A Toilet Paper Timeline of Evolution

5 E Cycle on the Concept of Scale

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The theory of evolution of the Earth system including both geological and biochemical parameters is challenging for both teachers to teach and students to learn due to a number of synergistically interactive conceptual, historical, methodological, philosophical, political and theological factors (see Miller 1998 and National Academy of Sciences 1998 & 1999). In fact, the AAAS *Benchmarks* (1993) argues that:

> *In the twentieth century, no scientific theory has been more difficult for people to accept than biological evolution by natural selection. It goes against some people's strongly held beliefs about when and how the world and the living things in it were created. It hints that human beings had lesser creatures as ancestors, and it flies in the face of what people can plainly see . . . (p. 122).*

That this is the case is clearly evident in the long running debate over teaching evolution in public schools [see the eight-part series ''Creationism in the United States'' in *The American Biology Teacher*, September 1998 to May 1999]. This debate continues to the recent situation in which the state of Kansas has removed any mention of the theory from its curricular standards and assessments. Yet, there is near universal consensus among scientists and science educators that evolution is a central explanatory and predictive theory that demands attention in both biology and geology curricula.

While teachers cannot be expected to single-handedly resolve the religious and political issues surrounding the misconstrued and ill-constructed ''evolution = atheism vs. creationism debate,'' they can and should be expected to confront students' motivational barriers and misconceptions about evolution and the nature of scientific inquiry. Unfortunately, all too frequently, core scientific concepts and theories such as evolution are ''taught'' without adequate attention to:

1. Personal and social relevance and usefulness
2. Analogies and models or physical representations that make otherwise abstract, counter-intuitive and difficult-to-conceive ideas more ''sensible''
3. A sense of ''how we know (or at least tentatively believe) what we know,'' including especially the interconnections with other scientific concepts and theories
4. The amount of time it takes to effect conceptual change and meaningful, lasting learning.

Without these components, science is presented as a form of indoctrination, wherein students are expected to quickly, mindlessly accept (and subsequently regurgitate) the ''answers'' from the unquestioned authority of the textbook and teacher. Such a ''rhetoric of conclusions'' type approach does not usually raise concerns among parents (perhaps regrettably so), because most scientific concepts and theories do not seem to pose a challenge to their more personal, deeply held religious and/or philosophical beliefs, whereas evolution does challenge those who believe in a strict, literal interpretation of the Bible. Clearly, teachers need high-quality hands-on/minds-on activities that make the theory of evolution sensible and relevant via an extended ''dialogue of discovery'' and reasoned argumentation. Books published by the National Academy of Sciences (1998), the National Association of Biology Teachers (McComas 1994) and The Woodrow Wilson National Fellowship Foundation (1995) are wonderful sources of such activities.

The following 5 E Teaching Cycle (see Trowbridge et al. 2000 for a general discussion on 5 E Teaching Cycles) was designed for and tested in a series of two-week teacher institutes titled ''Evolution and the Nature of Scientific Inquiry'' which ran at Binghamton University in the summers of 1996-99 with the support of a grant from the Howard Hughes Medical Institute. It has subsequently proven to be one of the most used teaching cycles from the institute in both grade 7/life science and grade 10/biology classrooms. It addresses one of the more basic, discrepant and truly mind-boggling conceptual barriers related to the theory of evolution: the idea of geologic time. Most people have trouble conceptualizing numbers larger than a thousand, much less the millions and billions of years of Earth history. The *National Science Education Standards* clearly identify this as an issue: ''in studying the evolution of the Earth system over geologic time . . . [to] . . . unravel the interconnected story of Earth's dynamic crust, fluctuating climate, and evolving life forms. . . . The challenge of helping students to learn the content of this standard will be to present understandable evidence from sources that range over immense time scales. . . . Many students are capable of doing this kind of thinking, but as many as half will need concrete examples and considerable help in following the multistep logic necessary to develop the understandings'' (National Research Council 1995, p. 188). This sentiment was also expressed in the AAAS *Benchmarks* (1993): ''Most variables in nature . . . show immense differences in magnitude. . . . A million becomes meaningful, however, as a thousand thousands, once a thousand becomes comprehensible. Particularly important senses of scale to develop for science literacy are . . . the enormous

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age of the earth and the life on it'' (p. 276).

The problem of the immense scale of evolutionary time is exacerbated by the way it is typically treated in textbooks. Specifically, textbooks commonly show split timelines with wavy or broken lines for the Precambrian Era (87% of Earth's history) and date specific periods back from the present (millions of years ago/mya) rather than forward from Earth ''time zero.'' Additionally, the numerous, hard-to-pronounce labels associated with the various eras, periods and epochs further alienate novice learners, as does the quick ''one time topic'' (vs. recurring theme) treatment. Of course, truncated time scales are a necessary evil given the dimensions of a textbook, but teachers should not be limited by the textbook scale. What is needed is an approach to the scale of time that is analogous to what Morrison, Morrison & Eames (1994) did for the ''relative size of things in the universe'' in their groundbreaking book and late 1970s film, ''The Powers of Ten.''

