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Native American Students' Understanding of Geologic Time Scale: 4th-8th Grade Ojibwe Students' Understanding of Earth's Geologic History

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Geologic time scale is a very important concept for understanding long-term earth system events such as climate change. This study examines forty-three 4th-8th grade Native American—particularly Ojibwe tribe—students' understanding of relative ordering and absolute time of Earth's significant geological and biological events. This study also examines how these students understand the time scale of human history in relation to the longer geologic time scale of the earth and of the Ojibwe's unique history. The students participated in a 15-hour lesson unit focused on the topic of climate change in Earth history. The two major sources of data included: 1) students' relative ordering and written descriptions of ten given Earth historical events and 2) student groups' placing of nineteen events on an absolute time line. Students' relative ordering of ten given events and student groups' placing of nineteen events on an absolute time line were analyzed quantitatively by descriptive statistics, whereas students' written descriptions of the relative ordering of the ten given events were analyzed qualitatively. The results show that the students understand Earth's geological events as three distinctive zones: near the beginning of Earth history, relative recent events, and between these two categories. The results also show that many students interpret general historical events in human history like "starting agriculture" through the lens of their own history and cultural viewpoints. This study shows that younger children have a general knowledge of major events in Earth's history, such as continental movement, but cannot organize an accurate chronological order of these events. This study also shows that indigenous students' knowledge of their own cultural and historical events affects their understandings of human history.

Keywords: earth history, earth geologic time scale, native American students

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INTRODUCTION

Earth system events, including climate change, have happened as cycles with different time scales. The recently released Next Generation Science Standards (National Research Council [NRC], 2013) recommends teaching the concept of Earth's geologic time scale to promote a deeper understanding of the earth systems concepts addressed not only in the Disciplinary Core Ideas of Earth and Space Science but also in Life Science and Physical Sciences. By the term 'geologic time scale, we refer to the idea that the earth is very old (4.5 billion years) and human existence on Earth is very short compared to the time scale of geologic events on Earth (Dodick & Orion, 2003b). Geologic time scale is considered a fundamental concept for scientific literacy in current earth science education documents, such as Earth Science Literacy (Earth Science Literacy Initiative, 2009), Climate Literacy (US Climate Change Science Program, 2009), and Ocean Literacy (Ocean Literacy Network, 2011). For example, Climate Literacy describes acquiring the concept of geologic time scale as a critical component for understanding global climate change (See essential principles 4 and its three sub-categories [4A, 4D, 4F]). Climate change can occur dramatically over a short period of time, like the current global climate change due to anthropogenic activities. However, there is much scientific evidence indicating that global climate change happened multiple times during Earth's history for a longer period of cycles (e.g. 100,000 years between ice ages) (e.g. Petit et al., 1999).

During the last two decades, students' understanding of geologic time scale has been studied in both earth science and biology education. In earth science education, researchers have focused on students' understanding of the time scale of Earth's geological events. These studies have been conducted with various age groups (from lower elementary to college students) as well as preservice and inservice teachers (e.g. Dahl, Anderson, & Libarkin, 2005; Libarkin, Anderson, & Science, 2005; Libarkin, Kurdziel, & Anderson, 2007; Trend, 1998, 2000, 2001). Some studies have also been conducted in informal science education settings, such as designing exhibits for earth history (e.g. Brzuszek et al., 2008; Clary, Brzuszek, & Wandersee, 2009). On the other hand, researchers in biology education were more interested in students' understanding of the evolution of life in Earth's history with correct time series comprehension (e.g. Decker, Summers, & Barrow, 2007; Marques & Thompson, 1997).

According to Dodick and Orion (2003a, 2003b), previous studies about students' understanding of Earth's geological events can be divided into two categories by research purpose: "event-based research" and "logic-based research" (p. 416). In event-based research, students' understanding of the relative order of Earth's geologic events, as well as of the absolute time of the entirety of Earth's geologic events, was probed (see Liberkin, Kurdziel, & Anderson, 2007; Libarkin & Kurdziel, 2004; Marques & Thompson, 1997; Noonan & Good, 1999; Teed & Slattery, 2011; Trend, 2000, 2001). Trend (1998) studied upper elementary (10-11 years old) students' understanding of geologic time scale. He found that while the students have a general awareness of major events in Earth's geological history, they do not have a clear chronology. Elementary students also categorized Earth's geologic events into two distinct time categories: extremely ancient and less ancient (Trend, 1998). Similarly, Marques and Thompson (1997) and Noonan and Good (1999) studied elementary and middle school students' understanding of bio-geological history on Earth and how they conceptualized the origins of Earth and life. They found a similar result indicating that elementary and middle school students have difficulty placing the earth's bio-geological events in the correct order. The students also did not possess a clear chronology of earth historical events. Liberkin and her colleagues' studies (e.g. Liberkin, Kurdziel, & Anderson, 2007; Libarkin & Kurdziel, 2004) examined college students' specific knowledge of geological events and their related time scales within the earth's entire history. Their findings show that college students have a better conceptual understanding of the order of Earth's bio-geological events than elementary or middle school students, but that they too do not possess a correct chronology of those events.

Logic-based studies have been conducted by relatively few researchers, including Dodick and Orion (2003a, 2003b, 2006) and Ault (1982). Compared to event-based research, logic-based research focuses more on probing students' cognitive ability or logical thinking involved in the transformation of geological events into correct time series. Ault's (1982) study shows that younger students (K-6) conceptualize geologic time scales more as relative order than absolute time. In other words, younger students may possess knowledge about the absolute time scale of Earth's historical events but might not correctly conceptualize Earth's historical time scale because of the extreme length of its geologic time scale compared to their own. Dodick and Orion's (2003a, 2003b) studies also show that the cognitive ability to understand geologic time scale is significantly related to students' cognitive developmental stages. They found that significant differences exist between middle and high school students in their ability to reconstruct geological events using logical thinking. In addition, Dodick and Orion found that students' lack of specific domain knowledge about geological processes was related to their logical thinking skills about those processes.

In summary, both event-based and logic-based research show that elementary students do not have a concrete understanding of the earth's geologic time scale (e.g. Trend, 1998). Research studies imply that elementary students cannot conceptualize the absolute geologic time scale of Earth historical events but can logically understand the relative order of Earth historical events depending on their science disciplinary knowledge related to this topic. Unfortunately, a gap exists in both event-based and logic-based research in that there are very few studies probing upper elementary and middle school students' understanding of geologic time scale.

