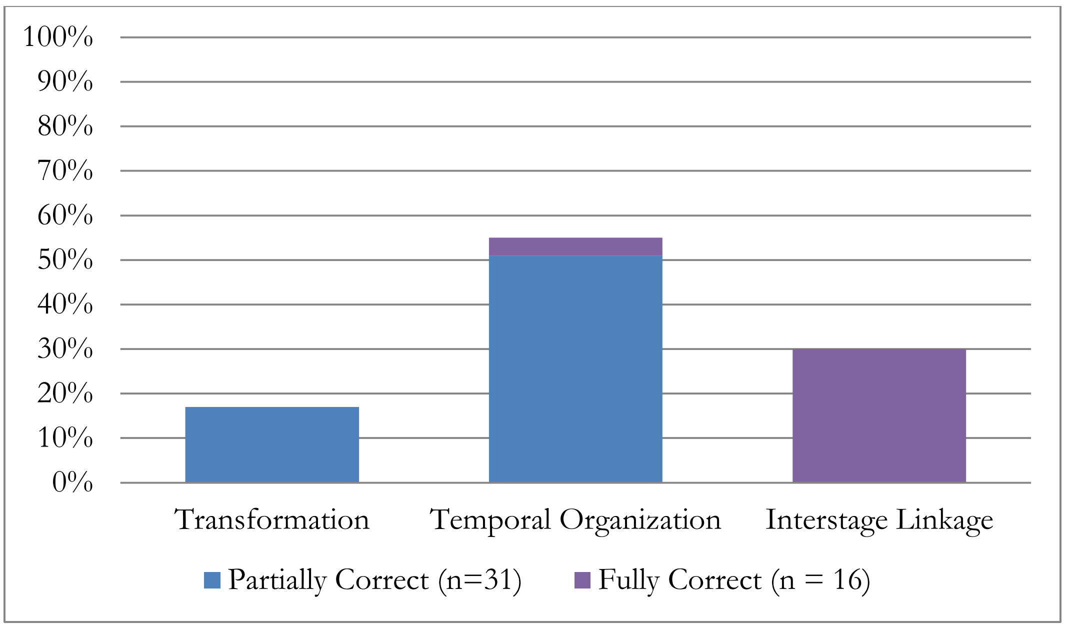


Figure 24. Diachronic thinking schemes for environmental changes over geologic time Q6.

Of the responses that were incorrect (n=2), one talked about a Noah's type flood, "there was a great flood that covered everything, and then when the water came down, down, down, down, boom there was layers in the rock" (Subject Respondent 081709_15). The other incorrect respondent stated that the colors of the rock layers are what attest to the age of the rocks, "I think they indicate age, how the lightest ones go into the darkest one is the oldest and the lowest. It looks like the lightest is the Kaibab and the cliff builder there [referring to the Coconino Sandstone]", (Subject 081409_02).

Respondents with incorrect answers to Q6 were able to use an integrated approach to the landscape. Referring to the observed layers, e.g., "boom there was the layers"; "the lightest one is the Kaibab" and the inferred previous landscape and geologic time e.g., "there was a great flood" and "indicate age…oldest one". In terms of the diachronic thinking scheme, the second incorrect respondent (above) was able to activate the temporal organization scheme, but used incorrect logic; therefore giving an incorrect answer "[color of the layer] indicates age".

Age of the oldest rock at Grand Canyon. When asked "how old are the oldest rocks at the Grand Canyon?" 27 (59%) of the total respondents (n=46) answered billions of years, and 18 (39%) answered millions of years.

Chapter 5

INTERPRETATION

Visitors' use of Grand Canyon's landscape is an integration of the inferred and observed landscape. Both incorrect and correct answers were derived from viewing and describing the landscape, and results provide a detailed account of how each of the landscape elements was used by visitors.

Using the observed landscape elements, the visitors were describing geologic features visible from the Rim today. Identifying landform characteristics helped to paint a picture for GCNP visitors, such as; layers and layer color, cliff and slope relief. Most visitors were able to understand that the layers erosional features and their colors represent transformations. Some respondents went on further to identify the transformation represented changes in the sediment mineral composition and paleoclimate.

The inferred landscape element of geologic time was the most abundantly coded scheme; the responses were focused on the relative timing of events rather than the absolute dating of events. Phrases such as "before", "after" and "later on" are all measures of relative time. Respondents were still confused about the absolute age of the geologic events as shown by the number of responses (44%) who indicated that the oldest rocks were millions of years old. This is an indication that the immensity of geologic time is not entirely comprehended by visitors to the GCNP. (See Libarkin, 2007, for similar findings using classroom-based timelines.)

Respondent's use of other inferred landscape elements are Earth processes not able to be seen at the Rim today, such as deposition and erosion. Using these Earth processes to explain geologic principles implies that respondents were accessing prior knowledge. While references to the exhibition were coded, this research design was not able to determine where the prior knowledge was gained, whether it is from the ToT temporary exhibit or knowledge from other Park literature. While the respondents' vocabulary may not be scientific, their answers contained clues to indicate a majority understood the Earth processes that help define the principle of superposition and lateral continuity.

Incorrect theories proposed to answer interview questions on the geologic principles were centered on the use of knowledge about Earth's processes of erosion, sedimentary deposition and tectonics. These incorrect theories indicate that the respondents could have been accessing incorrect prior knowledge to answer the interview questions.

Incorrect prior knowledge of erosion could have affected respondents' understanding of the role of the Colorado River in forming the Grand Canyon. Some respondents identified erosion as the agent itself which carved the Canyon; e.g., "erosion did it". Others appeared not to not understand that the River was able to carve the Canyon and gave alternative agents of erosion, including; tectonics, meteor impacts, and a large body of water decreasing and leaving rings.

Misunderstanding the processes of sedimentary deposition also appears to affect understanding of geologic principles. Some visitors were confused about the depositional process of the Colorado River, indicating that the river deposited the layers. These responses also indicate that respondents were not able to recognize changes in the environment from today. They instead indicated that the arid environment we have today at the Grand Canyon has not changed; only the river was somewhat higher.

Incorrect prior knowledge of marine sedimentary deposition can also affect understanding. Some respondents did not understand that the different layers represented more than one marine setting. They expressed "there was an ocean here once" but could not see the depositional cycles of transgressing and regressing oceans and that the layers of rock represented these changes.

