A Formative Assessment of Geologic Time for High School Earth Science Students

Ron Hermann Morgan State University, Baltimore, MD 21251, rhermann@bpcl.net
Bradford Lewis Morgan State University, Baltimore, MD 21251, blewis@moac.morgan.edu

ABSTRACT

Earth science courses typically include the concept of geological time. Traditional approaches to teaching geologic time have turned to constructivist methodologies in an attempt to increase student understanding, but these lessons often result in students determining the scale of geologic time instead of gaining an increased understanding of the geologic time scale. Here students create a geologic time scale based on an older adult's life complete with relative and absolute dates for the events in their lives. Students write a reflective paper about the process of constructing the time scale and compare their scales to the geologic time scale. The project is used as a formative assessment which serves to inform instruction, rather than assess students on the project. To that end, students submit project drafts for review and are given immediate feedback regarding improvements to the project. Through this process the teacher gains valuable insight into the direction instruction should take based on common misunderstandings or questions that arise during conversations with students.

INTRODUCTION

There are multiple ways in which teachers traditionally assess students' conceptions of geologic time. One traditional method provides students with a list of geologic events which students put in the correct sequential order, scaled to the length of adding machine tape. This method results in an assessment of students' understanding of the mathematical process needed for comprehending scale rather than assessing an understanding of geologic time. Science educators have strived to develop more innovative lessons with a constructivist methodology (Hemler & Repine, 2002) so that students develop a deep understanding and appreciation for the concept of geologic time. Here, we move past traditional assessment practices and develop a formative assessment of students' understanding of the construction of the geologic time scale and how it is interpreted. Through this approach students are challenged to conceptualize the geologic time scale by comparing it to a student-produced time scale for an older adult's life. This formative assessment allows the teacher to alter instruction based on students' feedback in order to maximize student understanding of geologic time.

GEOLOGY BACKGROUND

High school earth science courses typically cover basic geologic principles, such as the principle that the Earth is approximately 4.6 billion years old. To account for such a large period of time, geologists have divided the 4.6 billion years into smaller segments of time based on major events in Earth's history. This concept, known as "geologic time", is universally accepted by scientists and is used in the description and analysis of events of Earth's past.

Geologic time is measured in four units: eons, eras, periods, and epochs. These units are grouped in a hierarchy; however, the length of absolute geologic time that each unit represents is different. Eons are the largest unit of time, and are divided into eras. Eras, in turn, are divided into periods, and periods are divided into epochs (the smallest unit of geologic time). The actual duration of time varies for each unit of geologic time. For example, an era may last several tens of millions years or several hundreds of million of years. The duration of an era depends upon the significant geologic events and changes in fossil type or abundance that occurred during that time. The Mesozoic Era lasted from 245 million years ago until 65 million years ago, a total of 180 million years. These times mark two significant events: the emergence of dinosaurs 245 million years ago and the extinction of dinosaurs 65 million years ago.

Geologists have constructed two ways to determine geologic time: absolute dating and relative dating. Absolute dating is the process of determining the actual age of an object, perhaps a fossil or bone, through radiometric dating techniques. Radiometric dating is possible due to radioactive decay, a process in which the parent atoms change into daughter atoms by loosing or gaining subatomic particles (Conte, Thompson, & Moses, 1994). For example half of the atoms of the parent element potassium (K^{40}) convert into Argon (Ar^{40}) over the course of 1,300,000,000 years. Since this decay happens at a constant rate, one can surmise the age of an object by determining the ratio of the parent element (potassium) to the daughter element (argon).

Relative dating is the process of determining whether one object is older or younger than another object. This process is used when the absolute age is not known. Relative dating techniques are based on the law of uniformitarianism, which maintains that the geologic events and processes that are observable today must be the same geologic events that happened in the past. Therefore, by assuming similarity between current and past geological processes, geologists can infer the sequence of past events.

