Students' Geocognition of Deep Time, Conceptualized in an Informal Educational Setting

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ABSTRACT

Students in a Landscape Architecture Design 1 course (N = 25) at a research university in the southern US developed design solutions implementing geologic time for an informal education site. Those students who employed abstract metaphors for their designs (n = 8) were more successful than students who proceeded with a linear design construct. Pre- and posttest assessments using the Petrified Wood Survey and student-constructed timelines suggested that 1) 75% geoscience content knowledge is needed for successful design, and 2) relative understanding of Earth events and the barrenness of early Earth's landscape is also prerequisite for successful design implementation. Most revealing of students' cognitive processes were the concept statements and concept maps produced during the project. The concept statement forced students to address the project's requirements, take a position with their concept development of abstract metaphorical representation, and proceed with a final design solution. It appears that concept statements with accompanying concept maps facilitate student cognition by forcing student comprehension and application of geoscience content knowledge. We suggest that an inclusion of concept statements when teaching application of a complex Earth system or process may facilitate students' geoscience cognition in design and/or informal educational settings.

INTRODUCTION

When elementary and middle school students visit the geology museum on the campus of a research university in the southern US, many of them enter with misconceptions about the age of Earth. Responses to the query of the planet's age include a range from "30 years" to "6000 years" to "maybe a couple of million." Even university students have difficulties grasping the enormity of Deep Time, or the 4.6 billion year geologic history of the planet.

Tours of the Dunn-Seiler Geology Museum, located on the university campus in the southern US, usually include brief introduction to the ancient age of Earth, but visitors still struggle to comprehend the magnitude of 4.6 billion years. If visitors' ages are demonstrated with one hand clap per second, students will predict that it is possible to clap 4.6 billion seconds within a human lifetime. However, this is impossible, as more than 140 *years* are required!

Geologic time facilitates student understanding of the progression of life forms exhibited in the Dunn-Seiler Geology Museum, from the Precambrian to the Holocene Epoch. Housed in Hilbun Hall, the museum's rock, mineral, and fossil displays fill the physical space. However, the area in front of the main entrance of the building is a blank canvas, and an underutilized space (Figure 1). Crossed by sidewalks, and with planting areas only against the building, the one-half acre (2000 m^2) site could be designed to include informal educational exhibits. An effective landscape design could transform this undeveloped area into a learning extension of the museum.

This case study involved the collaboration of the geology museum director with a professor of landscape architecture. The researchers probed whether students in an introductory design course, through informed exercises, could effectively develop an informal learning site which represented geologic time to facilitate viewer understanding of the vast history of Earth.

CONCEPTUALIZING DEEP TIME

Deep Time, or the 4.6 billion year history of Earth, is one of the central constructs of the geosciences (Carlyle, 1832, McPhee, 1981; Rudwick, 1992). Student conception of the immensity of the planet's history can affect other disciplines as well (Dodick and Orion, 2003). The Earth's geologic past can inform us of the principles that have dictated our planet's past, and help us to discern ancient patterns and trends; this may help us to effectively predict the planet's future (Soreghan, 2005).

Student comprehension of geologic time has been studied at the elementary level (Ault, 1982), and among high school students and preservice teachers (Dodick, 2007; Trend, 2001, 2002). Dodick (2007) reported that the use of scaffolded investigations was successful in

FIGURE 1. The Geosciences Department is housed in Hilbun Hall, along with the Department of Physics and Astronomy. The main entrance of the building is an undeveloped landscape.

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developing better student understanding of geologic time, particularly with respect to evolutionary change. Researchers also have probed college students' understanding of geologic time (DeLaughter et al, 1998, Schoon, 1992; Libarkin et al, 2005). Recent research (Libarkin et al, 2007) revealed that while college students were able to successfully place events in Earth history in a relative *order* on a time scale, there was little understanding between the relative *time* involved between the transitions of various events. Whereas students recognized the order of events in Earth's history, they exhibited inadequate knowledge of the amount of time *between* events. One notable problem was the student disconnect concerning the immense amount of time between the appearance of Earth's first prokaryotic life forms, and the evolution of more organized life forms, including dinosaurs and humans.

Deep Time and Informal Educational Sites

Can geologic time be effectively included in an informal learning space, and facilitate public understanding of Deep Time? At the Grand Canyon, the newly developed Trail of Time interprets geologic time—albeit on a grand scale—through the landscape (Karlstrom et al, 2008). This project involved numerous individuals, including geologists, educators, and landscape architects, in the conceptualization and planning of the design. Its value to public understanding of geologic time has yet to be determined.

However, the value of informal education and free-choice learning is well-established (McComas, 1996, 2006; Wandersee and Clary, 2006a). McComas (2006) argued that classrooms become unnecessarily limited when teachers ignore informal resources, while Wandersee and Clary (2006a) discussed methods by which teaching can be improved via informal science learning experiences. Furthermore, if we do not fully understand how students *voluntarily* learn, we cannot fully tap into motivation in the classroom setting (McComas, 2006). Informal education sites are important resources for lifelong learners. In addition to being the default learning environment for the majority of the adult population, this type of learning is also engaged by *students* more often than learning in traditional school environments (Falk, 2002). Researchers have investigated the theoretical bases, motivators, and assessments of learning in informal settings (Anderson et al, 2003; Falk, 2001; Falk and Dierking, 2000; Orion and Hofstein, 1994; Meredith et al, 1997; Rennie and Johnson, 2004). Through informal educational programs, citizens can become engaged in global problems, and research and collect data independently (Roy and Doss, 2007).

Based on the research of Edward Tufte (1990, 1997), we recognize that a successful informal educational design for geologic time is not necessarily dependent upon a direct or proportional analogy of Deep Time. Visual confections, or those designs that give the mind an eye, can evolve from *imagined* scenes or the non-conventional placement of data (Tufte, 1997). Because Earth's geologic past includes countless origins, extinctions, and events, all of Earth's events and organisms cannot be successfully portrayed in a small space. Therefore, an efficient selection of Earth's milestones is required to convey the enormity and progression of Deep Time. The complexity of geologic time should be revealed within an "economy of means" (Tufte, 1990).