The following 5E Teaching Cycle goes beyond artificial constraints of ''2 x 4'' teaching (i.e. two covers of the textbook and four walls of the classroom) and moves the class out into a school hallway to enable students to better visualize how ''far out,'' seemingly OUTrAGEous, yet FUNdaMENTAL scientific concepts and theories can be. While other published activities make use of either relatively long scales [a football field (McComas 1994)] or scales that are rather short [five meters of adding tape (National Academy of Sciences 1998, pp. 90–92)]; this one employs an intermediate length that requires getting out of the classroom, but not outside of the school building. This particular 5E approach also provides a rich opportunity to teach the time scale of evolution in a way that goes beyond the linguistic and logical-mathematical levels to include the musical, spatial, bodily-kinesthetic, and personal intelligences (Armstrong 1994).

''Wiping Clean'' Misconceptions About Evolutionary Time

Engage

Consider wearing a ''Whoa, 40 (or 50) is getting pretty serious'' or similar ''old'' age-related T-shirt into class and/or playing any one of a number of popular songs from the last 50 years that feature the word ''time'' and/or ''changes'' (examples of 1960-90s songs: ''Turn, Turn, Turn''/Byrds; ''Long Time Gone''/Crosby, Stills, Nash & Young; ''Time in a Bottle''/Jim Croce; ''Time Keeps on Slipping''/David Bowie; ''Longer Than''/Dan Fogelberg; ''It's About Time''/John Denver; ''Time Passes By'' and ''Lonesome Standard Time''/Kathy Mattea, etc.). If an ''older,'' less familiar song is used, challenge the students to explain the phrase ''time is relative'' with respect to the fields of biology and geology vs. popular music.

Focus Questions

1. How ''old'' is the Earth? What ways do scientists have of estimating this number? SW_2C: So What, Who (or why should I) Care(s)?

Have students make guesses about the age of the Earth and compare their ideas to the scientific estimate of 4.5 billion years. Briefly discuss how fundamental concepts and theories in sciences as diverse as astronomy, biology, chemistry, climatology, geology, paleontology and physics have all contributed to and are somewhat dependent on the idea of a ''very old'' Earth as indicated by radiometric dating. Consider having students ''analyze'' science cartoons by Sidney Harris, Gary Larsen and others in terms of how they ''play with'' the concept of the Earth's (vs. human) history. Challenge students to explain the scientific concepts (or misconceptions) that make the cartoons funny.

2. How much is and how can we conceptualize one million? One billion?

The children's book *How Much is a Million* by David M. Schwartz and Steve Kellogg (1985) contains a number of fun, visual representations and analogies for a million (e.g. a fish bowl big enough to hold a million goldfish would be large enough to hold a 60-foot whale), a billion (goldfish would need a bowl as big as a sports stadium) and a trillion (goldfish would need a bowl as big as a city harbor). Challenge students to come up with their own representations for these large numbers. A simple model that can be displayed on the classroom walls is dots (as many as 4000 to 5000) on standard 11 x 8 1/2'' stationery (for a total of 200 to 250 pages to represent 1 million).

3. Has the Earth always contained a biosphere with living organisms? What evidence do scientists use to answer this question? In what ways did early life forms transform their environment?

Elicit and record student ideas that will undoubtedly contain a variety of misconceptions about the idea of the fossil record and the long time frame during which microbes were the only life forms present. Do not be concerned with teaching/telling the ''right answers'' at this time, but have students begin to explore the questions by consulting their textbook, reference materials [such as Hoagland & Dodson (1995) and Whitfield (1993)], and Web sites (see listing under **Explain**).

Briefly discuss the notion of decoupling Earth and human history by labeling 4.5 billion years ago as ''time zero'' for our planet vs. the standard method of dating the Earth's events in millions (or billions) of years ago (mya) from our current time. Segments from the videos listed below under the **Explain** section may also be useful here for motivational purposes.

Explore

Relevant data on the Earth's evolving natural history needs to be supplied by teacher, textbook, or multimedia or Internet source to teams working with calculators. Detailed timelines of key points in evolutionary history are available in McComas (1994, pp. 34–39), National Academy of Sciences (1998, p. 91), Tarbuck (1994, CD-ROM) and most extensively, in the *Correlated History of Earth* Poster, a highly detailed, full-color poster from Pan Terra, Inc. (available from the Worldwide Museum of Natural History at 800-216-8130 or www.wmnh.com). While this information is provided to students as ''received knowledge,'' it is important to emphasize again the concurrence of views arrived at through multiple scientific disciplines and to challenge students to consider if the sequence of interrelated events ''makes sense'' from a developmental perspective (as such evolution must be a theme that is repeatedly returned to throughout the entire school year).