The duration, timing, and results of tectonics were also not well understood by most of the respondents. While some visitors identified the concept of uplift, a majority of these visitors did not have a clear understanding about the timing or duration of tectonic events at Grand Canyon. When respondents identified that uplift had occurred it was usually in the context of relative dating, "at one point it was uplifted". The respondents did not have a clear idea on the timing of events and the immensity of time was not well understood. The results of tectonics were also not well understood. Some respondents indicated that earthquakes are what split the Canyon apart.

When walking the ToT timeline, a majority of visitors were able to understand the logistics of the exhibit. The horizontal timeline was understood to be going backward in time, with numbers increasing. They were also able to understand that the horizontal timeline was representing the stratigraphically encoded time. Success for understanding this relationship was most abundant when the visitors used an integrated approach to the landscape. This is interpreted to mean that to understand the horizontal/vertical relationship of the ToT the participant has to have correct prior knowledge on geologic time, sedimentary deposition, tectonics and erosion.

It was expected and confirmed that most of the Park visitors would able to activate the Temporal Organization scheme of diachronic thinking. This cognitive skill allows the person to reason out a logical understanding to principles of deep time which is used to reconstruct past environments and organisms. Dodick and Orion (2003a; 2003b) previously determined that this level of diachronic thinking would be activated to understanding the principles of superposition and lateral continuity. It is noteworthy that there were very few visitors who were able to activate the interstage linkage scheme. This can possibly be explained due to fact that they do not fully understand Earth's geological processes, including marine and terrestrial sedimentary environments, agents and processes of erosion and timing or results of tectonics.

Recommendations

While relative time is understood by the visitors to the GCNP, the idea of absolute time (billions of years) is not clearly understood. While the ToT is teaching this concept to a majority of visitors, special care needs to be taken to help visitors grasp this amount of time. Education on the timing and duration of different geologic processes could help visitors grasp the immensity of geologic time.

Education on the principles of erosion including the agents and processes of erosion, such as water (both fluvial and marine) and wind; and the duration of erosion at Grand Canyon, might help visitors understand the time in which the Colorado River carved the Canyon as well as the time it has taken to erode away the entire Mesozoic record from the Grand Canyon area.

Education on the principles of sedimentary deposition for different environments, including marine and terrestrial environments, could help visitors grasp the idea that the layers of Grand Canyon represent environmental changes over geologic time. Specifically, visitors could be taught about marine deposition including, eustatic sea-level changes and rock type deposition based on marine setting. Education focused on terrestrial environments could include river deposition versus erosion. Also, information on flood-plain and delta deposits could help visitors understand that different rock types are deposited in different terrestrial environments.

Finally, education on tectonic processes needs to be more fully explained. Helping visitors understand the duration and timing of tectonic events as well as the results of tectonics including uplift and earthquakes might help visitors more fully understand the geologic history of Grand Canyon.

There are several venues in which the National Park Service could try to teach about these different geologic processes. One recommendation would be to include a change to the Wayside Integration Section (WIS) at the bottom of every wayside panel. At the different wayside panel that introduces an Earth process a highlighted area of the timeline would appear on that WIS which would indicate the duration of the geologic process as represented at the Grand Canyon. It could also be important to give an absolute number and specifically state the length of geologic time that passed while the process was taking place. For example: island-arc accretion lasted approximately 110 My and the highlighted portion of the timeline as represented on the WIS would be highlighted 1,840 My through 1,730 My. These changes could provide both visual and concrete information on the duration of geologic time for each of the different geologic events.

Another option could be to add more wayside panels along the ToT that teach about geologic processes. These could be positioned on the south side of the Trail (away from the Rim) at locations that are timeline sensitive and then indicating how many steps someone would walk to represent the length of time the process was in action. These panels could focus on different geologic topics and give greater detail regarding deposition, erosion and tectonics.

Linking together the different Colorado Plateau National Parks could help to continue the education of these different topics. If at the beginning and end of the ToT the visitor was told to look for different examples of sedimentary deposition at Arches National Park, or to look for recent volcanism at Sunset Crater National Monument is too could lead to further understanding of geologic processes.

Geologic processes could also be featured in the Grand Canyon National Park visitors guide, *The Guide*. A monthly feature to help people understand geologic principles with games that help teach about geologic time could be very informative. This could also re-introduce the ToT and encourage visitors to walk the timeline.

Chapter 6

CONCLUSION

People visiting Grand Canyon National Park are offered an experience at the Trail of Time to walk a 2.2-km timeline that represents the age of the oldest rocks in the Canyon. This experience offers visitors the chance to grasp the immensity of geologic time. A majority of respondents were able to use the landscape and the Trail of Time to understand different geologic principles. Respondents were also able to reconcile the horizontal Trail of Time timeline to the stratigraphically encoded time.

Research results indicate that understanding geologic principles related to geologic time are understood when using an integrated approach to the landscape of Grand Canyon. This approach uses not only the physical landscape that is observed today at the Canyon but includes the inferred processes and previous landscapes that are recorded in the rocks of Grand Canyon.

While using the observable landscape and inferred knowledge about Earth's processes, most visitors were able to reconstruct Grand Canyon's geologic history on a relative scale. Although some visitors to GCNP had incorrect prior knowledge of Earth's processes which affected their understanding.

Incorrect prior knowledge of Earth's processes limited respondents' understanding of geologic principles, including the immensity of geologic time and the duration of geologic events. These misunderstandings also limit respondents' ability to reconcile the relationship between the horizontal ToT timeline and the stratigraphically encoded time.

Correcting these misunderstandings about geologic principles can help develop full diachronic thinking which allows people to understand not only the order of transformations within a process but to also understand the order of transformations throughout independent processes.

Chapter 7

REFERENCES

Ault, C.R. (1982). Time in geological explanations as perceived by elementary school students. *Journal of Geological Education*, *30*, 304–309.

Beus, S.S., (2003). Temple Butte Formation. In Beus S. & Morales, M., *Grand Canyon Geology* (pp. 107-114). New York: Oxford University Press

Beus, S.S., (2003). Redwall Limestone and Surprise Canyon Formation. In Beus S. & Morales, M., *Grand Canyon Geology* (pp. 115-135). New York: Oxford University Press

Blakey, R. (2003) Supai Group and Hermit Formation. In Beus S. & Morales, M., *Grand Canyon Geology* (pp. 136-162). New York: Oxford University Press

Blakey, R. & Ranney, W. (2008). *Ancient Landscapes of the Colorado Plateau.* Grand Canyon, AZ: Grand Canyon Association.