METHODS

The Project Design: "Big Time, Small Space"

Design 1 is a junior-level course taught in Fall semesters in the Department of Landscape Architecture at a research university in the southern U.S. The course is open to students enrolled in a Landscape Architecture curriculum who have completed introductory coursework in design, computers, and graphics. The objectives of the Design 1 course include investigation of small spaces, and the development of informal space solutions. Although natural science courses are required as part of the undergraduate Landscape Architecture curriculum, geology or earth science is not mandatory. However, 71% of the students enrolled in the Fall 2007 semester had completed an earth science course in high school (n = 4), and/or college (n = 14).

A total of 25 students (N = 25) enrolled in the Fall 2007 Design 1 course participated in the Hilbun Hall design project. Twenty-three students were undergraduate students and three students were enrolled as a graduate leveling class. (These graduate students did not enter the master's program with a bachelor's degree in Landscape Architecture, or had not previously completed a Design course.) Six of the undergraduate students were female with the remainder of the students being male. Student ages ranged from 20–25 years old (n = 18), 25–30 (n = 3), 30–35 (n = 1), and 35–40 (n = 3). This project, the third of the semester, involved the design of an informal geology education space in the front of Hilbun Hall, which houses the Geosciences Department and the geology museum (Figure 1). Students were requested to design an outdoor exhibit at the main entrance of the building with requirements to include the following Big Time concepts in their project solution: 1) geologic time of Earth should be conceptualized in the small space available; 2) both Earth's life and landforms change; 3) there is a progression of life forms; and 4) humans are insignificant within the context of geologic time. The four-week project utilized the standard design process (Booth, 1983), which employs a progressive series of analytical and creative thinking steps. The design process is a problem-solving process that provides a designer with a logical, organized framework for a design solution and is a standard approach in many landscape architecture, architecture, and engineering disciplines (Supplement Figure A). The use of this process insures that a solution is suited to the client and site needs, and allows for alternative solutions for best land use. The design process begins with a thorough inventory and analysis of the project site (soils, circulation, climate, topography, site context, hydrology, vegetation). Based upon the client's needs, a program is established for the types of landscape spaces and elements that will be included in the design. From this base information, concepts (design ideas) are explored which help lead to form generation for the preliminary design phase. These early conceptual designs are then refined to resolve pedestrian and vehicular circulation needs, proper landscape space sizes, site furnishings, vegetation needs, and other issues until the design is resolved into a final master plan. The master plan shows the exact locations of all proposed program and design elements and with supplementary elevation and perspective sketches, allows the client to visualize the intended design.

In addition to the design process, students were also required to research geologic time and the regional landscape, and produce a report (1000 word minimum) summarizing their research.. A list of references was provided with the project statement, and included websites, books, publications, and case study examples.

The geology museum director, acting as the client, introduced the concept of geologic time at the beginning of the project. The ancient age of Earth and the development of the geologic time scale were presented, and students briefly investigated the life forms of the Precambrian, and Paleozoic, Mesozoic, and Cenozoic eras. (The progression of life forms was presented not as linear evolutionary progress, but a relative time frame of the emergence of prokaryotic life, eukaryotic life, and multicellular organization from cellular grade to system grade organisms.) Tectonic plate movement, from 750 million years to the present, was displayed with the present-day state location highlighted throughout the animation. Finally, a toilet-paper time line demonstration was used to reveal the relative scale of life progression throughout the 4.6 billion years of Earth history.

Assessment Methods

Before the introduction of the project, incoming student geologic knowledge was assessed using petrified wood as a vehicle for probing understanding. The Petrified Wood Survey (Clary and Wandersee, 2007) explores student understanding of geologic time, fossilization processes, and evolution. This survey (Appendix A) was chosen as an appropriate instrument for assessing incoming knowledge because 1) it has been field-tested on multiple occasions, and its validity and reliability have been established (Clary and Wandersee, 2007), 2) the researchers were familiar with the instrument and past survey results, and 3) large public displays of petrified wood exist in the area, including a petrified log outside the university geosciences building (Figure 2). A blank "timeline" of Earth was also given to students, who were then asked to place 12 selected events from Earth history in a relative order and scale (relative distance between events).

Throughout the project, the landscape architecture professor and his teaching assistant helped the students with project development via desk critiques. Desk critiques, or individual student evaluations and discussions, are utilized with each student throughout the semester. Desk critiques are a standard method for studio class instruction in landscape architecture. Instead of traditional lecture presentations, desk critiques allow the instructor to meet individually with each student at his/her desk to review the progress of the student's work. The instructor does not provide design answers or solutions for the student's project nor tries to influence the design ideas, but instead alerts the students to the proposed design's functional flaws (such as incorrect sizes of parking spaces or sidewalks, appropriate siting of landscape elements, or aesthetics). Students visited the Hilbun Hall site, and had an opportunity to explore some of the fossils recovered from the local area, including petrified wood and ammonites. Students were instructed that they must utilize the petrified log, donated to the Geosciences Department by the Class of 1920, within the final landscape solution (Figure 2).

After two weeks, students were required to turn in their concept statement. The concept statement serves as a summary of student understanding of the client request, and also presents the student's major idea for the project development (Reid, 1993). This statement becomes the organizing tool from which students design their landscape solution; it helps students clarify their intent for their project. During the process of formulating their concept statements, students were asked to construct concept maps, diagramming how they arrived at their organizing theme. The resulting graphics captured the student's organization and representation of knowledge (Ruiz-Primo and Shavelson, 1996; Novak 1990). Visualization techniques such as concept mapping can also help students process information and consolidate understanding (Johnson and Reynolds, 2005). Concept map construction, and the resulting condensation of the student's plan for the landscape solution in the concept statement, revealed students' thought processes and their perception of the scale of geologic time. Inter-rater reliability of concept maps and desk critiques has been established at 80–85% between this case study's landscape architecture professor and another professor of landscape architecture who has team-taught this course. However, in this case study, all concept map and desk critiques were conducted by the landscape architecture professor of record.