EDUCATIONAL RESEARCH OF GEOLOGIC TIME

The phrase "geologic time" often is extended beyond the geologic time scale to refer to the comprehension of geologic principles that are based on the geologic time scale. This fundamental understanding of geologic time is a prerequisite for a deeper understanding of geologic principles such as original horizontality, superposition, and others associated with interpreting rock layers and embedded fossils. Therefore, this assessment becomes an important tool that can help teachers determine whether students are capable of understanding more challenging

Laura's Time Line			
Eras	**Periods**	**Relative Dates**	**Absolute Dates**
Infancy	Infancy	Birth	January 27, 1953
Childhood	Toddler	Moved to MD	
	Elementary School	Moved to Long Bar Harbor	
		Moved back to IL	
Young Adult	Pre-teen	Met best friend Eric	
	Teen	Started High School	
		Graduated from H.S	June 6, 1971
Adulthood	Tough Times	Father Passed Away	April 9, 1973
		Accepted Jesus Christ as Savior	
	Career	Started Criminal Justice Career	
		Started Dating Joyce	
		Started Working for Harford Co. Sheriff's Dept.	
	Married	Married Joyce F.	April 18, 1978
		Moved into first house	
Family	Family	Birth of Krista W.	April 19, 1983
		Moved to Current House	
		Birth of Laura and Leslie W.	May 16, 1988
	Retired	Retired from Harford Co. Sheriff's Office	Oct. 31, 2002

Table 1. Laura's time line of her father's life.

problems regarding geologic time. Dodick and Orion (2003) have suggested that it is possible to start teaching the logical principles used in geology to reconstruct geological structures somewhere between grades 7 and 8. Their research suggests, however, that students in higher grades fair significantly better on assessment measures regarding geologic time. The assessment outlined here is intended for high school students who should be cognitively capable of understanding geologic time.

In dealing with such an enormous time scale, students and teachers often struggle with the sequence of events and an estimation of the time between events. A common problem is that events that happened at two different periods of Earth's history are either perceived to happen at the same time or with less time in between the events. Trend (2001) noted that primary school in-service teachers tend to place events into three categories: extremely ancient, moderately ancient, and less ancient. Teachers, and students, place past geologic events into these categories based on prior knowledge of geologic time or existing schemata with connections to the prior conception of time. This suggests that difficulty exists, for both teacher and student, when attempting to assign an absolute date to an event. Dodick and Orion (2003) noted that a large portion of their sample population of middle and high school students did not understand absolute time measurement; hence the students partitioned strata into equal portions of time, as if they were units on a ruler. Their findings suggest that students view the units of geologic time as equal units of time instead of varied amounts of time based on the occurrence of significant geological events. Furthermore, students with a weak understanding of Earth's history may have an alternative perception of relative time and the amount of time between geologic events may not be fully recognized. Events that occur hundreds of millions of years apart may be perceived to happen with the same passing of time as events that occur only millions of years apart. A complete understanding of geologic time can be identified by an understanding of, not only the dates of occurrence or relative sequence of particular events, but also the time span between events.

THEORETICAL UNDERPINNINGS

To facilitate an understanding of the scientific principles underlying geologic time, this assessment occurs within the instructional period, as opposed to an end-of-unit evaluation. Shepard (2000) refers to this as dynamic, on-going assessment that allows teachers to find out what students are able to do independently and what can be done with adult guidance – an integral part of Vygotsky's idea of the zone of proximal development. Vygotsky's (1978) concept of zone of proximal development (ZPD) bridges the gap between what a student knows and what can be known. This assessment can also be categorized as a formative assessment. The purpose of a formative assessment is to determine what adjustments should be made to instruction (Oosterhof, 1999). This approach allows instructors to interact with students and provide assistance as part of the assessment.

The potential to provide feedback students can use to self-assess their understanding is greatly increased when assessment is moved to the middle of instruction. The best feedback, according to Wiggins (1998), is "highly specific, directly revealing or highly descriptive of what actually resulted, clear to the performer, and available or offered in terms of specific targets and standards" (p. 46). Feedback is more effective when students have an opportunity to change their thinking and improve understanding. Therefore, feedback may be ineffective at the end-of-unit evaluation if students don't see benefit in improving understanding after instruction. Likewise, teachers may also receive feedback from students. However, this opportunity may be lost at the end of the instructional unit as the time may have passed to change instructional approaches.

