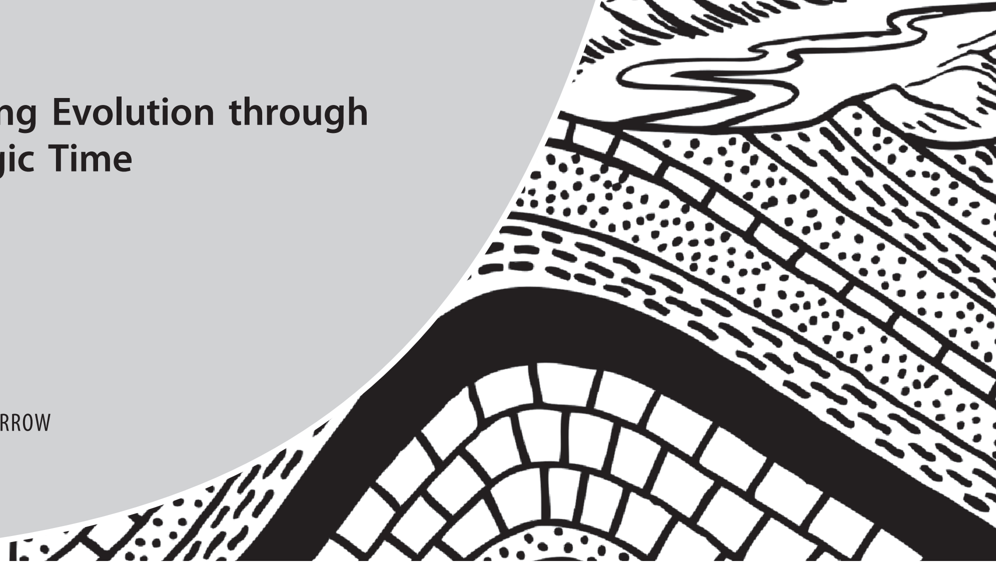
INQUIRY & INVESTIGATION

Picturing Evolution through Geologic Time



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Abstract

The purpose of this activity is to provide precollege biology students a visual representation of evolution. Unfortunately, many resources begin with the start of life, which ignores the fact that the Earth is 4.6 billion years old. This model uses adding-machine tape to sequence events. Representation of major evolutionary and geologic events helps students visualize macroevolution.

Key Words: *Macroevolution; model; geologic events.*

One recommendation made in the *Next Generation Science Standards* (NGSS) is the inclusion of seven crosscutting concepts that have application across all disciplines of science (NGSS Lead States, 2013). These include scale, proportion, and quantity, which are in turn related to size, time, distance, and so on. A prime example that may serve to focus on several of these issues is geologic time, a notoriously difficult topic for students to visualize and comprehend (Decker et al., 2007).

Here, I describe a simple model by which geologic time is translated into distance to assist students in understanding issues of scale and size. Certain issues in science, such as the vastness of geologic time and objects that are too big to be comprehended or too small to be seen, present instructional challenges. For instance, a study by Dahsah et al. (2012) was focused on secondary students' mental models of the Earth–Moon–Sun system; the students had difficulty understanding distance and size, even when using 2D and 3D models. The *Framework* that led to the NGSS reminded teachers that it is important for students to realize that "scientists construct mental and conceptual models of phenomena" (National Research Council, 2012, p. 56). Such mental models help students make sense of their experience and formulate predictions that can be tested. Conceptual models are used to visualize and understand phenomena.

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Scientists use models to help develop explanations that go beyond their observation and are, in turn, used to formulate hypotheses. Such models include diagrams, physical replicas, mathematical representations, analogies, and computer simulations (NGSS Lead States, 2013). Students must realize that these models are external forms of the concept that simplify and illustrate, but do not duplicate the phenomena. A model must be consistent with the evidence and frequently needs to be revised when new evidence is found. In presenting a model, its creator should (1) explain the phenomenon the model represents, (2) show how the model is consistent with the evidence, and (3) explain the limitations of the model. The construction of a model of geologic time will help students visualize and better understand that evolution requires a long period of time.

○ How Old Is Old?