In landscape architecture, concept maps are allowed creative leeway. Instead of evaluating concept maps for concepts, nodes, and labeled lines, the landscape architecture professor is more interested in representation of the progression of student thought from concept to

FIGURE 2. The petrified log currently resides in a planting area in front of the main entrance to the Geosciences building. The log, found locally in the state, was donated by the Class of 1920.

implementation. Successful concept maps are those which congeal thought student thoughts into a design that can be implemented. In Supplement Figure B, the concept map displays a student's progression of thought starting with a general term of geology and transitioning through life and landform change to a concept statement of transition and interweaving transformations. The student successfully provides a sketch of interweaving river channel forms which leads to possible form constructions for the design project.

Not all students were able to solidify their ideas into a practical design implementation. Supplement Figure C shows a student's concept sketch that also starts with geology, but the progression of thought bifurcates a loosely organized series of terms that leads to "rock cycle." With more careful consideration, this undeveloped concept map could have progressed to a more serious and challenging design idea.

Students presented their projects to the class, the geology museum director, and several landscape architecture professors at the conclusion of the project. Final projects were assessed by the landscape architect on how well students utilized the design process by 1) understanding the site though site inventory and analysis, 2) developing a concept statement, 3) developing the program and sequencing of spaces, and 4) master plan refinement. Each student received detailed feedback on her/his project.

At the end of the semester, and following the conclusion of another design project, a modified version of the Petrified Wood Survey was administered as a posttest to ascertain student geologic knowledge gains. Specifically, the posttest omitted the questions that probed students' past earth science high school and college courses, and the identification of a famous paleontologist (section A, Appendix A). Students also were asked to construct their own timeline, while including the 12 selected Earth history events.

RESULTS

Because of the constraints of the limited space, student designs that utilized abstract representations of Deep Time were more successful at conveying the enormity of Earth's history than linear design solutions (Brzuszek and Clary, 2008). Students who incorporated abstract metaphors in their final design solutions (n = 8) were able to select a concept that was universal to all time, while students using linear time design solutions struggled with their spatial understanding of a geologic timeline in their designs. Successful projects are defined as those that had a thorough site inventory and analysis, a workable concept, an effective use of space, and a detailed final master plan. In this case study, successful projects are further defined as those that represented a critical Earth process or pattern as a universal metaphor to convey to enormity of Deep Time.

Students' Level of Cognition: Design Solution Evaluation

To assess the level of intellectual behavior that students implemented towards concept and design resolution for their informal geology education projects, points were assigned for each of the four client-requested concepts (big time-small space, life and landform change, progression of life forms, humans are insignificant) according to Bloom's levels of cognition (evaluation– 6, synthesis–5, analysis–4, application–3, comprehension–2, knowledge–1, and 0–topic lacking or poorly addressed).

Students addressed the concepts of life and landform change, and progression of life forms, more successfully in their design solutions than the other two concepts. Students' scores on these concepts averaged higher than 1.0, while students' average scores of the other concepts (big time-small space, humans are insignificant) were below 1.0. In their search for concept or meaning behind the design, a few students did not incorporate any of the four client-requested concepts.

Students who scored highest—or those students exhibiting cognition above the general knowledge level—for incorporating the client-requested concepts of big time -small space and insignificance of humans tended to use abstract metaphors for their design concept instead of time-moving metaphors for particular periods.

Although students' knowledge of geologic time was probed with the Petrified Wood Survey, the student-constructed timelines, and an assigned research report, we eliminated the research reports from further coding and analysis. Initial scoring revealed that the students' reports on geologic time and the regional landscape were remarkably similar, and did not discriminate between students. Therefore, we further analyzed the pre- and posttest Petrified Wood Surveys and student-constructed timelines to determine changes, if any, in student understanding of geologic time throughout the semester.

Student Understanding of Geologic Time: Petrified Wood Survey

The pre- (n = 24) and posttest (n = 16) administration of the Petrified Wood Survey was utilized to investigate whether a prerequisite geoscience content knowledge was required for successful design (Clary and Wandersee, 2007). In the pretest responses, several student misconceptions were revealed. A majority of students (54%) responded with "young Earth" beliefs for fossilization processes and time constraints. By the end of the semester, however, 75% of posttest responses reflected student understanding of the enormity of time required for fossilization and Earth processes (Table 1).

Analysis of differences in pre- and posttest responses (n = 16) for individual students resulted in a mean gain of 3.56, which is higher than the previously reported gains among non-science majors (Clary and Wandersee, 2007). Therefore, advances in student geoscience cognition appear to have been achieved through the informal education design project.

Further investigation of the Petrified Wood Survey responses for those students who utilized abstract design solutions and who took both pretest and posttest surveys (n = 5) revealed that all but one student achieved geoscience content knowledge in evolution, geologic time, and fossilization to a minimum 75% content knowledge (i.e., 8 questions correctly answered out of 12). The student who was the exception (Student 15) exhibited 50% content knowledge levels in *both* pre- and posttest survey

TABLE 1: PAIRED PRE- AND POSTTEST PETRIFIED WOOD SURVEY RESULTS

NAME	PRE-TEST	POST-TEST	DIFFERENCE	DESIGN SUCCESS
Student 1	3	8	5	Y
Student 2	1	8	7	N
Student 3	4	10	6	N
Student 4	9	11	2	Y
Student 5	2	5	3	
Student 6	3	6	3	
Student 7	3	7	4	
Student 8	1	2	1	
Student 9	5	8	3	N
Student 10	5	8	3	N
Student 11	6	6	0	
Student 12	4	5	1	
Student 13	3	9	6	N
Student 14	2	8	6	Y
Student 15	6	6	0	**Y**
Student 16	2	9	7	Y

[1]The numbers reflect correct responses (out of a possible 12) in pre- and posttests. Students with successful design solutions scored at 75% content knowledge on the posttest (n = 8 correct responses). Successful design solutions are marked with Y, with the **Y** indicating the one student who exhibited no gain in content knowledge between pre- and posttest survey scores. Students with 75% posttest content knowledge who did *not* successfully abstract geologic time are marked with N.

assessments. However, the questions successful answered by this student differed between the pre- and posttests. (We also were unable to measure content gains for one student because he was not present for the administration of the posttest survey.)