Bond, C.E., Philo, C., & Shipton, Z.K. (2011). When there isn't a right answer: Interpretation and reasoning, key skills for twenty-first century geosciences. *International Journal of Science Education, 33*, 629-652.

Catley, K., & Novick, L. (2009). Digger deep: Exploring college students' knowledge of macroevolutionary time. *Journal of Research in Science Teaching, 46*, 311-332.

Cheek, K.A. (2010). Commentary: A summary and analysis of twenty-seven years of geosciences conceptions research. *Journal of Geoscience Education, 58*(3), 122-134.

Chi, M.T.H. (1997). Quantifying qualitative analysis of verbal data: A practical guide. *The Journal of the Learning Sciences, 6*(3), 271-315.

Chronic, H. & Chronic, L. (Eds.). (2004). *Pages of Stone. Geology of the Grand Canyon & Plateau Country National Parks & Monuments.* Seattle, WA: The Mountaineers Books.

Cohen, J., Cohen, P., West, S.G., & Aiken, L.S. (Eds.). (2003). *Applied Multiple Regression/Correlation Analysis for the Behavioral Sciences.* Mahwah, NJ: Lawrence Erlbaum Associates.

Coladarci, T., Cobb, C.D., Minium, E.W., & Clarke, R.B. (Eds.). (2008) *Fundamentals of Statistical Reasoning in Education*. Hoboken, NJ: John Wiley & Sons, Inc.

Dodick, J., & Orion, N. (2003a). Cognitive factors affecting student understanding of geologic time. *Journal of Research in Science Teaching, 40*, 415–442.

Dodick, J., & Orion, N. (2003b). Measuring student understanding of geological time. *Science & Education, 40*, 708-731.

Dodick, J., & Orion, N. (2003c). Geology as an historical science: Its perception within science and the education system. *Science & Education, 12*, 197-211.

Dodick, J., & Orion, N. (2006). Building an understanding of geological time: A cognitive synthesis of the "macro" and "micro" scales of time In Manduca, C.A., & Mogk, D.W., *Earth and Mind: How Geologists Think and Learn about the Earth: Geological Society of America Special Paper 413*, (pp. 77-93).

Dodick, J., & Orion, N. (2007). Understanding evolutionary change within the framework of geologic time. *Science Education, 87*, 708-731.

Friederici, P. (2005). *Earth Notes: Exploring the Southwest's Canyon Country from the Airwaves.* Grand Canyon, AZ: Grand Canyon Association.

Gould, S.J. (1987). *Time's arrow, time's cycle.* Cambridge: Harvard University Press.

Green, J.L., Camilli, G., & Elmore, P.B. (Eds.). (2006) *Handbook of Complementary Methods in Education Research*. Mahwah, NJ: LEA.

Gyllenhaal, E.D., & Perry, D.L. (2004). *Phase One of Formative Evaluation of the Trail of Time at Grand Canyon National Park*, Albuquerque, NM, University of New Mexico, 82p.

Hendricks, J. D., & Stevenson, G. M., (2003) Grand Canyon Supergroup: Unkar Group. In Beus S. & Morales, M., *Grand Canyon Geology* (p 39-52). New York: Oxford University Press

Hopkins, R. L., Thompson, K. L., (2003) Kaibab Formation. In Beus S. & Morales, M., *Grand Canyon Geology* (196-211). New York: Oxford University Press

Huntoon, P. W., (2003) Post-Precambrian Tectonism in the Grand Canyon Region. In Beus S. & Morales, M., *Grand Canyon Geology* (222-259). New York: Oxford University Press

Karlstrom, K., Ilg, B. R., Williams, M .L., Hawkins, D. P., Bowring, S. A., & Seaman, S.J. (2003) Paleoproterozoic Rocks of the Granite Gorges. In Beus S. & Morales, M., *Grand Canyon Geology* (p 9-38). New York: Oxford University Press

Karlstrom, K., Semken, S., Crossey, L., Perry, D., Gyllenhaal, E. D., Dodick, J., Williams, M., Hellmich-Bryan, J., Crow, R., Bueno Watts, N, & Ault, C. (2008). Informal geoscience education on a grand scale: the Trail of Time exhibition at Grand Canyon. *Journal of Geoscience Education, 56*(4), 354-361.

Kastens, K.A., Manduca, C.A., Cervato, C., Fordeman, R., Goodwin, C., Liben, L.S., Mogk, D.W., Spangler, T.C., Sillings, N.A., & Titus, S. (2009) How geoscientists think and learn. *EOS, 90*, 265-272.

Lewis, Beth. (2008). Content is Not Enough: A History of Secondary Earth Science Teacher Preparation with Recommendations for Today. *Journal of Geoscience Education, 56*, 445-455.

Libarkin, J., Kurdziel, J., & Anderson, S. (2007). College student conceptions of geological time and the disconnect between ordering and scale. *Journal of Geoscience Education, 55*, 413-422.

Littlejohn, M., & Hollenhorst, S. (2004). *Grand Canyon National Park South Rim visitor study. Summer, 2003. Visitor Services Project Report #144*. Moscow, ID: National Park Service and University of Idaho, Cooperative Park Studies Unit.

Macar, F., Pouthas, V. & Friedman, W.J. (1992). *Time, Action and Cognition Towards Bridging the Gap*. Dordrecht: Kluwer Academic Publishers.

Morales, M. (2003) Mesozoic and Cenozoic Strata of the Colorado Plateau Near the Grand Canyon. In Beus S. & Morales, M., *Grand Canyon Geology* (90-106). New York: Oxford University Press

Middleton, L. T., Elliott, D. K., (2003) Tonto Group. In Beus S. & Morales, M., *Grand Canyon Geology* (90-106). New York: Oxford University Press

Middleton, L. T., Elliott, D. K., (2003) Coconino Sandstone. In Beus S. & Morales, M., *Grand Canyon Geology* (163-195). New York: Oxford University Press

Montangero, J. (1996). *Understanding changes in time*. London: Taylor and Francis.

National Park System (NPS) Advisory Board. (2001) *Rethinking the National Parks for the 21st century*, http://www.nps.gov/policy/futuerreport.htm (2007, July 01).

National Park Service. (2002). *The National Park Service comprehensive survey of the American public: Intermountain Region technical report.* Flagstaff, AZ, Northern Arizona University.

National Research Council. (1996). *National science education standards*. Washington, DC: National Academy Press.

Price, L.G. (1999). *An Introduction to Grand Canyon Geology*. Grand Canyon: Grand Canyon Association.