With some flair and sense of fun, introduce the ''Toilet Paper Timeline of Science'' as an inexpensive, long roll of paper that can be used as a simulation for geological time. Prior to unrolling the toilet paper down a long hallway and marking key points of interest, have groups check each other's calculations. The scale can be given to or derived by the students depending on their experience and the amount of time allotted. Many common brands of toilet paper have 280 sheets per roll and will easily fit in typical school hallways. (Alternatively, some cheaper, single-ply brands of toilet paper come with 1000 sheets.).

SCALE: 4.5 x 10^9 yrs /280 sheets = 450 x 10^7/280 = 16 x 10^6 yrs/sheet

16 x 10^6 yrs/11.1-cm sheet = 1.44 million yrs/1 cm = 1 million yrs/0.69 cm

Focus Questions

1. How does the history of living organisms (including eventually humans) compare in length (duration) to Earth's history? How many sheets of toilet paper would this be from Earth time zero?

Microbial Life (prokaryotes) began approximately 3.8 x 10^9 yrs ago or 0.7 x 10^9 yrs from Earth ''time zero'':

0.7 x 10^9 yrs/4.5 x 10^9 yrs = 0.1555 [During the first 15.5% of Earth's history, there was no life present or, conversely, life has been present for 84.5% of Earth's history.]
0.1555(280 sheets) = 43.54 sheets from Earth ''time zero.''

Until recently, it was believed that prokaryotes were the only forms of life for roughly the next two billion years. Research by Brocks et al. (1999) now seems to indicate that eurokaryotes evolved as early as 2.7 billion years ago. To help students better visualize the idea of ''billions of years,'' have them work with a Time Travel Analogy: Assuming a year of time was represented by one mile and that you could travel back in time in a conventional car traveling at the speed limit of 65 mph (or use 100 mph for easier calculations if desired).

2. How long would your auto trip back to see the beginning of life on Earth take? How many typical human lifetimes is this? How many generations?

3.8 x 10^9 miles x 1 hr/65 miles x 1yr/8760 hours = 6674 years [Note: The earliest human cities were built approximately 6000 years ago.]
6674 yrs/80 yr lifespan = over 83 lifetimes of auto speed travel time
6674 yrs/20 yrs reproduction cycle = approximately 334 generations

3. Given that bacteria can still arguably be considered the most prevalent life form on Earth and assuming bacteria can reproduce every 20 minutes, what's the maximum number of generations of bacteria that could have theoretically existed over the last 3.8 billion years?

3.8 x 10^9 yrs x 8760 hrs/1 yr x 60 min/1hr x 1 generation/20 min = 10^{13} generations = a lot of evolutionary time

4. Where would the following significant events occur on the Toilet Paper Timeline? Any of the previously cited evolutionary timelines can be used to identify the developmental timeline for all the major plant and animal group [fish—amphibians—reptiles (including dinosaurs)—mammals—birds] ''firsts'' that occur between points (a) and (b). The *Correlated History of Earth* poster is especially detailed and includes pictures of the coinciding positions of the Earth's continents. Look for connections such as links between plant reproduction and animal pollinators and be sure that students note that the poster's timeline is NOT/cannot be drawn to a uniform scale.

(a) **Cambrian ''Explosion'':** 570 million yrs ago = 0.57 x 10^9 yrs: segmented worms, coral anemones, jellyfish, sponges, lamp shells, clams, snail, squid, trilobites, crabs, etc.

4.5 x 10^9 yrs—0.57 x 10^9 yrs = 3.93 x 10^9 yrs from Earth ''time zero''
3.93/4.5 = 0.8733 [87% of Earth's history occurred *before* invertebrates]
0.8733(280 sheets) = 244.53 sheets from Earth ''time zero''

(b) **First ''Homo''**: 2 million yrs ago: Homo habilis → Homo erectus

4500 x 10^6 yrs—2 x10^6 yrs = 4498 x 10^6 yrs from Earth ''time zero''
4498/4500 = 0.99955
0.99955(280 sheets) = 279.88 sheets from Earth ''time zero''
0.88 sheets(11.1 cm/sheet) = 9.8 cm from start of last sheet #280 on roll

(c) **Homo sapiens neanderthalis**: 200,000 yrs ago = 0.2 x 10^6 yrs

4500 x 10^6 yrs—0.2 x 10^6 yrs = 4499.8 x 10^6 yrs from Earth ''time zero''
4499.8/4500 = 0.999955
0.999955(280 sheets) = 279.9875 sheets from Earth ''time zero''
0.9875 sheets (11.1 cm/sheet) = 10.96 cm from start of last sheet/ #280

Homo sapiens sapiens: The sole ''survivors'' of the Homo line date to approximately 100,000 yrs ago, apparently overlapping in time and location with the Neanderthals whom they subsequently re/displaced, and show up in the last 0.1 cm (or 1 mm) of the toilet paper timeline.