In addition, no study exists that probes Native American students' understanding of the time scale of earth history. Native American students could have authentic understandings of earth history that originate from their unique traditional stories and worldview (Barnhardt & Kawagley, 2005). For example, Ben-Zvi Assaraf et al. (2012) found that Bedouin students who did not have school science education had richer mental models of water cycle phenomena than Jewish students who had school science education; Bedouin students' models included more components of the water cycle and were more authentic and connected to other natural phenomena. Researchers are finding an increasing amount of evidence that supports how Indigenous students' conceptual understanding of a science concept is deeply related to their particular belief system or traditional view of nature (e.g. Mbajiorgu, Ezechi, & Idoko, 2007). Ben-Zvi Assaraf et al. (2012) also found that, while Bedouin students had a richer conceptual understanding of the water cycle, they employed theological explanations to make sense of water cycle phenomena. Ben-Zvi Assaraf et al. (2012) shows that indigenous students' traditional belief system or worldview could affect their understanding of natural phenomena. In other words, Native American students would use their traditional story of creation and earth history to make sense of a science concept presented in a classroom. In what Aikenhead (1997) termed "border crossings," Native American students need to cross the border between one science knowledge domain interpreted by their traditional beliefs and another science domain that is mostly interpreted by Western science in order to make sense of a school science concept. Because this mental process is difficult for many Native American students, teachers should carefully design science instruction by considering the students' traditional beliefs and knowledge (Nelson-Barber & Estrin, 1995).

The Ojibwe people have traditional beliefs about creation and earth history. For example, a traditional story that has been orally handed down from their ancestors describes the order of creation and the beginning of humans in earth history that is similar to the order of development of Earth's physical environment and biological evolution (e.g. Johnston, 1976). However, in the story there is no specific indication of the time interval between the events.

In addition, in Ojibwe tradition, time is not structured into components like hours or the days of the week. Before European contact, the Ojibwe counted time by day (number of nights), season (6 seasons with 13 months) and winters (years). Technically, they have 13 lunar calendar months in a year. The Ojibwe people named the months based on their observation of changes in nature and used those observations to schedule important community events during the months. In other words, they used changes in nature to count time and measure the passage of time. The Ojibwe count larger temporal distance by the passage of nights (days) and winters (years) and describe a certain year by things that occurred within that year. However, since they did not have a written counting system to record the specific time of historical events that had a much longer temporal distance, traditional history has only been handed down orally and does not contain specific information about the timing of particular events.

Thus, the current study probes Ojibwe students' understanding of earth history in the context of geologic time scale. Particularly, this study explores how Native American students, particularly 4^{th}-8^{th} grade (upper elementary and middle school) Ojibwe students, understand geologic events in both relative ordering and absolute time (chronology) of Earth's historical events. In addition, the Ojibwe's traditional beliefs about earth history include specifics about the origin of humans and how human society affects mother earth (nature) in a negative way. The history of human society in Ojibwe tradition mostly deals with their migration timeline from east to west and prophecies that led to the migration. Thus, this study also examines how Ojibwe students understand the time scale of human history in relation to the longer geologic time scale of the earth. This study was conducted in an out-of-school summer science program for Ojibwe students. The specific research questions for this study were:

1) What is Ojibwe 4^{th}-8^{th} grade students' conception of the relative order of ten major Earth's geological and biological events?

2) What is Ojibwe 4^{th}-8^{th} grade students' knowledge of the absolute time scale of Earth's historical events?

3) What is Ojibwe 4^{th}-8^{th} grade students' understanding of the time scale of human history in relation to geologic time scale?

METHODS

Context

This study was conducted as part of a summer program for Native Americans that was designed to make learning STEM (Science, Technology, Engineering and Mathematics) disciplines accessible and more culturally relevant to Ojibwe youth (grades 4-8). One of the topics of the program used in this study was climate change in Earth history and its local impacts. A lesson unit was purposefully designed and implemented (the details of the unit are described in the following section) to help students understand the concept of Earth history and the time scale of climate changes that have occurred multiple times throughout this history. To design the lesson to be more culturally relevant, the program invited elders from the Ojibwe

Table 1. Students' Demographic Data (N=43)

Entering Grade	Gender		Total
	Female	Male	
4th	3	5	8
5th	0	1	1
6th	4	6	10
8th	12	12	24

reservation to tell their traditional oral history stories about creation. Students spent time with the elders and learned traditional stories with support from different educational technologies including sky domes that showed night skies with traditional constellations. In the following section we also briefly describe the traditional Ojibwe stories of creation and history.

Forty-three 4th-8th grade students from five American Indian reservation schools participated in the lesson unit (for a total of fifteen hours of lessons). The majority of the students ranged from grades 6 to 8 (34 out of 43 students). During the lesson activities, the students were assigned to one of fifteen small groups composed by grade level. Table 1 presents students' demographic data.

Ojibwe People's Traditional Oral History about Earth History and Migration

The Ojibwe are one of the most widely distributed Native American groups in North America, with 150 bands throughout the north-central United States and southern Canada (Native Languages of the Americas, 2015). The Ojibwe people use a language called Anishinabe (plural: Anishinabeg). Traditionally, Ojibwe peoples believed that human beings were made by a creator called The Great Spirit. Thus the Ojibwe do not accept the Bering Strait hypothesis for the peopling of North America or the theory of the evolution of human beings in a Darwinian sense (Callahan, 2015). Their oral tradition explains this well. While there are slightly different versions, the Ojibwe people share similar storylines and common characters about creation and earth history. Based on Johnston (1976), we have summarized the story:

The creation story describes a creator called Kitche Manitou (The Great Spirit) of the Ojibwe. First the Great Spirit created four substances and gave each its own spirit and nature. Then he created the physical world of the sun, stars, moon, and earth and earth's physical environment. After that, he made four kinds of plant beings: flowers, grasses, trees and vegetables, and gave each a spirit of life, growth, healing and beauty. Then he created four kinds of animal beings and conferred special powers and natures on each: two-legged, four-legged, winged and swimmer. Last, the Great Spirit created humans. The story describes humans as being the weakest in bodily power and the most dependent on other creatures, but also as having "the power of dream," which was the greatest gift from the creator. Then the Great Spirit made the Great Law of Nature to govern all things and help the creatures live in well-being and harmony.