DESCRIPTION OF THE ASSESSMENT

This long-term, formative assessment requires students to synthesize information and solve a novel problem, over a three-week time frame. Students are asked to

Sam's Time Line			
Eras	**Periods**	**Relative Time**	**Absolute Time**
Care-free time	Childhood	Birth	May 3, 1929
		Two room schoolhouse	
World War II	Young Adult	WWII Begins	Dec. 7, 1941
		Met Husband in High School	
	Adult	First Job	
		WWII Ended	
Family	Wife	Married	April 2, 1949
		First Car (1941 Chevy)	
	Parent	First Child Born	Oct. 22, 1949
	Home-owner	Bought House	April 28, 1962
		Last Child Born	Dec. 26, 1967
	Grand-parent	First Grand-child	Jan. 16, 1968
		Father Elected County Commissioner	
Relaxing Time	Retiree	Retired	July 8, 1988
		Began Line Dancing	

Table 2. Sam's time line of her grandmother's life.

interview a grandparent or older community member and gather data to make a geologic timescale of that person's life. Students then select 15 events of the person's life and arrange them sequentially from the most recent event to the oldest event. These events represent relative dates of the person's life. These are events in which the exact date of the event is unknown, but the event is memorable. Students also identify 8 exact dates for events that represent absolute dates. These are significant events in the person's life, for which the exact date on which the event occurred is known. Next, students develop segments of the older adult's life that represent significant stages. These stages are separated into two units of time representing eras and periods of geologic time. Large segments of time are referred to as eras and the smaller units of time are referred to as periods. Students negotiate with the interviewed person to decide how his or her life can be divided into significant segments representing eras and periods. These segments of time are based on the list of events already placed on the time scale. Each student then constructs a time scale and writes a reflection paper on the process. Two examples of time scales are shown in Table 1 and Table 2.

The instructor meets with students during construction of the time scale to offer feedback. Students make adjustments to the time scale as needed based on feedback and self-assessment. The instructor can adjust whole class, group, or individual instruction based on common misunderstandings presented in students' work. Adjusting instruction permits the instructor to address misunderstandings that may go unnoticed in a summative evaluation at the end of an instructional unit.

Once the instructor has met with students and everyone agrees that the time scale meets the requirements (see section on scoring below) students begin writing a reflection paper. The paper requires each student to reflect on the process of timeline construction and compare his/her timeline to the geologic time line. Reflection papers should include the following:

1. a statement of how this timeline is similar to the geologic time line;
2. a statement of how this timeline is different than the geologic time line;
3. a description of the difference between absolute and relative dating;
4. an explanation for the manner in which eras and periods were decided; and
5. a comparison of how the segments of the geologic timeline are similar to the older adult's time line.

Initial drafts of the reflection paper are shared with the instructor for review, feedback is given on the paper through dialogue with individual students and through written comments. For promoting thought and reflection; the most effective type of feedback is the use of questions aimed at eliciting more detailed responses from students. Typical questions were, "What are the similarities between the older adult's timeline and the geologic timeline with respect to how the duration of time segments were developed?" and "By looking at the older adult's timeline you can infer that some events occur between events listed. Do you think the geologic timeline allows scientists to make similar inferences?" Grammatical errors and errors in sentence structure are also identified so that students may correct these errors. Common themes that represent misunderstandings may be identified during this process. These may be addressed through re-teaching or lessons may be developed to further clarify a topic that was problematic for students. For example, instruction regarding radioactive dating might occur prior to this assessment. If it becomes clear that students are not connecting the process of radioactive dating to the absolute age of an object, a new lesson could be presented in which the connection between absolute age and radioactive dating would be made more explicit.