Ranney, W. (2005). *Carving Grand Canyon*. Grand Canyon, AZ: Grand Canyon Association.

Semken, S., Dodick, J., Ben-David, O., Pineda, M., Bueno Watts, N., & Karlstrom, K. (2009). Proceedings from NARST 2009 Annual Meeting: *Timeline and Time Scale cognition Experiments for a Geological Interpretative Exhibit at Grand Canyon.* Reston, VA: JRST.

Stynes, D., & Sun, Y. (2005). *Economic impacts of Grand Canyon National Park visitor spending on the local economy, 2003*. East Lansing, MI: National Park Service and Michigan State University, Cooperative Park Studies Unit.

Trend, R. (2000). Conceptions of geological time among primary teacher trainees, with reference to their engagement with geosciences, history and science. *International Journal of Science Education, 22,* 539–555.

Trend, R. (2001). Deep Time Framework: A preliminary study of UK primary teachers' conceptions of geological time and perceptions of geoscience. *Journal of Research in Science Teaching, 38,* 191–221.

Trend, R. (1998). An investigation into understanding of geological time among 10 and 11-year old children. *International Journal of Science Education, 20,* 973–988.

Tretter, T., Jones, M.G., & Minogue, J. (2006). Accuracy of scale conceptions in science: Mental maneuverings across many orders of spatial magnitude. *Journal of Research in Science Teaching, 43*, 1061-1085.

APPENDIX A

APPROVAL DOCUMENTS

Arizona State University Institutional Review Board Protocol Exemption

ASU Arizona State University
RESEARCH AND ECONOMIC AFFAIRS

Office of Research Integrity and Assurance

To:	Steven Semken PSF
From:	Mark Roosa, Chair Soc Beh IRB
Date:	06/03/2009
Committee Action:	**Exemption Granted**
IRB Action Date:	06/03/2009
IRB Protocol #:	0905004046
Study Title:	Trail of Time Experiment (To TEx): A study of visitor understanding of basic principles of geologic time in the context of the Trail of Time interpretative exhibit at Grand Canyon National Park

The above-referenced protocol is considered exempt after review by the Institutional Review Board pursuant to Federal regulations, 45 CFR Part 46.101(b)(2) .

This part of the federal regulations requires that the information be recorded by investigators in such a manner that subjects cannot be identified, directly or through identifiers linked to the subjects. It is necessary that the information obtained not be such that if disclosed outside the research, it could reasonably place the subjects at risk of criminal or civil liability, or be damaging to the subjects' financial standing, employability, or reputation.

You should retain a copy of this letter for your records.

APPENDIX B

INTERVIEW PROTOCOL

STRUCTURED INTERVIEW QUESTIONS FOR TRAIL OF TIME RESEARCH, LOCATION 1

1: If you were to walk west along this Trail, would the numbers on the time markers be increasing or decreasing? *(Interviewer will point towards the west when asking the question.)*

2: Does walking west represent moving forward in time (toward the present), or moving backward in time (toward the past)? *(Interviewer will point towards the west when asking the question)*

3: Note that you are standing at the marker for 270 million years ago; this is when the Kaibab Formation was deposited. (*Interviewer should point out the Kaibab Formation*.) The layer just below the Kaibab Formation is the Toroweap Formation. *(Interviewer could point out the Toroweap Formation by using the exposed Canyon wall, as well as the picture associated with the wayside marker.*) Is the Kaibab Formation older or younger or the same age as the Toroweap Formation? Please explain your reasoning.

4: Now, going back to the exhibit, we are at 270 million years and we read that this is when the Kaibab Formation was deposited. In which direction would you walk along this Trail to reach the time in which the Toroweap Formation was deposited? Please explain your reasoning.

5: We are here on the South Rim, standing on the top layer, the Kaibab Formation. Looking across the Canyon to the North Rim, you are able to see layers that look similar to the layers here at the South Rim. In fact, if you were standing on the top of the North Rim you would be standing on the same Kaibab Formation. (*Interviewer* *could point out the Kaibab Formation by using the exposed Canyon wall, as well as the second picture associated with the 270 MA wayside marker*.) How does that work? How do we get the same rocks on both sides of the Canyon? Please explain your reasoning.

APPENDIX B

INTERVIEW PROTOCOL

STRUCTURED INTERVIEW QUESTIONS FOR TRAIL OF TIME RESEARCH,

LOCATION 2 CHANGES

1: If you were to walk west along this Trail, would the numbers on the time markers be increasing or decreasing? *(Interviewer will point towards the west when asking the question.)*

2: Does walking west represent moving forward in time (toward the present), or moving backward in time (toward the past)? *(Interviewer will point towards the west when asking the question)*

3: Note that you are standing at the marker for 580 million years ago; this is when the Bright Angel Shale was deposited. Let's look into the Canyon to see the Bright Angel Shale. As we walk up Trinity Wash we see the small cliff which is the Tapeats Sandstone. Above the Tapeats is the Bright Angel Shale where the soft rolling hills are. This leads up to the Muav Limestone. *(Interviewer could point out the Tapeats Sandstone by using the exposed Canyon wall, as well as the picture associated with the wayside marker.)* Is the Bright Angel Shale older, younger or the same age as the Tapeats Sandstone? Please explain your reasoning.

4: I am going to introduce you to another layer in the Grand Canyon. That is the Kaibab Formation: The top layer of the Canyon. We are standing on it. You can look across to view the South Rim we can see it. *Interviewer could point out the Kaibab Formation by using the exposed Canyon wall, as well as the picture associated with the 270 MA* *wayside marker*. Now, going back to the exhibit, we are standing at 580 million years ago and we read that this is about the time when the Bright Angel Shale was deposited. So along this Trail in which direction would you walk to then find when the Kaibab was deposited? Please explain your reasoning.

5: Another layer exposed at the Grand Canyon is the Coconino Sandstone. You can see that white cliff exposed in the Canyon wall. (*Interviewer could point out the Coconino Sandstone by using the exposed Canyon wall, as well as the picture associated with the 270 MA wayside marker.*) If you look over to the North Rim you can also see the white cliff. How does that work? How do we get the same rocks on both sides of the Canyon? Please explain your reasoning.

In addition to the above questions, 6 and 7 were asked at location 2.