As the story shows, the Ojibwe people have their own traditional beliefs about creation and earth history that are similar to Western ideas of earth history in terms of relative order. Along with this story about earth history and creation, they also have a traditional oral history. While most of these stories do not indicate specific times in human history, the 7 Fires Prophecy is the one that is related to the timeline of their migration from the East coast to western parts of North America (Callahan, 2015). According to the story, the prophet of the 1st Fire told the people to move or be destroyed. During the Ojibwe migration, they stopped in different places marked by sacred Miigis shells and continued until they found a turtle-shaped island and "the food that grows on water (wild rice)" near the Great Lake (Superior) (Callahan, 2015). The migration from the East coast to the Lake Superior area is thus described in the first three prophecies of this story. Native American traditional history is handed down with a strong sense of place (Bíró-Nagy, 2009). The 7 Fires Prophecy is a good example of how the Ojibwe migration history is described based on place. The Ojibwe also believe that the place where they settled was sacred and that they were led there by a spiritual power. Thus the wild rice (food that grows on water) has been considered a sacred plant for the Ojibwe. Later, Europeans came to their place and made ditches from the lake to help the Ojibwe practice agriculture. But this resulted in a change of water level in the lake, decreasing the production of wild rice.

The Lesson unit

The lesson unit designed for the study had two main instructional goals: 1) to improve students' understanding of the concept of geologic time in Earth's climate change history and 2) to help students understand the impacts of climate change on local ecology through the hands-on experience of reconstructing the planet's past climate conditions by analyzing local tree-ring data. The unit also included three major activities that helped students understand the scale of Earth's geologic time from relatively short-term to long-term climate change history: 1) reconstructing 150 years of local climate history using tree ring data, 2) reconstructing 1000 years of climate event history on an Earth geologic timeline represented by 10m machine paper (1cm representing 1 year), and 3) making a list of the relative order of ten major geologic events in Earth's history on a worksheet and locating nineteen geologic event cards on an Earth entire history timeline represented by 4.5m machine paper to show the absolute time of the events. The main data source for this study came from the final activity: making a relative order of the ten given Earth historical events and identifying the absolute time of the nineteen geologic events provided. Each activity is briefly described below.

The first activity involved reconstructing the last 150 years of local (Minnesota state in U.S.) climate history using tree ring data. Prior to this activity, students had a short pre-phase lesson that explained two important facts about tree ring growth: 1) a tree ring is composed of a lighter part (showing spring-early summer growth) and a darker part (showing summer-early fall growth), and 2) precipitation and the length of daylight are two critical conditions for tree ring growth. After the pre-phase lesson, students made a correlation graph representing both historical precipitation data and tree ring growth chronology data. By creating a graph representing both data sets, students had the opportunity to think critically about the relationship between precipitation and tree ring growth across a long period of time (150 years). To make the activity more relevant to the students, we used local tree ring growth chronology data from NOAA's paleoclimatology database. Because the numeric data from NOAA could be difficult to understand, the authors (two of them instructed the lessons) purposefully represented the numeric data as simulated magnified tree ring figures, which allowed the students to measure each annual tree ring by ruler instead of reading numeric data directly from the NOAA data set. The students represented both data sets using the Y axis (inches) for precipitation and the X axis (millimeters [mm]) for tree growth (from measuring simulated tree rings). Through the activity, the students could identify correlations between annual precipitation change and annual tree ring growth of local trees for the last 150 years (Figure 1).

The second activity involved reconstructing the last 1,000 years of Earth's climate history. The instructor prepared a 10m strip of machine paper, on which 1cm represented a year. First, the students transferred their data from the first

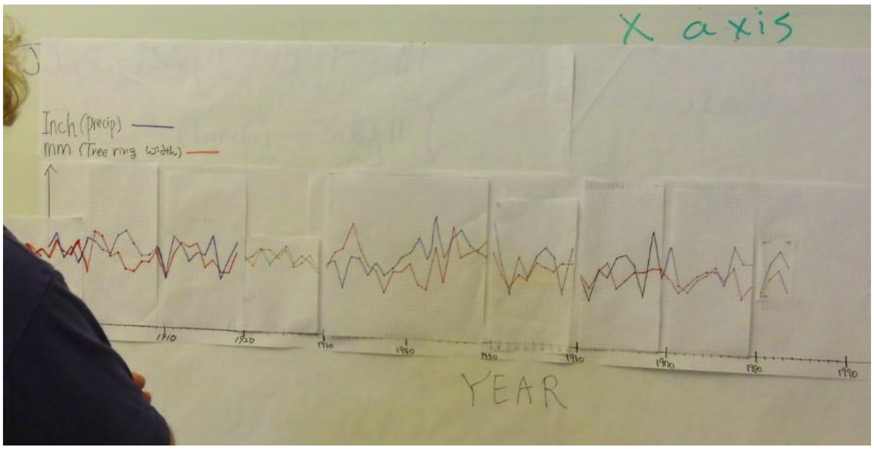

Figure 1. Students' work of making a correlation graph of precipitation and tree ring growth.

activity onto the 10m strip. Because the prior activity (using 150 years of climate data) was presented in a roughly 150 centimeter (cm) wide graph, we purposefully used 10m (1,000cm) tape to represent 1000 years of climate change events. This was done to help students understand 150 years in the context of 1,000 years of history. Next, the students were given a list of historically significant climate events from the last 1,000 years, such as volcanic eruptions and droughts. For example, we introduced the Little Ice Age (a period of cooling after the Medieval Warm Period), which occurred during the 16th-19th centuries. By placing the periods of the Little Ice Age (there are three particularly cold periods: about 1650, 1770, and 1850) on the 10m strip, students could learn that climate change has happened multiple times during the last 1,000 years. Students also included important human history events they knew about during the last 1,000 years on the 10m paper. The final activity aimed to help students apply their understanding of the geologic time scale they developed in the first two activities to the context of Earth's entire history. This activity included two tasks; first the students made a relative order of ten Earth geologic events that were provided by the instructor (see Table 2), and second, the students placed nineteen event cards on a 4.5m strip of machine paper (every 1 meter representing 1 billion years was marked on the tape). Before the first task of relative ordering, students did a short activity in which they made a relative order of ten events that had happened during their own lifetime, such as first birthday, first day of kindergarten, and so on. Then the students were asked to put each event on a timeline. This activity was meant to help students understand what relative ordering and absolute time for each event means. The second activity of placing nineteen major earth event cards was a group activity, so the students decided the place on the timeline through negotiation with group members. Students from different grade levels were mixed in each group. First, to show the entire earth history at a glance, we put the 4.5m strip machine tape on one side of the classroom walls. One side of the tape represented the beginning of the earth, while the other side represented the present time. We also explained that the entire human history timeline presented on the 10m tape was represented by just a single line on the 4.5m entire earth history tape. The nineteen event cards included earth's major geological and biological events throughout Earth's history as well as human history. In particular, four of the five human history events were relevant to Ojibwe history: 1) 7 Fires Prophecy, 2) Anishinabe Nations, 3) Columbus Arrives, and 4) Agriculture Starts. The 7 Fires Prophecy is an Anishinabe prophecy which was closely linked to Ojibwe migration to the West and also represents the beginning of this migration. These events were specifically selected to examine Ojibwe students' understanding of human history. As a group effort, the students first chose to make a relative order of the event cards (Figure 2) and decided and marked the location at which to put each card on the machine tape to represent an absolute time of each event in Earth's history (Figure 3).