We used a Wilcoxon matched-pairs ranks test to determine statistical significance for the 16 students with paired pre- and posttest Petrified Wood Survey scores. Analysis revealed a significant difference in mean scores between the pre- and posttest survey results (test statistic = 5.935, prob >|t| <0.0001). A two sample paired t-test resulted in the same conclusion. However, we caution that the sample size is small. Although we suspect that basic research for the required paper and the experience of designing an informal educational space on Deep Time may have contributed to student knowledge gains, we are reluctant to over-generalize the results to a larger population without further research.

It first appeared that a connection existed between a minimal geoscience content knowledge and the ability of the student to abstract geological time in a project design when we recognized that students with successful designs were represented among those with a final 75% content knowledge. However, there were also students who exhibited introductory geoscience content knowledge but who did not take a posttest (n = 2), or students with changes in geoscience content knowledge during the semester (n = 6), to the 75% content level. Although the prerequisite content knowledge was present or acquired, these students were unsuccessful in incorporating an abstract metaphor in their design solution. Even with a post-project 75% content knowledge, these students could not represent Deep Time within the project area.

Student Understanding of Geologic Time: Student-Constructed Timelines

Prior to the project's introduction, students were also asked to place 12 Earth events on a timeline, whose endpoints were designated "Origin of Earth" and "Today." The events were presented to the students as alphabetized lists, and included Organisms' Origins (Amphibians, Bacteria, Dinosaurs, Fish, Humans, Mammals, Reptiles, Shelled Organisms), Plant History (Flowering Plants, Grasses, Land Plants), and one Extinction event (Dinosaurs).

When students' pretest designs were analyzed, three consistent findings emerged: 1) Relative time between events—as represented between the relative spacing of events on the Earth timeline—was problematic for all students; 2) Milestones in plant evolution, solely and within a broader context of other organisms' evolution, were poorly understood by all students; and 3) Several students (n = 9) exhibited misconceptions about the origin of life forms with reference to complexity (e.g., students did not know that fish show up in the fossil record before amphibians and reptiles).

We categorized pretest time scales into three groups, in which students were "beginning time bunchers," "equal-time dividers," or "barren time assigners" (Supplement Figure D). Most students (n = 14) began the project as "beginning time bunchers" and heavily weighted the placement of Earth events toward the "Origin of Earth," 4.6 billion years ago. The second most popular student style (n = 6) of timeline development was the "equal time divider," with Earth events approximately equidistant between Earth's origin and the present day. Only four students acknowledged the passage of Earth time before the evolution of life forms as "barren time assigners;" however these students still exhibited lack of understanding about the great time involved between prokaryote evolution and the origin of higher life forms. Half of the early "equal time dividers" (n = 2) were among those who produced a successful abstract project design.

Following the initial pretests, the museum director presented an overview of Earth's history that included discussion of the major Earth events. At the end of the semester, students were provided with the same 12 Earth events, but there was no pre-drawn timeline with labeled endpoints. Students were instructed to quickly sketch a timeline and incorporate all the 12 Earth events. The majority of students (n = 13) reverted to a line segment to represent time, but two students utilized a spiral or curved line, and another student had a non-scaled progression of events.

Analysis of the posttest timelines revealed that students' cognition of geologic time improved throughout the semester (Table 2). The majority of students (n = 11) had progressed to become "barren time assigners." The "equal-time dividers" were now extinct, with students evolving into the two other categories. There were minimal "beginning time bunchers" (n = 3) who persisted in their misconception that life forms evolved when Earth formed. Posttest timeline analysis further revealed that although students gained an understanding of scale, many

TABLE 2: SELECTED PRE- AND POSTTEST STUDENT-CONSTRUCTED TIMELINES

NAME	PRE-TEST	POST-TEST	DESIGN SUCCESS[3]
Student 1	BTB[1]	BTA	Y
Sudent 2	BTB	BTA	N
Student 3	BTA	BTA	N
Student 4	BTA	BTA	Y
Student 5	ETD[2]	BTA	N
Student 6	BTB	BTB	
Student 7	BTB	BTA	N
Student 8	BTB	BTA	N
Student 9	BTB	BTB	
Student 10	BTB	n/a	
Student 11	ETD	n/a	
Student 12	BTB	BTA	N
Student 13	BTB	n/a	N
Student 14	BTB	BTB	**Y**
Student 15	BTA	BTA	Y
Student 16	BTB	BTA	Y
Student 17	BTA	n/a	N

[1]Most students entered the design assignment as "beginning time bunchers" (BTB).
[2] There were also misconceptions held by students who were "equal time dividers" (ETD).
[3]The most successful timeline design belonged to those who acknowledged time between the origin of Earth and the earliest fossil prokaryotes, and who acknowledged great time between bacteria evolution and more complex multicellular organisms. These are the "barren time assigners" or BTA. All but one successful design solution belonged to a student who ended the semester with BTA understanding. (The exception is a student who maintained his BTB misconception.) Although several students ended the semester as BTAs, they did not produce successful design solutions. This table only reflects the timelines which can be attributed to specific individuals; not all timelines were labeled. Grayscale highlights the two successful students who entered the semester as BTAs.

still exhibited a disconnect between evolution of bacteria and higher life forms, and they did not note the large amount of relative time between these events. Interestingly, students maintained their misconceptions on the progression of plant history. Although in general people know less about plants than animals (Wandersee and Clary, 2006b), we were still surprised that individuals who work more closely with plants than the average individual still held misconceptions about plant complexity. Plant evolution was included during the introduction to geologic time at the beginning of the project.

All but one of the students (n = 5) who produced successful abstract metaphors in their landscape solutions finished the semester as a "barren time assigner." The exception was a lone student who maintained geologic time misconceptions, and remained a "beginning time buncher." However, this student did show progress in the Petrified Wood Survey posttest. Therefore, timeline pre- and posttests also indicate that an understanding of relative time is necessary for successful implementation of abstraction in design solutions. Similar to the Petrified Wood Survey results, there remained some students who were able to comprehend relative geologic time, but were still unable to successfully abstract geologic time within their designs.