The age of an object is determined by either relative or absolute means. In the best cases, both might be applicable. Furman (2013) reminds us that absolute time is based on the known radioactive decay of primarily igneous or metamorphic rocks. Using such means, the age of the Earth is frequently cited as about 4.5 billion years (Senter, 2013). Relative dating is based on the assumption that rocks (and the fossils they contain) found deeper in the Earth are older than those found near the surface. If the sedimentary layer in which fossils are found can be dated, those fossils are considered to be of the same age as the rock. No location on Earth has all of the layers deposited since its beginning, but examination of overlapping layers found across the planet reveals a fairly good picture of life though time. Geologists compare different sets of rock layers to form the total life

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story of an organism. Geology, paleontology, and radioactive dating all work together to show us that the Earth is 4.5 billion years old, that life has changed through time, and that macroevolution or speciation has occurred during the course of the Earth's development.

The opening sequence of the television program *The Big Bang Theory* represents, in about 17 seconds, the time frame for formation of the Earth and its subsequent life forms. Even though it offers a generally correct sequence of events, students would certainly gain a disjointed view of geologic time if they relied on this presentation alone. Likewise, the single-page illustrations often found in science textbooks cause students to form an incomplete model of geologic time, especially for visual learners. Consider the following problems that students typically have in understanding geologic time and evolution:

- They have difficulty comprehending the meaning of a billion years ago (bya) or a million years ago (mya) (Decker et al., 2007).
- They are not aware that simple forms of life first appeared more than 2.5 bya (i.e., stromatolites; Clary & Wandersee, 2013).
- They have difficulty putting the elapsed time between events in perspective (Furman, 2013).
- They have the misconception that major life forms evolved only in the past 590 million years (Clary & Wandersee, 2013).
- The commonly used calendar-year model, which represents the Earth as having formed on 1 January, dinosaurs becoming extinct on 24 December, and humans appearing at 8:30 P.M. on New Year's Eve, is difficult for students to comprehend.

○ Constructing a Scale Model of Geologic Time

Materials

- Adding-machine tape, 6 m long
- Metric ruler
- Geologic time chart (in case you want students to add more details to their model)
- List of key events (Table 1)

Procedure

The geologic time scale contains and illustrates everything that has happened since the Earth was formed (4.6 bya). In this activity, students represent time by translating it into distance. When finished, students will have a timeline of major geologic historical events and evolution. It is possible for students to produce a simple model with the events in the chart provided here, or you might consult McComas (1990), which includes a more detailed list of geologic, atmospheric, and biological events to be used on a timeline. Of course, depending on the goals of the lesson, events can be added or omitted as desired.

In the example presented here, the size and scale of the students' timelines will be identical. Each student will use a piece of adding-machine tape that is 6 m long, on which 1 mm = 1 million years. However, to add an element of inquiry to the exercise, the responsibility of choosing both the length of the tape and the scale could be the responsibility of the students, thus providing a degree of challenge that will not exist if all students use the same tape length.

To begin, students will measure about 10 cm from the end and draw a vertical line across the tape and label it "The Present." Using the metric ruler and the information desired (such as shown in Table 1), students can measure all distances from the "Present" line (using column A in Table 1) or from the previous vertical line (using column B in Table 1), moving to the left, draw a new vertical line and label it. Table 1 includes events to be labeled, age (mya), and the distance to measure. Keep in mind that if students use a different length of tape and/or a different scaling factor, the distances will change.

Furman (2013) noted that certain events are less frequently mentioned by students and teachers than others. Geologic events happen very slowly over long periods and are not directly observed. The dating of some biological events cause confusion for students, such as the origin of invertebrates and the extinction of specific dinosaurs. Teachers tend to be more familiar with the sequential order than with the dates of geologic events.

Questions to Guide Discussion of the Geologic Model

(Please note that "first" refers to the oldest fossil.)

1. How much longer have fish been on the Earth than birds?
2. How long was it after dinosaurs disappeared before humans appeared?
3. How does animal life on Earth compare with the age of the Earth?
4. How long after the first mammals appeared did dinosaurs become extinct?
5. How long had dinosaurs existed before the first mammals appeared?
6. How long was it between the first reptile and the appearance of dinosaurs?
7. How long was it between the first plants and the first flowering plants?
8. How long was it between the first fish and the first amphibian?
9. How long was it between the first fish appearance and the first mammal?
10. How long was it between the first flowering plant and the first form of animals?
11. How does the age of dinosaurs relate to Pangaea?
12. How long was it between the last ice age and the extinction of dinosaurs?