Figure 2. Students working to make a relative order of the nineteen Earth event cards before they place them on a 4.5 meter machine tape.

Figure 3. Students working to place the Earth geologic event cards on a 4.5 meter machine tape.

Data Collection

The data for this study came from two main sources. The first was the students' individual worksheets completed at the beginning of the final activity, which examined students' conception of the relative order of ten Earth historical events prior to instruction. Students were also asked to provide written explanations for their relative order of the given ten significant geologic events in Earth's history. The students were also asked to explain their understanding of geologic time scales. The second data source was the students' group task of creating Earth's geologic timeline following the second activity in the unit.

Data analysis

We specifically examined both the students' relative order of the given ten Earth's geologic history events and the locations where the students placed the given nineteen Earth's geological and human historical event cards on an absolute timeline. We calculated a mean and mode of the students' placement of each geologic event in relative order (1-10), as well as in an absolute timeline (4.5 billion years-present). A mean value of an event in students' relative ordering was calculated by averaging the placement of the event in the relative order of ten events based on a numeric scale of 1-10 (1=earliest event and 10=latest event). Student Rank in Tables (Tables 2 and 3) was determined by ordering of the mean values. Compared to the relative ordering, a mean value of the absolute time scale represents where students placed each geologic event using absolute time, from 0 (beginning of the earth) to 4.5 billon years (present). Next, we developed two different graphs; the first (Figure 3) represents students' average placement of nineteen Earth geologic events on an absolute timeline, and the second (Figures 4-8) represents students' average relative ordering of five selected pairs of events: 1) "Oxygen Rich Atmosphere" and "Development of Photosynthesis," 2) "First Continent" and "Breaking up of Pangaea," 3) "First Animal on Land" and "Extinction of Dinosaurs," 4) "Columbus Arrived" and "Agriculture Started," and 5) "Columbus Arrived" and "Anishinabe Nations." These event pairs were purposefully chosen to show students' alternative conceptions about Earth's geological history and human history related to the Ojibwe peoples. Three researchers participated in the data analysis process in order to enhance the authenticity of the interpretations and the credibility of the findings (Patton, 2002). The students' written descriptions of the relative order of Earth's historical events were analyzed qualitatively. We first focused on why the students placed geologic events in a certain order in the written descriptions and then we looked for common themes that emerged from the descriptions of event order.

FINDINGS

Ojibwe students' conceptions of geologic time scale as relative order

Table 2 presents the students' relative order of the ten geological events given to them using two statistical values: mean and mode. Based on the mean value, the "Students' Rank" represents an average of where the students placed an event in the relative order from 1 to 10. For example, "Formation of the Moon" is the earliest event among the ten events in Earth's history and it is also the first or "1" event in the Students' Rank column, with twenty-nine students correctly identifying the formation of the moon as the first event in Earth's history. The mode value represents where in the relative order (1-10) most students placed an event. So, while the event "First Photosynthesis" is ranked fourth in the Students' Rank column based on the mean, its mode is "2," as most students chose it as the second event among the ten events provided. Student mean ranks do show some general patterns, such as what kinds of events were placed prior to other events in general. However, this does not say much about how many students had correct or incorrect conceptions of the relative order between certain events. Thus here we explain the students' understandings of the relative ordering of the given events based on both the results from: 1) students' mean rank and correct student rank percentage (%) presented in Table 2, and 2) the results of the relative ordering of certain events

Table 2. Individual students relative ordering of Earth's geologic events (N=43)

Ten Earth Geological Events in Correct Order	Students' Rank	Mean (Relative order)	Mode	SD
1. Formation of the Moon	1	2.40	1	2.03
2. First Photosynthesis	4	4.54	2	2.84
3. Dinosaurs	2	2.74	2	1.42
4. First Mammal	5	5.23	6	1.81
5. First Bird	6	5.44	5	0
6. First Flower	3	4.35	3	0.71
7. End of Dinosaurs	8	6.64	6	2.02
8. Humans Appeared	9	7.05	7	2.25
9. The Last Ice Age	7	5.67	8	3.54
10. End of Last Ice Age	10	8.87	9	1.43

from comparison between each student's data.

As shown in Table 2, "Formation of the Moon," "Dinosaurs," and "First Flower" are the first three events in earth history based on student mean ranks. Based on the analysis, we found that 30% of students thought that dinosaurs were the second event that happened right after the "Formation of the Moon," In addition, 18.6% of the students thought that "Dinosaurs" were the first event that happened among the list of ten given earth historical events. Some of the students mentioned that their ideas about when dinosaurs first appeared came from movies and television. For example, one of the students commented on her worksheet, "I think the moon was made after dinosaurs because I did not see the moon when I saw a dinosaur movie, there was no night and dinosaurs were dying because of the hot sun all day." Students' ideas were not coherent with the Western scientific idea that dinosaurs appeared after photosynthesis. However, we found that most of the students had some kind of useful conception of the relative order of the appearance of animal beings. 93% of students put "First Mammal" after "Dinosaurs," and 93% of students put "Humans" after "Dinosaurs." More importantly, 80% of the students placed the following three events in the correct order: "Dinosaurs"→"First Mammal"→"Humans." Unfortunately, we found that almost half of the students (48.8%) did not correctly order "First Mammal" and "First Bird." Only 41.2% of the students ordered these two events correctly, and the rest of the students (10%) thought these two events happened at the same time.