Not all student-constructed timelines were labeled with students' names, and we were unable to conduct a complete analysis between pretest- and posttest-constructed timelines. However, we were able to document that one of the four original "equal time dividers" had progressed to become a "barren time assigner" by the end of the semester, but was still unsuccessful in the landscape design solution. Although the two other "equal time dividers" were unsuccessful in their design solutions, we are unable to determine at what stage of geologic time understanding they ended the semester. Of the initial 14 "beginning time bunchers," three were successful in their design solutions and these three had become "barren time assigners". Three of the original "beginning time bunchers" maintained their misconceptions, and ended the semester as they had entered the assignment. As previously noted, one of these "beginning time bunchers" did manage a successful design solution, but the other two students did not.

Conceptualizing Geologic Time: The Concept Statement

Concept statements, with accompanying concept maps and desk critique conversations, were the tools most revealing of students' cognitive changes throughout the project. Design analysis of the final projects by the landscape architect differentiated two groups of student design solutions: linear designs, and design abstraction. The most successful design solutions were those projects which incorporated an abstract metaphor in the representation of geologic time (Brzuszek and Clary, 2008). There was a notable exception: One student utilized a linear progression of geologic time, but was able to convey an early barren Earth, and the enormity of Deep Time (Figure 3). This student's interpretation of the design requests, as well as the basis for his solution, is summarized within his concept statement. This student's solution has an entry space to the exhibit that signifies the beginning of the solar system's formation, with a linear walkway (timeline) that condenses and exhibits Earth's major events. These events include tectonic movements, asteroid impacts, and formations of life. Therefore, the design from the entry space is a largely rocky barren landscape until the culmination of the life in the Phanerozoic Eon. Although the design incorporates a linear progression of time, the student uses a camera's aperture as a metaphorical device for the prospects for Earth's future. The aperture represents a snapshot, or moment in time, of Earth's history.

All other successful design solutions utilized abstract metaphors that selected an Earth process or pattern to symbolize elements common to all Earth time. For example, one student chose a concept solution for a space that used the cyclical progression of time as the unifying element for Earth's history (Figure 4). The design features a large equatorial sundial that dominates the space and overwhelmingly represents "big time." A key statement in the concept map mentioned that "physical movement can only be understood as a unit of time." To fulfill the additional client requirements, the student rationalized

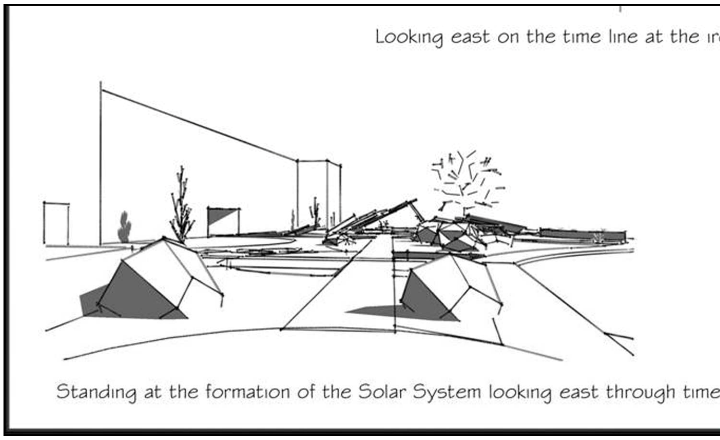

FIGURE 3. Although successful project design solutions were those which incorporated abstract metaphors, this student's linear progression design is an exception. Earth's history proceeds from the origin of the solar system with an early barren Earth (top view), to an aperture of Phanerozoic time.

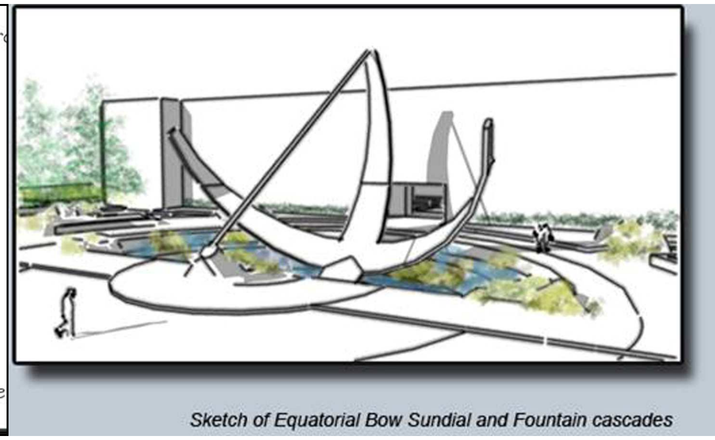

FIGURE 4. One student chose to abstract geological time in the informal space by utilizing the progression of time as the unifying element, represented by an equatorial bow sundial.

the use of a sundial 1) as a large focal point to show "enormous timespan through the history of Earth;" 2) as an exhibit with active movement to symbolize that life and landforms change; 3) as a progression of shadow to represent the change in life forms; and 4) as a large-sized object to show that humans are insignificant. The location and form of the sundial set the pattern or forms for the remainder of the exhibit space (Figure 4).

Another successful abstract solution employed huge granite monoliths to represent the enormity of time in the eons of Earth's history (Figure 5). The student chose to dwarf visitors with the immense physical representation of the enormity of time. Long linear pathways allow visitors to experience various block forms, whose sizes and locations correlate to various time units in Earth history. The organizing quote used by the student was Schopf's, "For four-fifths our history, our planet was populated by pond scum." The simplicity of abstract block forms reveals the subtlety of Earth processes.

Students who employed process concepts were better able to unify the entire exhibit space. One student chose Earth's dynamic changing nature as the organizing theme; he was able to use shifting landscape forms to organize the exhibit space (Figure 6). The design featured tilted rock archways that symbolize plate tectonic movement, berms of Earth in the shape of cinder cones, and various rock forms. This design used geologic processes to shape the experience of users in the space, regardless of any particular time period.