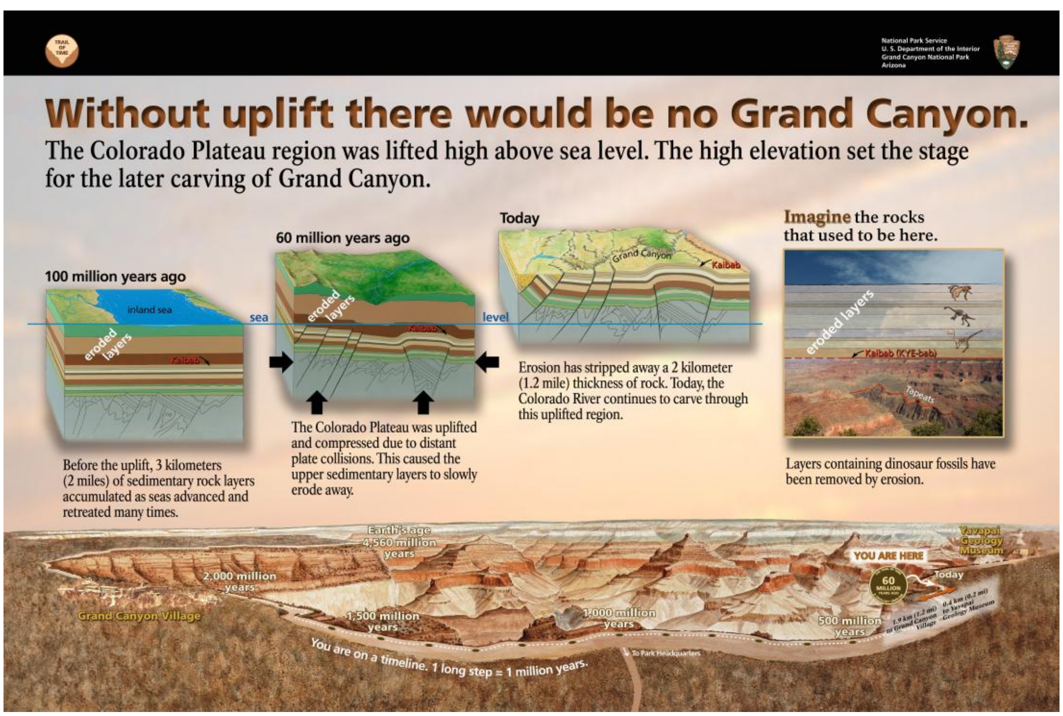
6: Today we have been introduced to three different types of sedimentary rock layers: The Kaibab Formation, the Coconino Sandstone and the Bright Angel Shale. *Interviewer would point out these formations again*. Now when we look at all of the layers in the Grand Canyon, what story do those layers tell?

7: How old is the oldest rock in the Grand Canyon: Hundreds, thousands, millions, billions?