Most of the students (69%) correctly ordered the events "Photosynthesis" and "First Flower." 12.8% of the students thought these two events happened at the same time, and the rest of the students incorrectly ordered these events, which indicates that students do not understand photosynthesis as a fundamental process used by plants and how it is indispensable for the existence of flowers.

More than 95% of the students ranked all of the events in the list except "End of Dinosaurs." Only 32% of the students ranked that event. In addition, only a small number of students thought that the "End of Dinosaurs" happened before the "Last Ice Age" (11.6%) and that "Humans Appeared" happened after the "End of Dinosaurs" (17.9%). This result indicates that most of the students (more than 80%) were not sure about the relative order of the "End of Dinosaurs" within the context of all of the given events.

Ojibwe students' knowledge of Earth historical events in absolute time scale

In this section we present the results regarding students' knowledge of absolute time scale. The students worked in groups and were tasked with placing nineteen geological event cards in order on an Earth history timeline. We present our data using three different types of representation methods (Table 3, Figure 4, and Figures 5-8) and discuss each representation under separate subsections. The first subsection shows students' relative ordering and absolute time of the nineteen historical events (Table 3). The second subsection displays a pattern found from the time distance between the events: three distinctive zones where students placed each of the nineteen events on the timeline (Figure 4). The third subsection shows the relative ordering of two specific events with absolute time information (Figures 5-8).

Relative ordering and absolute time of nineteen Earth historical events.

Table 3 presents results from the analysis of the groups' final Earth history timelines. Mean and mode were calculated from where the students placed each event on the absolute timeline on 4.5m machine tape. Based on the mean value, we also represented students' relative ordering of the nineteen events in the "Students' Rank" column using a numeric scale of 1-19 (where 1=earliest and 19=latest event). As expected from the relative ordering of ten Earth events (Table 2), there are differences between the "correct order" of the 19 Earth events and "Students' Rank" in Table 3. The high SDs in Table 3 also show that there was a large variation between the groups' choices of the absolute time of each given Earth geologic event. This is partially due to the nature of the task. Students had to recognize how much time a 1-centimeter difference represents on the entire Earth history timeline.

Three distinctive zones in students' representations of Earth's historical events.

Figure 4 provides a graphical representation of the mean ranks from Table 3, with a variation of SD on the earth history timeline. As Figure 4 shows, the event cards were roughly placed on the 4.5m tape in three distinctive zones. These zones were determined by the time interval between the events. The time interval between the zones next to each other was more than 0.5 billion years. As Table 3 shows, the two earliest events have mean ranks of less than 2.46, whereas the others have mean ranks of above 7.73. Figure 4 presents the difference in mean ranks between the first two events and the other events. It appears that the students perceive certain events to have occurred much earlier than the others. The first two events (Students' Rank = 1-2) placed in the first zone were "Formation of the Moon" and "Oxygen Rich Atmosphere." The second zone included the events that students ranked from 3-13, from "First Plant" (Students' Rank = 3) to "End of First Ice Age" (Students' Rank = 13). The third group of events included the last six events close to the end (Students' Rank = 14-19). The students' mean rank difference between the last event in the second zone (Students' Mean Rank = 20.00) and the first event in the third zone (Students' Mean Rank = 27.60) was 7.60. This is longer than the time interval in student mean ranks between the first and second zone (5.27) and also much longer than the average mean rank difference between events (next to each other) in the second zone (1.23) and the third zone (1.90).

This result echoes Trend's (1998) study that found that 10 and 11 year old students conceive the earth's geological events as distinct time zones: "extremely ancient" and "less ancient." However, the results of this study also show that the students especially distinguished these first two events as the oldest among the extremely ancient events. While the chronology (relative ordering) of these events was not correct, they thought that the events occurred close to each other, early in the earth's history (Mean < 0.8 billion years), especially before the development of plants. In particular, these first two events were placed near the very beginning of Earth's history with fewer SDs (SDs < 2.0). This result might show that the students' understanding of the first two major events in earth history is related to their traditional oral stories of earth history and creation, which state that the universe and physical earth environments were made before the creation of plant beings. As expected from the results presented in Table 2, "Formation of the Moon" ranked as the first or "1" in both mode and Students' Rank.

The events in the second zone varied from concepts related to the development of plants and the evolution of animals to other geological waypoints of the earth such as "First Continents" and "End of First Ice Age." As noted earlier, the chronology of these events was mixed and incorrect. As shown in Figure 4, most of the events should be placed less than 4.5 billion years from the beginning of the Earth, which is near the top line of the graph.

The students placed events related to human history in the third zone, which is relatively recent compared to the rest of the events. Five out of six event cards placed in the third zone were related to human history: "Agriculture Started," "Modern Humans," "Columbus Arrived," "7 Fire Prophecy," and "Anishinabe Nations." However, the events in the third zone were placed incorrectly around 2.7 billion years from the beginning of the earth. These events should have been placed near the very top line of the graph (4.5 billion years from the beginning of the earth) in Figure 3. The wider range of SDs (vertical lines), as well as the mean in Figure 4, shows that there was a large variation between the student groups' placement of the event in the absolute time line. Considering the SDs, Figure 4 shows that all student

Table 3. Student groups' knowledge of absolute geologic time of the given events (Groups of students, N=15)

Earth's Geological Event		Students' Rank	Mean (0.1 billion yrs)	Mode (0.1billion yrs)	SD
Correct Order	**Correct Time (0.1 billion yrs)**				
1. Formation of the Moon	0	1	1.60	1	0.99
2. First Continent	5	6	12.33	5	9.68
3. Development of Photosynthesis	10	4	8.00	6	5.62
4. Oxygen Rich Atmosphere	13	2	2.46	2	1.64
5. First Snow Ball Earth	22	5	12.13	19	6.45
6. First Plant	35	3	7.73	8	4.32
7. Cambrian Explosion	39.7	11	17.46	13	9.79
8. First Vertebrate Animal	39.9	10	15.40	9	9.59
9. First Animal on Land	40.5	9	15.06	12	7.59
10. Permian/Triassic Extinction	42.5	8	14.70	7	10.42
11. Break up of Pangaea	43.25	7	13.40	9	10.75
12. Extinction of Dinosaurs	44.37	9	15.05	12	7.59
13. Dogs and Bears Appeared	44.62	14	27.60	23	9.35
14. Modern Human	44.98	17	31.13	33	10.78
15. End of Last Ice Age	44.99989	13	20.00	13	10.54
16. Agriculture Started	44.99990	15	30.13	23	10.22
17. 7 Fires Prophecy	44.99999	16	31.00	39	8.59
18. Anishinabe Nations	44.999991	19	36.85	45	12.56
19. Columbus Arrived in America	44.999995	18	34.67	41	7.14