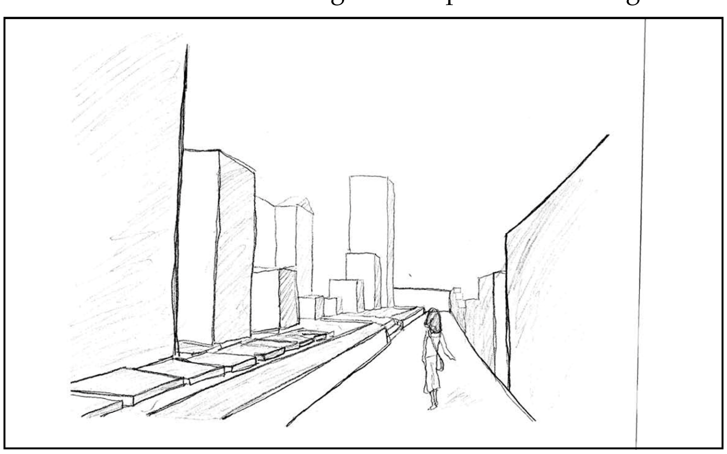

FIGURE 5. One student chose to abstract geologic time by using the enormity of Deep Time to dwarf the visitor.

Similar to Earth processes, forms may be used to abstract biological constructs. The concept statement sketches in Figure 7 display the forms selected by the student that would be utilized in the landscape solution. These were abstracted in a spiral design (Figure 8). The final design employed a spiral fountain (Figure 9), rising above the landscape space. The abstracted design (Figure 10) also utilized the large spiral to arrange the entire exhibit space. The word "undulating" was key in the concept statement, and led to the selection of the spiral form as the organizing element. The spiral, when combined with another concept of the branching patterns of life forms, allowed the student to create a branching spiral pattern that signifies the progression of life on Earth.

DISCUSSION AND IMPLICATIONS

There appear to be three criteria for achieving a successful design of Deep Time in an informal learning exhibit: 1) sufficient content knowledge, 2) the thoughtful use of concept maps to explore the depth of an idea, and 3) the ability to convey large time periods through representation, most often abstract metaphorical representation.

The results of the pre- and posttest Petrified Wood Surveys indicate that a minimum geoscience content knowledge is important for successful Deep Time implementation in an informal space. Successful project designs were developed by students who had achieved a 75% content knowledge. However, the converse did not hold: Students who achieved a 75% content knowledge during the semester were not necessarily able to design informal spaces that conveyed the enormity of Earth time.

The Petrified Wood Survey results also showed

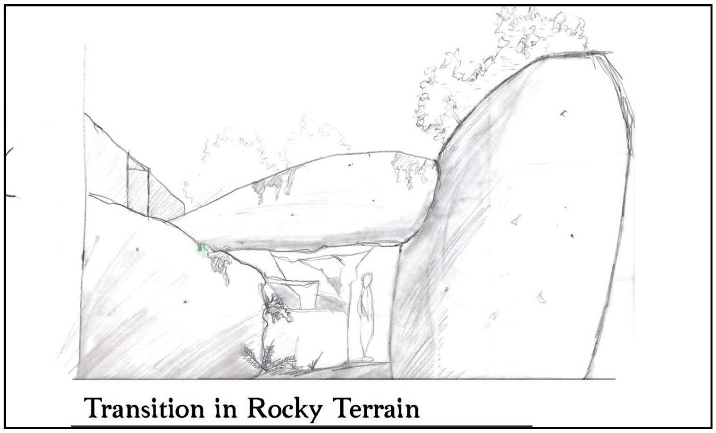

FIGURE 6. Students who utilized Earth processes as organizing themes were able to successfully abstract the enormity of geologic time in their project designs. This student incorporated Earth processes in his design solution, such as this area that represented tectonic movement and shifting plates.

greater gains between pre- and posttest responses than the previously reported values in science education literature (Clary and Wandersee, 2007). These greater gains may be coincidental, or they may reflect genuine geoscience knowledge gains from the research process, the formulation of the concept statement, and the application of the research into a final design solution.

More research is needed to compare the knowledge gains between large-lecture introductory geoscience students, and non-geoscience majors who must *apply* their geoscience knowledge in project designs.

Similar results were noted for the pre- and posttest student-constructed timelines. Whereas the majority of the class started as "beginning time bunchers," progress in student cognition of Deep Time was achieved during the semester. Most students recognized a lack of life forms during the early Precambrian by the end of the semester ("barren time assigners"). All successful abstract design solutions, with the exception of one student, were constructed by students who noted this early barren Earth history. However, not all students who comprehended a relative scale and order of Earth events were able to successfully abstract geologic time in a final design solution.

We noted that the concept statements and concept maps revealed the most about students' cognitive processes. The requirement of a concept statement appeared to solidify students' cognition, and force them to address the requests of the client. Those students who were able to visualize an abstract metaphor as a representation of Deep Time were more successful in their design solutions; the development of metaphorical representations is demonstrated within concept maps,