SCORING

Students are given the parameters of the assignment and the scoring rubric (Table 3) simultaneously. The scoring rubric states the performance objectives and provides descriptions of performance rating categories. According to Airasian (1997) the scale of a rubric should have an optimal amount of between three and five rating categories. The scoring rubric contains descriptive summaries for each of the different categories of student performance. These categories of performance were labeled with descriptions such as "excellent," "good," "fair," and "poor." This analytical rubric divides the product into several dimensions so that each can be judged separately providing specific feedback about each dimension (Arter & McTighe, 2001). Before the project commences, students are given a copy of the rubric so that a comparison can be made between the students' products and the idealized performance rating categories from the rubric (Table 3). Students and instructor are able to compare the students' project to the

Geologic Time Scale				
Dimension	**Excellent**	**Good**	**Fair**	**Poor**
Number of Events	Includes all 15 relative dates and 8 absolute dates.	Includes between 13-14 relative dates or between 6-7 absolute dates.	Includes between 11-12 relative dates or between 4-5 absolute dates.	Includes fewer than 10 relative dates or fewer than 3 absolute dates.
Understanding of Relative Dates and Absolute Dates	Events are clearly relative or absolute for a reason which is evident in the time scale.	Partial confusion of relative and absolute dates evident in the time scales structure.	Seemingly little difference between why events were selected to be relative or absolute.	Extremely difficult to discern absolute from relative events.
Selection of Eras and Periods	Selection of eras and periods is logical and requires no speculation.	Selection of eras and periods is understandable but raises questions.	Selection of eras and periods is uncertain and needs further clarification.	Selection of eras and periods is seemingly random and not comprehensible.
Presentation of Geologic Time Scale	Time scale is neatly produced as word-processed table or drawing of appropriate size and arrangement. Spelling, grammar and mechanics are correct.	Time scale is neatly produced as word-processed table or drawing of appropriate size and arrangement. One to three spelling, grammar or mechanical errors.	Time scale is not neatly produced or is not of the appropriate size or arrangement. Four to six spelling, grammar or mechanical errors.	Time scale is disorderly in production and size and arrangement is not appropriate. Greater than seven spelling, grammar or mechanical errors.
Reflection Paper				
Similarities and Differences to Geologic Time Line	A complete and thorough comparison made between the constructed timeline and the geologic timeline.	Numerous similarities and differences are listed but they lack thoroughness and detail.	Few similarities and differences are listed and they lack thoroughness and detail.	Similarities and differences are only described in terms of the structure of the time lines.
Description of the Difference Between Absolute and Relative Dating	A complete and thorough description is given and analogies are made to the constructed timeline.	An accurate description is given and reference is made to the constructed timeline.	A partial description is given and little reference is made to the constructed timeline.	The description is vague and the timeline is not referenced.
Explanation of the Manner in Which Eras and Periods were Chosen	A detailed, logical explanation is given for selection of eras and periods.	A detailed explanation is given, but lacks a logical selection method.	An explanation is given, but lacks detail and logic of selection method.	A vague explanation is given with no logical selection method.
Comparison of the Construction of the Geologic and Older Adult's Time Line	A detailed and complete comparison of the reasons the segments of geologic time are similar to the older adult's timeline.	The comparison lacks detail and completeness, but does compare the segments of time between the two timelines.	A superficial understanding of why each timeline has similar construction of segments.	Little understanding of why the segments of each timeline appear as they do given the events needed for construction.
Presentation of Reflection Paper	Spelling, grammar and mechanics are correct. Writing is well organized	One to three spelling, grammar or mechanical errors. Writing is organized.	Four to six spelling, grammar or mechanical errors. Writing lacks strong organization.	Greater than seven spelling, grammar or mechanical errors. Writing is disorganized.

Table 3. Scoring rubric used by students and teacher for assessing the geologic time scale project.

rubric to assess the strengths and weaknesses of the project, thereby becoming better at self-assessment. Students begin to realize what they have learned and what they need more help with, thus actively participating in their education. Depending upon the outcome of self-assessment and negotiations with the instructor students make changes to the project. Likewise, if the instructor realizes that students, as a group, are weak in a given area, lessons are altered to address these issues and suggest considerations that students may have overlooked or were not cognizant of while developing the project.