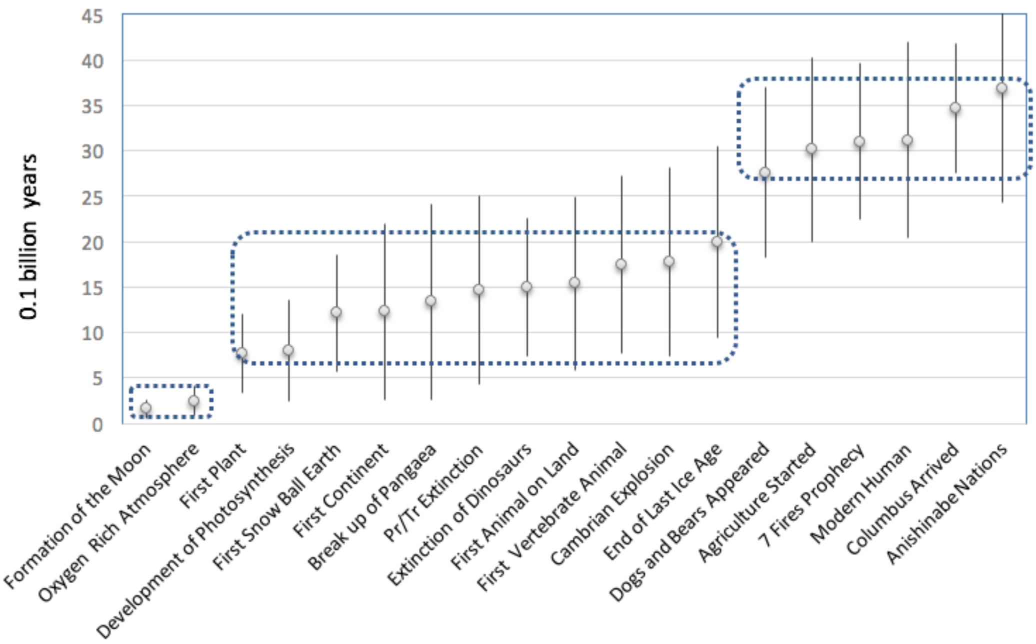

Figure 4. Student groups' placement of the given events on an absolute geologic timeline. A short horizontal bar in the graph indicates a mean value and a vertical bar represents SD range of the student groups' placement of an event. Three dotted line boxes show three distinctive zones of students' understanding of Earth geologic time.

groups placed "Formation of the Moon" and "Oxygen Rich Atmosphere" as the first two events near the beginning of earth history. Also, the next three events, "First Plant," "Development of Photosynthesis," and "First Snow Ball Earth," were always placed before the events in the third zone, without exception. As mentioned in related literature, students' lack of understanding of the time scale of the earth's geological and biological events might cause misconceptions about the concept of Earth's geological events and the evolution of its biological history (e.g. Dodick, 2007; McComas, 1990; Trends, 1998).

Students' understanding of the relative orders of two specific Earth historical events in an absolute time context.

Figures 5, 6, and 7 present evidence of students' ordering of two given Earth history events using a different representation method. This representation shows how close or far apart students placed two events on the earth history timeline. For example, a dot placed on the 45-degree line represents that the student group put two events on the same spot on the timeline. A dot placed below the 45-degree line means that the student group believed the event on the Y-axis occurred prior to the event on the X-axis. Using this method, we have represented three pairs of events that present critical evidence of students' misconceptions based on documented misconceptions in related literature (e.g. Libarkin & Anderson, 2005).. First, as shown in Figure 5, 14 out of 15 groups placed "Oxygen Rich Atmosphere" earlier than "Development of Photosynthesis," as most of the dots were placed above the 45-degree line. This indicates that students thought an "Oxygen Rich Atmosphere" existed before "Photosynthesis" happened. As described in the Methods section, Ojibwe people's traditional beliefs about creation state that Earth's physical environment was set up before the creation of plant beings. If we consider the fact that all student groups placed "Oxygen Rich Atmosphere" (Mean rank=2) as the second earliest event with "Formation of the Moon" (Mean rank=1), this result indicates that students considered "Oxygen Rich Atmosphere" more like a component of Earth's physical environment, rather than making a conceptual connection between it and photosynthesis.

Second, we found evidence of students' incorrect chronology between the geological events of "First Continent" and "Breaking up of Pangaea." 10 out of 15 groups placed "First Continent" after "Breaking up of Pangaea," with various amounts of time difference, as the scattered dots in Figure 6 show. In the correct order, "Breaking up of Pangaea" happened about 3.8 billion years later than "First Continent." This result implies that the students thought that Pangaea was the supercontinent formed before the first continent or that the first continent originated from part of Pangaea. This result also reflects Libarkin and Anderson's (2005) study showing that many students think Earth had a single continent when humans first appeared.

Third, Figure 7 shows that 8 out of 15 groups placed the event "First Animal on Land" after "Extinction of Dinosaurs." The spread of dots from the 45-degree line shows that the students placed these two events far apart on the earth history line. In other words, whether or not the order of these two events was correct, the students thought the events happened with a large time interval in between.

Ojibwe students' understanding of human history in Earth geological time

Students placed human-related history in the last time zone (from 1.5 billion years ago to the present). However, as noted earlier, their chronology of modern human events and events related to human society was incorrect. While two groups placed "Modern Human" on the correct spot of the timeline, the rest of the groups scattered the time of this event within the last half period of the earth's history. In fact, 10 out of 15 groups placed "Modern Human" after the start of "Agriculture." On the other hand, the scattered placements of the event (Modern Human) on the timeline could illustrate that the students did not possess correct chronology that humans appeared at the very end of current Earth history.