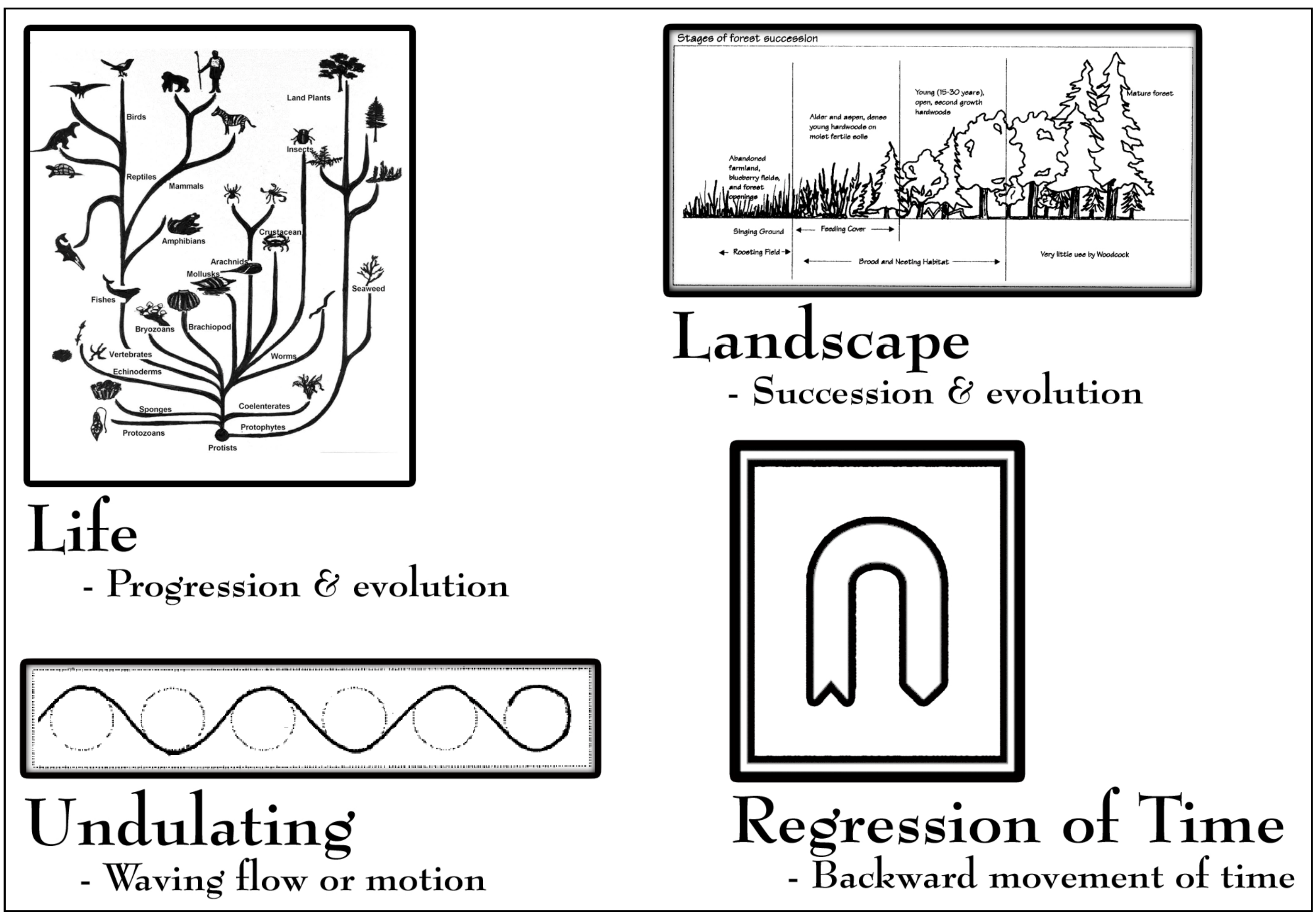

FIGURE 7. These forms, selected by the student in his concept statement, became the basis for the design solution.

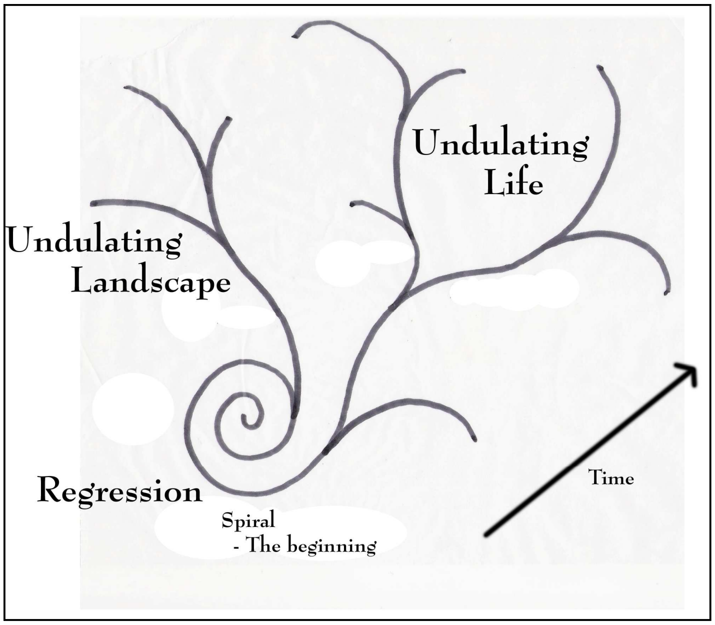

FIGURE 8. The concept statement forms (Figure 7) were combined by the student into a spiral design.

with final selection of abstraction visible in the concept statement. From the concept statement, students developed a final plan for the informal education space. Therefore, all activities *before* the finalization of the concept statement (geology presentation, independent research, site visit and fossil exploration) may have provided raw material to the student for visualization and application of geologic time in an informal space. Following the concept statement, the student's geocognitive processes were developed only as a design implementation in the final solution. However, more research is needed to fully understand the role that the design exercise played in students' general understanding

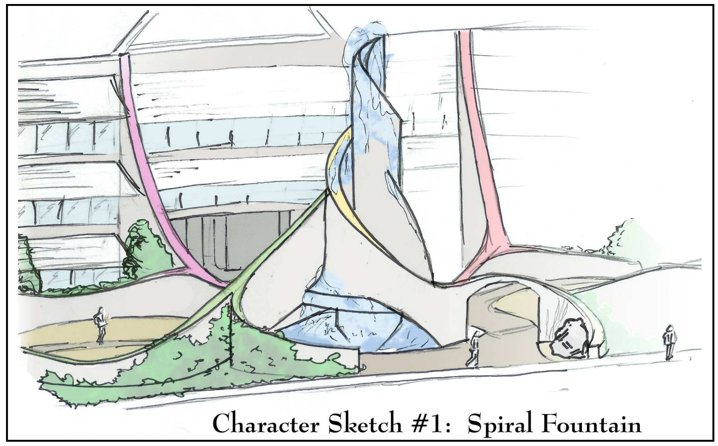

FIGURE 9. The spiral design evolved from the student's concept statement (Figures 7, 8), which was developed into a spiral fountain rising centrally above the landscape space.

of geologic time.

The concept statement for these Design 1 students functions as a tool similar to Gowin's (1981) Research Vee that is used in advance of scientific research. Gowin's Vee forces students to identify their theoretical base for a project, and identify their activities and final products of their research *before* research commences. This becomes the blueprint from which students' research proceeds. Although not as detailed, and without various levels of conceptual and methodological constructs, the concept statement functions in a similar manner by forcing students to identify their intent before the application process begins.