FIELD TEST OF THE PROJECT

A field test was conducted by Hermann with 140 ninth-grade earth science students in a suburban high school in the mid-Atlantic region. Initially, students were apprehensive about submitting drafts for review. Students were largely unfamiliar with formative assessment and felt they might be assessed on rough drafts, or that asking for help meant they were not at the same cognitive level as their peers. Therefore, the instructor should discuss the purpose of formative assessment with the class.

The time lines of two students, Laura (Table 1) and Sam (Table 2), provide examples of completed projects. Both time lines begin with the birth of the older adult, whereas the geologic time line begins with present day and extends back to the formation of earth. Most students constructed their time lines in this manner as everyday thinking probably precludes students from viewing life spans as directional towards present day. Laura's time line is indicative of a common tendency among students to label some eras and periods the same, for example both era and period are labeled "family". Perhaps this is due to the structure of the geologic time line, in which some periods are not divided into epochs, for example the cretaceous period. Laura's time line provides more detailed information in the relative date's column, while Sam's time line has a more consistent overall structure where eras are divided into periods based upon major events. Similar to the geologic time

line, both examples contain events that mark the beginning and end of eras and periods. For example, Sam's grandmother was affected by the beginning and ending of World War II, so that era of her life is labeled "World War II". Other events are vague, such as Laura's choice of labeling an era as "young adult" which lacks a major beginning and ending event. These two examples also depict a higher frequency of events in the older adult's life with increasing proximity to present day, possibly due to memories that are more readily recalled. More important, is the observation that both Laura and Sam gained a better sense of how and why segments of geologic time are divided into subsections.

The reflection paper provided greater insight into understanding of geologic time line construction. Within the reflection paper some students needed to be prompted to elaborate on similarities and differences between the constructed time line and the geologic time line. Students also needed to be asked to expand on the reason why the eras and periods were constructed as they were. Laura provides a fairly common example when she said, "The manner in which the eras and periods were decided was that first I determined the periods and then I picked the era that would best describe or summarize the periods. I determined the periods by knowing when the events occurred." Laura's statement was the result of a discussion regarding a rough draft she submitted previously, in which she did not explicitly state that the events governed the establishment of eras and periods. This example illustrates the benefits of a formative assessment, where the instructor can determine if a student has an understanding of a concept and did not communicate the concept clearly or simply had not fully developed the concept. As a summative evaluation the instructor would subtract grade points, not knowing if the student understood the concept and, more importantly, the student may never come to understand the concept.

During the creation of reflection papers students provided input that shaped the course of instruction. As students began reflecting on the process of creating the older adult's timeline they raised questions that suggested that the instructor either spent too little class time discussing or neglected to cover with adequate scope. The formative assessment structure provided an opportunity for students to inform instruction and determine what concepts should be more thoroughly discussed to enrich student understanding.

CONCLUSIONS

A dynamic, on-going assessment such as this allows for immediate and useful feedback that students can use to improve their understanding of the topic. Likewise, teachers are provided with valuable feedback regarding the degree to which instruction is effective in increasing students' knowledge of a concept. While the intent is to change instruction based on students' feedback, a subsequent increase in students' understanding develops from teacher feedback. Only by modifying instruction based on the input of students can teachers expect students to become better learners. Through an ongoing dialogue with the teacher, students develop a greater understanding of not only geologic time, but also how to develop products, through use of a rubric, that meet the expectations of the scientific community. Students can perform to a greater level of excellence when the task is clearly defined, the instructions are precisely stated, the performance rating categories are clearly defined within a scoring rubric, and the assessment is on-going.

Based on this project, one factor that affects the degree to which a formative assessment is effective is the students' prior exposure to this assessment technique. Students expressed a lack of familiarity with formative assessments, suggesting that summative evaluations are still the norm among science educators. Clearly, students benefit from exposure to the formative assessment process, as it may help students reach a higher degree of understanding through increased teacher input. With abstract conceptions such as geologic time, teachers benefit from the increased dialogue with students afforded during formative assessment and have the opportunity to modify instruction to maximize student understanding.

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