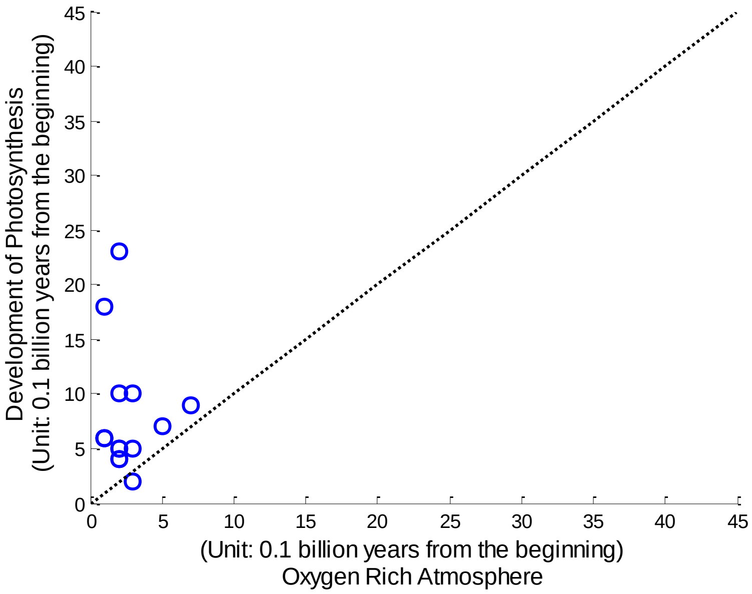

Figure 5. Students' relative ordering of two geologic events: Oxygen Rich Atmosphere vs. Development of Photosynthesis.

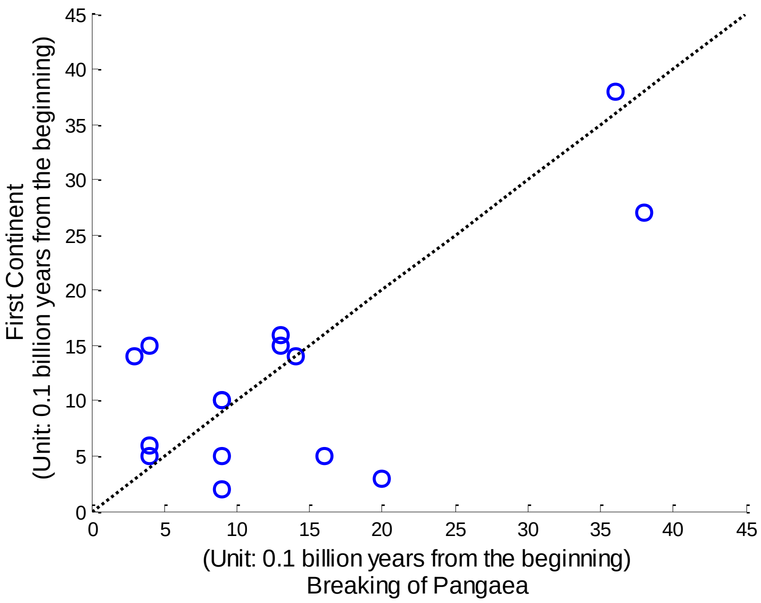

Figure 6. Students' relative ordering of two geologic events: First Continent vs. Break up of Pangaea.

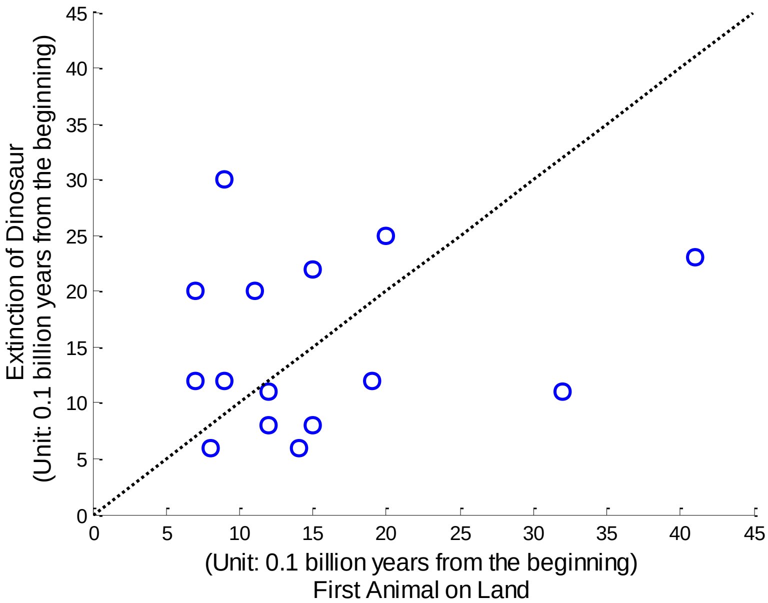

Figure 7. Students' relative ordering of two evolutionary events: Extinction of Dinosaurs vs. First Animal on Land.

Figure 8 shows the Ojibwe students' relative ordering of two events, "Columbus Arrives in America" and "Anishinabe Nations," on the absolute time scale. Most of the student groups (N=11 out of 15 groups) put "Anishinabe Nations" after "Columbus Arrives in America". Anishinabe is the name used by the Ojibwe people to refer to themselves or their language, and the Anishinabe Nations refer to groups of Ojibwe peoples who share similar Anishinabe languages and traditions in the Great Lakes area. The Anishinabe people migrated from the East Coast of North America before Europeans arrived. The Ojibwe people's oral tradition explains that their migration from the east to their current locations was directed by the First, Second, and Third Fire Prophecies. The migration began with the First Fire Prophecy, which told them to move or be destroyed by white skinned people. In other words, most of the students knew that Anishinabe people have existed before Columbus arrived in America. However, 11 out of 15 groups of students thought that "Anishinabe Nations" happened after "Columbus Arrives in America". This result shows that the students thought that the "Anishinabe Nations" were identified after white people or "Columbus Arrived". From our informal conversation with students during the lesson, we found that they thought Anishinabe Nations was a formal name for the Ojibwe people group or was the name for an independent governmental group used to identify themselves to Europeans. In other words, students separated the term Anishinabe Nations from Anishinabe or Anishinabe people and thought its use began after "Columbus Arrives."