Therefore, this case study research indicates that the use of concept statements, with accompanying concept maps, helps facilitate student cognition by forcing student comprehension and application of geoscience content knowledge. Concept statements may have implications for

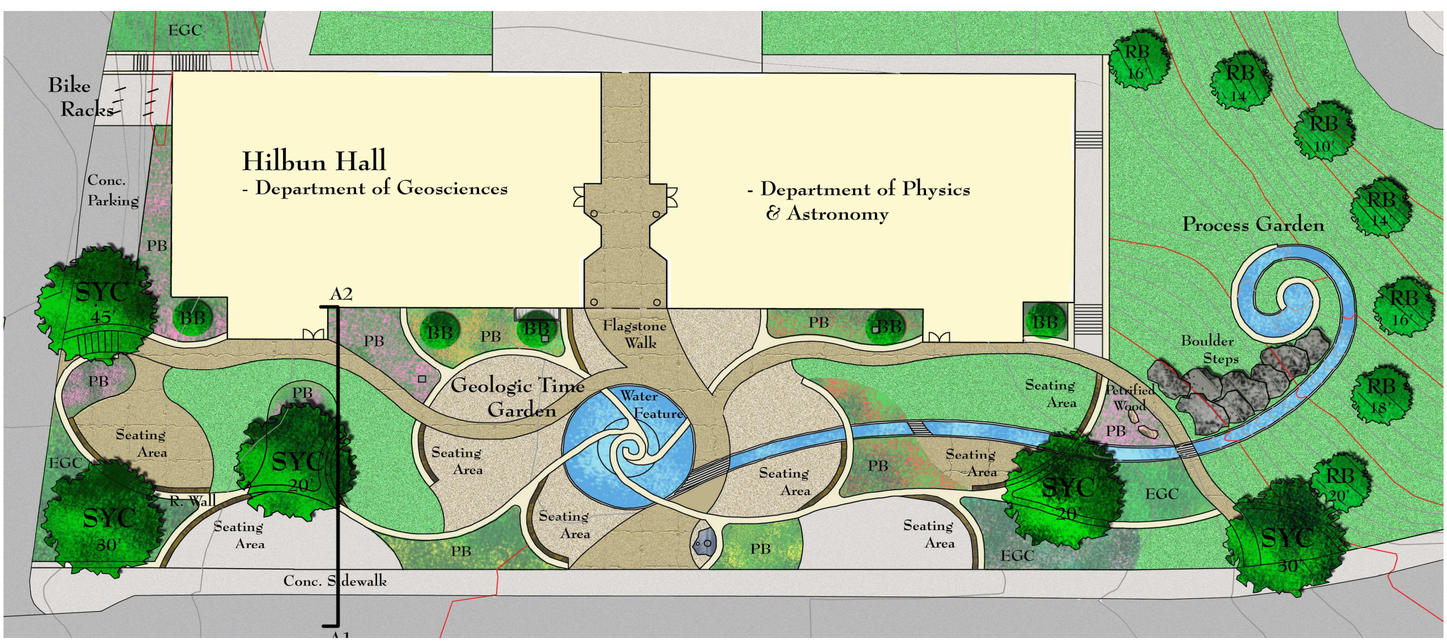

FIGURE 10. The final design solution included abstraction of geologic time as a spiral form. The student focused upon the word "undulating" in the landscape design.

success in informal science site development by pushing students to assimilate and synthesize their science understanding, and reveal their plans *before* design implementation. We suggest that an inclusion of concept statements when teaching application of a complex Earth system or process may facilitate students' geoscience cognition in design and/or informal educational settings.

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An online supplement to this article, with additional figures and images, is available at http://www.journalofgeoscienceeducation.org/

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APPENDIX A: THE PETRIFIED WOOD SURVEY

A. Questions probing student perceptions and background information:

*Within which school science subject does petrified wood and petrified forests seem to fit best?
Biology
Chemisty
Earth science/geology
Choices Biology/Geology
All of the above choices

*Looking back across all your years in school, how many times were you taught about petrified wood?
Never
Once
Twice
Three or more times

*When did you have an earth science course?
Not in high school or college
In high school
In college
In both high school and college

*Which famous scientist do you most strongly associate with the study of fossils?
(Fill in the blank)

B. Questions probing the properties of petrified wood

*Which of these methods do you think scientists are LEAST likely to use to estimate the age of petrified wood samples?
Analyzing associated fossils of other organisms found surrounding the petrified wood
Analyzing the sequence of rock layers in which the petrified wood was found.
Counting tree rings visible in a stem section.

*If you held a piece of South African black ironwood (today's heaviest wood) in one hand, and an identically sized piece of petrified wood in your other hand, which do you predict would happen?
The ironwood would feel heavier
The petrified wood would feel heavier
They would seem to be about the same weight.

*Which of the following do you think is NOT true of petrified wood?
It's a fossil
It's a rock
It mostly contains ancient wood, plus some minerals
Many species of petrified plants have been found

C. Questions probing geologic age concepts

*Which one of these three time periods is the one that occurred longest ago on the geologic time scale?
Cambrian
Devonian
Jurassic

*Someone says, "Today's physical processes, such as those mentioned in the previous question, continue to operate on earth at essentially the same rate and in the same way as they did in the past." Do you think this is true or false?
True
False

*How long do you estimate it took for a tree from the past to become completely petrified?
Less than 100 years
Hundreds of years
Thousands of years
Millions of years
Billions of years

D. Questions probing geographical occurrences

*To which US State would you travel if you wanted to visit the largest public display of petrified forests?
Arizona
Colorado
Mississippi
New Mexico
Wyoming

*Petrified wood has been found
In a few US states
In a few countries
On a few continents
On every continent except Antarctica
On every continent

E. Questions probing fossilization processes

*Which of the following do you think is NOT required in order to form petrified wood?
Dead trees
Rapid burial
O_2-rich environment
Time

*Which of these natural processes do you think is NOT important to the formation of petrified wood?
Dissolving
Permeating with mineral-rich solution
Replacing with minerals
Decaying

F. Questions probing chemical composition

*What gives petrified wood its colors?
Climate during fossilization
Minerals associated with groundwater
Natural color of original wood
All of the above

*With a typical petrified wood sample, what type of mineral has replaced the original wood?
Carbonate, $CaCO_3$
Phosphate $Ca_2(PO_4)_3$
Pyrite FeS_2
Quartz SiO_2