APPENDIX C

DEEP TIME TRAIL WAYSIDES

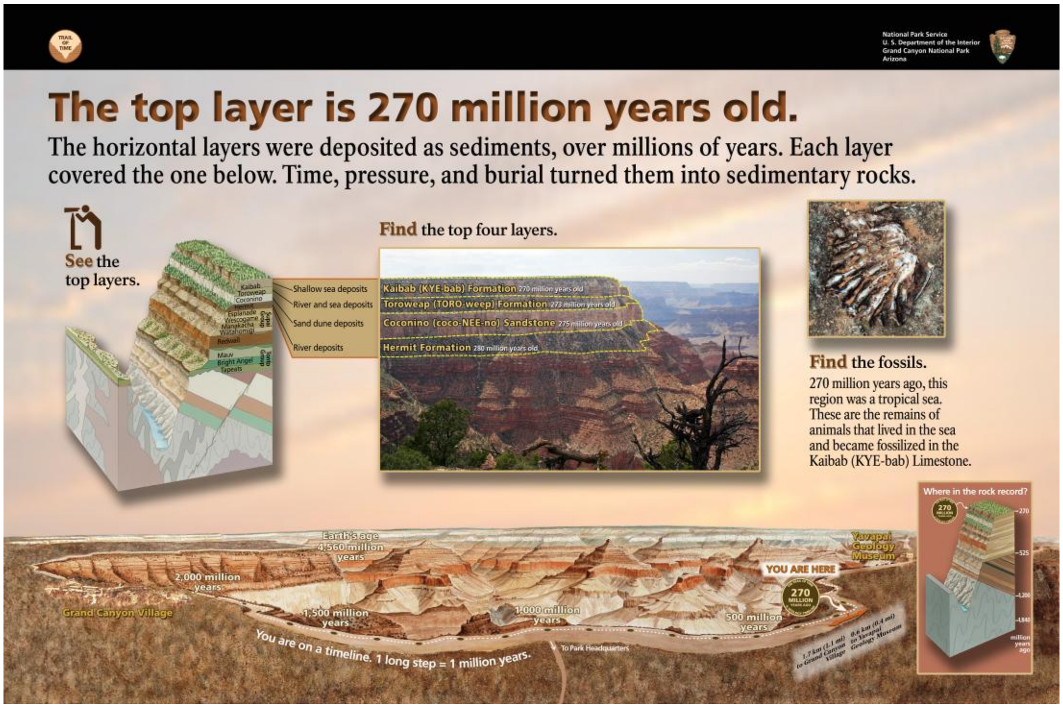
COURTESY OF ‘TRAIL OF TIME

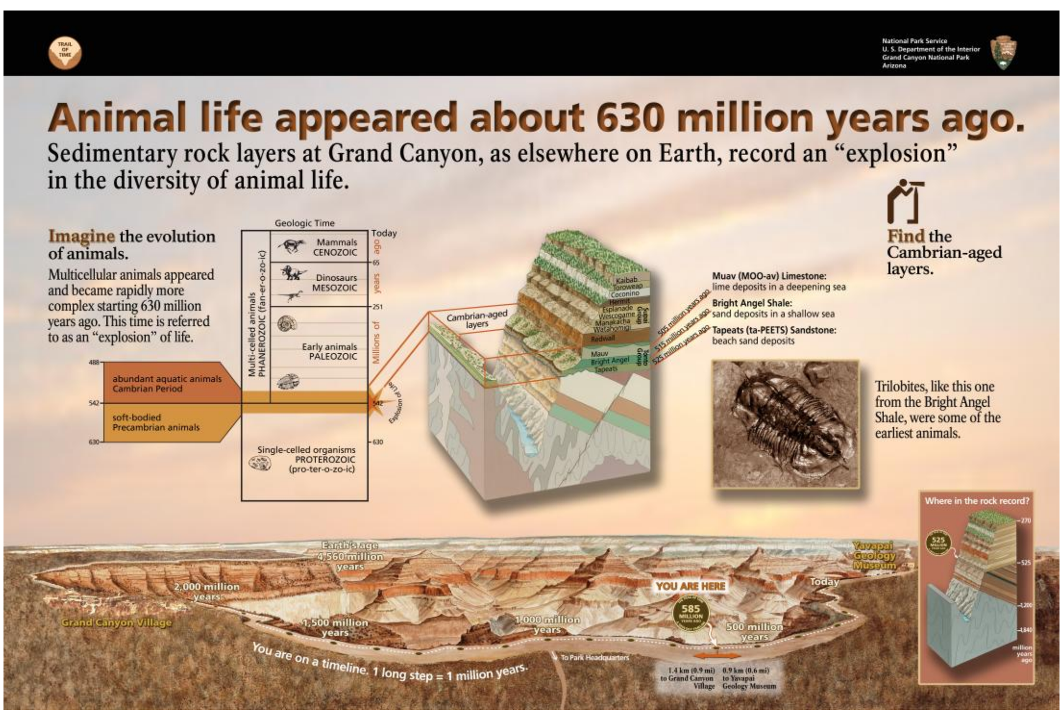


APPENDIX C

DEEP TIME TRAIL WAYSIDES

COURTESY OF 'TRAIL OF TIME

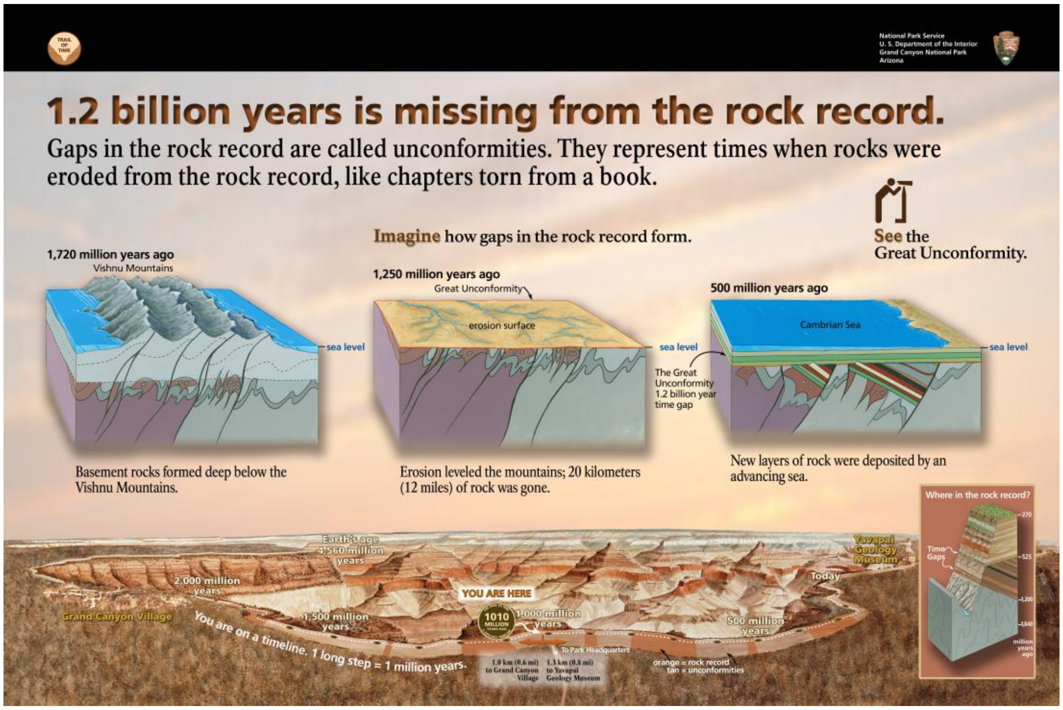


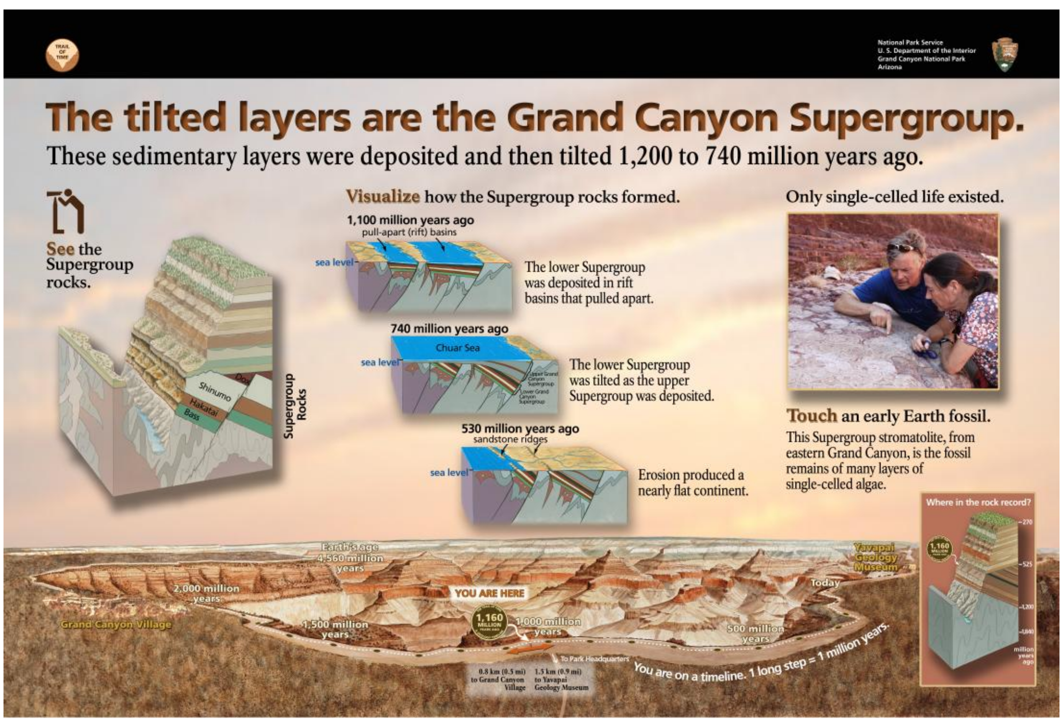


APPENDIX C

DEEP TIME TRAIL WAYSIDES

COURTESY OF 'TRAIL OF TIME

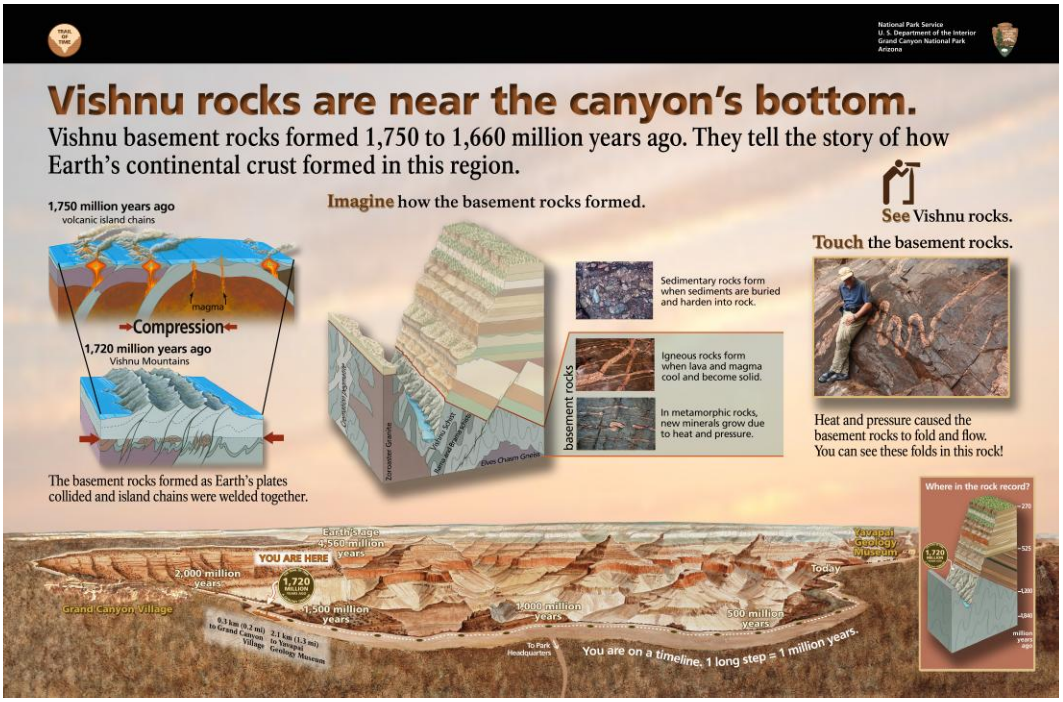


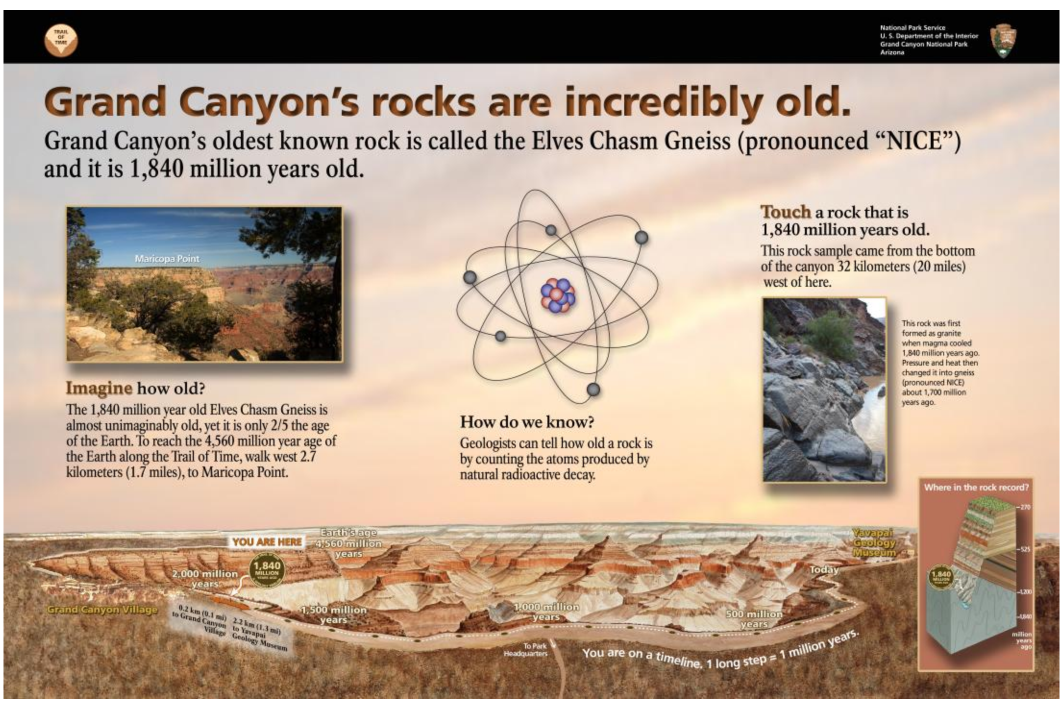


APPENDIX C

DEEP TIME TRAIL WAYSIDES

COURTESY OF 'TRAIL OF TIME





APPENDIX D

DIACHRONIC SCHEME AND ITS GEOLOGICAL CORRELATE WITH TRANSCRIPT EXAMPLES

Transformation:	Explicit ToT respondent transcript
This scheme defines a principle of change, whether qualitative or quantitative (Montangero, 1996). In geology, such changes are understood through the principle of uniformitarianism ("the present as key to past"), in which geological or biological change is reconstructed through comparison with contemporary biological and depositional environments (Dodick &	Subject: 081509_04 "R: Presumably it was flat at one point. As the Colorado came down and eroded or washed away that portion. Sort of taking your hand and dragging it through sand. You are still going to have the same sedimentation levels. At one point presumably I guess it was the same and all we are doing is exposing the different layers below it. " Here the respondent is explicitly using the previous landscape "it was flat at one point" and erosion "eroded or washed away that portion".
	Implicit ToT respondent transcript
	Subject: 072509_04 "R2: Originally the formation was like under the sea and the Kaibab Formation was like silt on the bottom of the sea" The respondent implies his understanding of