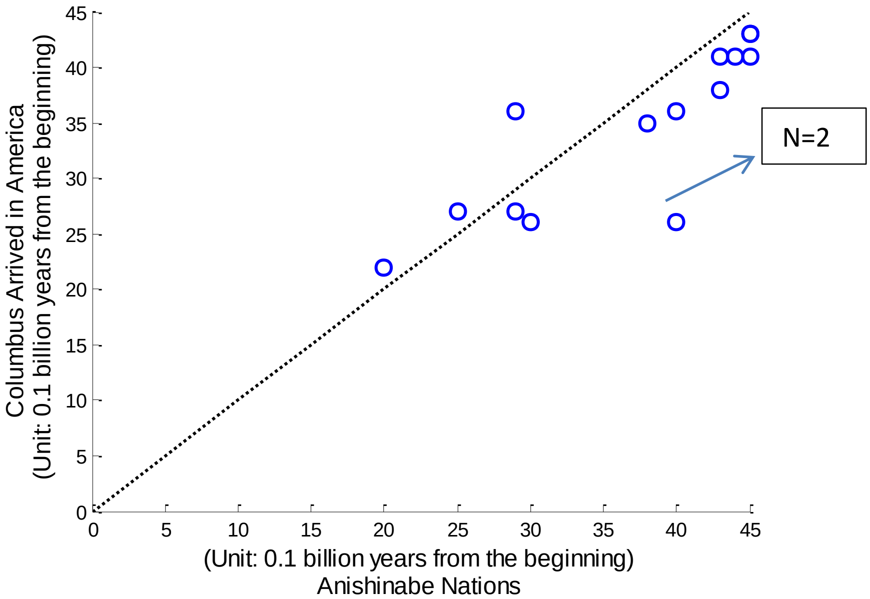

Figure 8. Students' relative ordering of two historic events: Columbus Arrived in America vs. Anishinabe Nations.

CONCLUSION AND DISCUSSION

Students' knowledge of geologic time scale is very important for understanding Earth system events (Libarkin, Kurdziel, & Anderson, 2007; Trend, 1998, 2000, 2001). However, few studies exist that focus on upper elementary and middle school students' understanding of geologic time scales. This study presented upper elementary and middle school Ojibwe students' (4^{th}-8^{th} grade) understanding of the relative order as well as absolute time of Earth's geological events with particular attention to their unique history and culture. The results of this study show that the students did not have the correct chronology of Earth's geological events, either in relative order or absolute time.

Three important points arose from our analysis of students' conceptions about geological time scales. First, students conceive Earth's geologic events in three distinctive time zones: near the beginning of the planet, near the present, and between these two. The first zone includes two events related to Earth's physical environments: "Formation of the Moon" and "Oxygen Rich Atmosphere." The second zone includes various events from the development of plants and the evolution of animals to other geological waypoints of the earth. Lastly, the third zone includes events related to human history. This result might show that the students' conceptions of the relative order of major events in Earth history is related to their traditional oral stories of Earth history and creation, which state that the universe and physical earth environments were made before the creation of plant beings and that humans were created last. This result also echoes the findings of other studies showing that 10 and 11 year old elementary students understand Earth events as a relative series of two distinct time zones (e.g. Trend, 1998).

Second, the events included in each zone were related to the Ojibwe's traditional oral history of creation and earth history. The first zone included specific events that are related to the earth's physical environment, such as "Formation of the Moon" and "Oxygen Rich Atmosphere." Ojibwe students have a traditional oral history about creation and earth history. In the creation story, the entire physical environment was created before life was created, and humans were created last. The zone near the present time zone included events that were more related to human history. However, as noted earlier, their chronology of modern human events and events related to human society was incorrect. Other events were scattered between these two zones. In this second zone, events related to plants were placed before the events related to animals. This result shows that the Ojibwe's traditional oral history is reflected in the students' ordering of Earth's geological and biological history. As other studies show, Indigenous students' environment and oral traditions affect their conceptions of natural phenomena and historical events (e.g. Ben-Zvi Assaraf et al., 2012). The results also imply that Indigenous students understand Earth's history based on the knowledge of their own cultural and historical events.

Third, the results of this study show that students have alternative conceptions about Earth's historical and evolutionary events critical to understanding important concepts in the planet's geological history and biological evolution. Two critical alternative conceptions found in the study were: 1) Most students thought that photosynthesis started after the earth developed an oxygen rich atmosphere, rather than that the oxygen rich atmosphere was a result of photosynthesis and 2) Most students thought Earth's first continents resulted from the breaking up of a bigger continent, Pangaea, and 3) Many students also thought that animals appeared on land after the extinction of the dinosaurs and that these two events happened with a large time interval in between. However, we also found that most of the students have some kind of useful understandings about the relative order of the appearance of animal beings. Most of the students has correct understanding of the order between three animal related events: "First Mammal" after "Dinosaur" (93%), "Human" after "Dinosaur" (93%) and more importantly, "Dinosaur"→ "First Mammal" →"Human" (80%). This result reflects findings from other studies that younger children have a general understanding of major events in Earth's history, but cannot organize an accurate chronological order of these events (e.g. Trends, 1998).

The results of this study have implications for teaching concepts related to the earth's geological events and biological evolution. First, the study shows that Ojibwe students have an understanding of the origins of Earth and life that is very similar to Western scientific knowledge, and that this understanding originates from the Ojibwe people's traditional oral history of creation and earth history. In other words, Indigenous people's traditional knowledge and history can be a useful resource for teaching Western science as well as for making science teaching more relevant to Ojibwe students.

Second, this study shows that understanding of the correct relative order of Earth's bio-geological events should precede teaching about the absolute time scale of these events. Dodick and Orion (2003) stated that concrete understanding of geologic time scale requires the cognitive skill of abstraction that enables students to apply their knowledge of causal relationships between Earth's geologic and evolutionary events to the real absolute time scale. Ault (1982) also asserted that elementary students have the ability to conceptualize geologic time scales even if they conceptualize time scales as relative order more often than absolute time. While understanding of the correct absolute time of Earth's geological history might be difficult for younger students, they might understand the relative order of the planet's geological and evolutionary events if teachers scaffold them to use sound scientific reasoning. Thus, as teachers, we should first help students understand the correct relative order of Earth's historical events by addressing misconceptions such as those described in this study. We should also help students connect and order Earth's historical and evolutionary events by addressing scientific causal relationships between them. As Dodick (2007) suggests, teachers should use scaffolded investigations where students apply their knowledge of Earth's geologic and evolutionary events by using absolute time. We believe the results of this study will help further the investigation of younger students' understanding of Earth's geological events and their relation to evolutionary events.

Based on the study, we suggest that we need further research about other Native American groups' understanding of geologic time scale and its relationship to their traditional oral history of Earth and creation. This kind of study will enrich our understanding of how traditional knowledge and culture affect students' learning of science concepts and how to develop more culturally relevant science curricula, not only for Native American students but also for Indigenous populations in general

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