○ Additional Background & Teaching Suggestions

Evolution is the best scientific explanation for how populations of living things have changed through time. The geologic time scale allows biologists to arrange biological and evolutionary events in sequence. On the timeline described here, 1 mm = 1 million years (1 m = 1 billion years). Frequently, geologists report time in millions

Table 1. Key geologic and biological events for inclusion on a scale model of Earth history, based on a 6 m length of adding-machine tape.

Event	Age	(A) Distance measured from the line marked "The Present"	(B) Distance from one mark to the *previous* one
Present	Today	0 mm	
Last ice age	1 mya	1 mm	1 mm
Humans first appear	2 mya	2 mm	1 mm
Age of mammals	65 mya to present	65 mm	63 mm
End of the age of the dinosaurs	65 mya	65 mm	0 mm
First flowering plants	125 mya	125 mm	60 mm
Birds first appear	165 mya	165 mm	40 mm
Breakup of Pangaea	175 mya	175 mm	10 mm
Beginning of the age of the dinosaurs	245 mya	245 mm	180 mm
First mammal-like animal	275 mya	275 mm	30 mm
First reptiles appear	350 mya	350 mm	75 mm
Vascular plants first appear	425 mya	425 mm	75 mm
Amphibians first appear	435 mya	435 mm	10 mm
First fish appear	520 mya	520 mm	85 mm
Shelled animals first appear	600 mya	600 mm	80 mm
First evidence of life	1600 mya	1600 mm (1.6 m)	1 m
Formation of the Earth	4.5 bya	4.5 m	3.5 m

of years ago. They are often not able to establish an exact date (usually a small date range), but timelines such as these do accurately represent one event in relation to another event. Geologists refer to events when certain living creatures first appeared or disappeared. For example, the age of dinosaurs was about 120 million years long (on the timeline, 120 mm).

Biologists have studied evidence of past life over the entire Earth by examining fossils. It has been difficult to piece together the Earth's history, because the fossils from different times are not all in one place. Particular layers of rock with their fossils are identified as either older or younger than those of another area. This requires the careful study and comparision of several regions to verify correct sequences. The kinds of plant and animal fossils change through time, which Pojeta and Springer (2001) call the "law of fossil succession." When geologists find the same kind of fossils in rock at different places, they may consider them of the same age. Also, geologists use similarity of rock formations in different locations to correlate age. Specific fossils are found only in locations where rocks of a particular age are exposed, and such exposures can be separated by great distances. Students need to be aware that the formation of a fossil is rare. Most fossils are of organisms with shells or bones, since soft tissues decompose rapidly. Rapid burial is necessary to prevent decomposition, and over time the hard remains become fossils. Consequently, the timeline is a composite of many sites, which illustrates a limitation of the geologic time model – it is not for one location.

The timeline can be used as a catalyst for further study into prehistoric life. Students can work in small groups or individually to form their personal geologic timeline. The completed timeline tape can be mounted vertically to provide a better representation of sequence in the strata. Students can prepare a class presentation (poster, Smartboard, etc.) about each of the major events. This timeline provides a clear visual display of evolution over time.

Students can do in-depth research about particular dinosaurs of interest. They should provide detailed information about first discovery, common and scientific names, carnivore or herbivore (based on teeth pattern), movement pattern (two or four legs used for walking), type of hip arrangement, geologic age, predators, unique characteristics, and so on. They could investigate how Alvarez (1997) concluded that an asteroid impact caused dinosaurs' extinction, thereby providing an excellent example of the nature of science (Lawson, 2004). Or they could investigate the mass extinction of the Permian (Ward, 2004). If students have studied gill arches, they can prepare a report on anatomical evolution (vision, ears, adaptation to life on land, etc.) or hiccup reflex (Shubin, 2009.) Also, high school students could do in-depth evolutionary studies of specific plants or animals; each of these organisms should be noted on the timeline.

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