Orion, 2003a; 2003b).	sedimentary deposition where "the Kaibab Formation was like silt on the bottom of the sea". He further explains the transformation of the environment by stating that "originally the formation was under the sea", inferring his knowledge that the dry, arid environment of today's Grand Canyon is different from the environment during which the Kaibab was deposited.
Temporal organization: This scheme defines the sequential order of stages in an evolutive (or transformational) process (Montangero, 1996). In geology, logical principles are used as a means of determining temporal organization, including; superposition, correlation, and original horizontality, all of which	Explicit ToT respondent transcript Subject 072809_09 "Well because the older one was first to be distributed by whatever means, and then the next layer isn't going to go under it. It will go on top of it." In describing the logic behind the principle of superposition, the respondent is utilizing the temporal organizational scheme of diachronic thinking. Explicitly describing the three dimensional strata, by the process of what was first, next and last gives an order to the depositional sequence. Implicit ToT respondent transcript Subject : 072509_06

are based on the 3-D relationship amongst strata (Dodick & Orion, 2003a; 2003b).	"Because it [Kaibab] is on top of the other one [Toroweap]." An implicit understanding of deposition is applied to this response as he or she answers the question as if it were simple and widely understood.
Interstate linkage: The connections between the successive stages of evolutive phenomena (Montangero, 1996). In geology such stages are reconstructed through the combination of uniformitarianism (as defined above) as well as through the use of (scientific) causal reasoning (Dodick & Orion, 2003a; 2003b).	Both Implied and Explicit ToT respondent transcript Subject: 081409_06 "This was the sea floor at one point all of it was much lower and much flatter and it was uplifted as one unit and then eroded away, in the center, so these are the same rocks at different elevations." By indicating that "this was the sea floor" implies that the respondent understood the process of sedimentary deposition and has activated the transformational scheme of diachronic thinking through actualism. Expressing that there was a temporal order starting with "the sea floor at one point" and "then erosion" indicates the use of temporal organizational scheme. The respondent utilizes the interstage linkage scheme because not only did she imply her knowledge of sedimentary

	deposition as well as the sequence of events, but she also was able to link together a series of independent events “this was the sea floor”, “it was uplifted” and “then eroded away”.

APPENDIX D

CODING SCHEME FOR CORRECTNESS

Question 1: Logistics for horizontal timeline: "Moving towards the west the numbers are"	Correct	Increasing
	Incorrect	Decreasing
	Other	Don't Know
Question 2: Logistics for horizontal timeline: "Moving towards the west are you going forwards or backwards in time?"	Correct	Backwards
	Incorrect	Forwards
	Other	Don't Know
Question 3: Testing for comprehension of superposition: "what is the age of the top layer when compared to lower layers?"	Correct	Younger
	Incorrect	Older or Same Age
	Other	Don't Know
Question 4: Testing for ability to reconcile time encoded vertically in strata with the horizontal timeline: "which direction along the timeline would you walk to find when an older or younger rock unit was deposited?"	Correct	Younger to the east / Older to the west
	Incorrect	Older to the east / Younger to the west OR Other orientation (up/down)
	Other	Don't Know
Question 5: Testing for comprehension of lateral continuity: "how do both rims have the same rocks?"	Correct	Used to be connected AND river carved it
	Incorrect	None of the correct items
	Other	Don't Know

Question 6: Testing for comprehension that rock records changes to environment over geologic time: "what do all of the layers of the Canyon represent?"	Correct	Environmental Changes AND Geologic Time AND Mode of Deposition
	Incorrect	None of the correct items
	Other	Don't Know
Question 7: Quantitative number on "how old is the oldest rock found at Grand Canyon?"	Correct	Billions
	Incorrect	Millions
	Other	Don't Know

APPENDIX D

TRANSCRIPTS AND CODING SCHEME FOR LANDSCAPE USE

Question 3: Relating to the principle of superposition (Respondent 073009_11)	
"Because it [the Kaibab Formation] is building on top. Isn't that the way it says, it's building on top… the layers are building, is what it said, over there you are here and we are on the top so everything else was here before and it is building up"	Coded into: Layers Built on top Direction Elevation Relative Age Use of Exhibit
Question 4: Reconciling the relationship between the horizontal ToT timeline and the vertical strata. (Respondent 081309_14)	
"So the Kaibab is way above, to then that way [east]" because "that [the Kaibab] must be younger because it is high above this [Bright Angle Shale], which is older to the left [west]."	Coded into: Direction Elevation Relative Age
Question 5: Relating to the principle of lateral continuity (Respondent 081309_15)	
"Well the river went through it and it cuts deep inside of it and it cut down not like slicing it like it cut downward and so if you start there and you look across the then you still have the same thing because it's like a flat plain but it's just cut down."	Coded into: River Cuts/Slicing Continuous Direction Elevation

Question 6: Identifying that the layers of Grand Canyon tell a story of the environmental changes over geologic time (Respondent 081309_04)	
"It [the layers of Grand Canyon] tells you that as the Earth was forming that different environments create different types of rock. And you know at one point it had that rock bed was formed by that volcanic activity and then you know like the ocean comes in and you have the winds push the sands here. Which creates a lot of the sandstone and then the water came in and then the little trilobites and others create the limestone layer. And so just different periods in time this surface looked different and it creates kind of a history in the rock.	Coded into: Environments Rock bed Volcanic Oceans Winds Life Layer Sedimentary rocks Forming/creates Relative Age Deposition Surface

APPENDIX D

CONSOLIDATION OF LANDSCAPE CODING SCHEME

Description of Characteristics

-cliff, color, erosional pattern, layer thickness, layers, stacked, basement rocks, canyon wall, north rim, the void itself, washes and river bed, width of the canyon, peak, rocks, vegetation seen on the landscape

Direction (horizontal)

- north, east, west, that way, stay in same place

Elevation (vertical)

- closer to the surface, up, down, higher up, on top, layer is lowest, superposition, bottom of the Canyon

Environment

- environmental changes, weather, atmosphere, life, environment types, rock represent change, climate, wind, decomposing animals

Erosion

- carved, canyon does action, gravity, exposed, ate down, uncovered, cut, wind blew it, the river split it

Geologic Time

- relative order, time, later, older, sooner, younger, before, years ago, long ago, closer to today, history of the earth, at one point, sometime later, millions, billions

Means of Catastrophic Deposition

-eruptions, impacts, volcanoes, earthquakes

Means of Sedimentary Deposition

- built, sedimentary, layered, formed, lain down, same formation, rock cycle, rocks have dinosaurs, layers formed, compressing, sediment, building, cemented

Previous Landscape

-connected, continuous, filled in, flat, joined, one big piece, plateau, same, split into two parts, used to be an ocean

River

-Colorado River, the river

Tectonics

-pushing up, uplift, mountain building, coming from down below, cut it, earthquake, plate movement, split open, tilted

Use of exhibit

-medallion, the numbers on the markers, the sign said, that's what it said, back there it said, I read that it said something about…

Water

-sea, ocean, flood, ice, lake