Explain

Use discussions, simulations, videos, virtual trips on the World Wide Web, etc. to explain the idea that current species have evolved via descent with modification over long expanses of time and to provide a clearer sense of the data and reasoning that supports this idea.

Internet

American Museum of Natural History in NYC: http://www.amnh.org/
Human Origins & Evolution in Africa: http://www.indiana.edu/~origins/
National Museum of Natural History (Smithsonian Institution), Department of Paleobiology: http://www.nmnh.si.edu/departments/paleo.html
Online Literature Library *(Voyage of Beagle, Origin of Species & Descent of Man)*: http://www.literature.org/authors/darwin-charles/
Paleontological Research Institution: http://www.englib.cornell.edu/pri/
Royal Tyrrell Museum: http://www.tyrrellmuseum.com/home
UC-Berkeley Virtual Museum of Paleontology: http://ucmp.berkeley.edu
U.S. Geological Survey:
Dinosaurs: Fact & Fiction: http://pubs.usgs.gov/gip/dinosaurs/
Fossils, Rocks and Time: http://pubs.usgs.gov/gip/fossils/
Geological Time (online edition): http://pubs.usgs.gov/gip/geotime

Multimedia

Life on Earth: A Natural History. (David Attenborough). Two 233-min. videos with Chapter Search and on-screen numerical codes for quick access to each of the program's 13 chapters (keyed to the accompanying book published by Little, Brown & Co., 1979). Carolina Biological: 1-800-334-5551 for $39.95 (K3-49-1150-V).

Planet of Life (Discovery Channel): 6 hrs 50 min. on 4 videotapes: #1: Part 1/Birth of Earth & Part 2/Ancient Oceans; #2: Part 1/When Dinosaurs Ruled & Part 2/Creatures of the Skies; #3: Part 1/Insect World & Part 2/Apes to Man; and #4: Evolution's Next Step. Discovery Channel Video, PO Box 4055, Santa Monica, CA 90411-4055; 1-800-207-5775. [$49.95].

A Science Odyssey: The Journey of a Century (Host: Charles Osgood). Five two-hour videos including ''How We Know What We Know'' about *Origins* (1st hr: Wegener & continental drift/plate tectonics, geological forces, age of the Earth, Darwinian evolution, paleontology + 2nd hr: genetics, DNA, Miller & Urey and the first life forms). PBS Home Video, 1-800-645-4727. $79.98/A3078 + $30/B3078/accompanying book by Charles Flowers (William Morrow & Co., Inc. 1998, pp. 126–177).

Elaborate

Formative assessment is ongoing throughout the various activities. If the

students have not already done so in the **Explore** phase, use the aforementioned timelines to ''fill in the details'' of major ''firsts'' in the evolution of life. If the toilet paper timeline is taped to the walls in the hall, students can add relevant artwork and information above and below the timeline for semi-permanent display to catalyze out-of-class conversations about expanding the idea of ''prehistory'' to include the huge expanses of time before the arrival of humans.

Evaluate

Students can be challenged to develop other models such as a 365 ''day'' = Earth's 4.5 billion year calendar for display and/or check the accuracy of geographic analogy scales (1 mile = million years) such as that published by Packard (1994). Other summative projects might include graphic displays, computer simulations, cartoons, science songs, fictional news releases challenging Darwin's critics (such as Lord Kelvin's faulty estimate for the age of the Earth), skits, etc. for individual students and/or student teams. Another possible extension is to challenge students to critically analyze the flaws in the arguments of young Earth creationists by reviewing Internet sites such as:

Creationism & Pseudoscience: http://users.deltanet.com/~fsteiger/creation.htm

Dialogue Between Science & Religion/AAAS: http://www.aaas.org/spp/dspp/dbsr/default.htm

Evolution Controversy/Talk Origins Archive: Exploring Creation http://www.talkorigins.org/origins/other-links.html

National Center for Science Education: http://www.NatCenSciEd.org/

Science & Creationism: http://www4.nas.edu/opus/evolve.nsf

The key factors to remember throughout this 5 E Teaching Cycle are:

1. Students need multiple, rationally sequenced experiences that draw on a full array of intelligences to counter their everyday conceptions of ''history'' and its unduly restrictive association with humans and human lifespans.
2. Engaging students in a ''dialogue of discovery'' and ''questioning the answers'' takes more time than simply providing them authoritative, ''just the facts'' answers. Conceptual change is an evolving, dialectical process as was the development of the target scientific theory.
3. Some students will find it difficult to ''believe'' the scientific view, even if they understand it conceptually, due to deeply held, conflicting personal religious beliefs which must be respected. Minimally, assure such students that science in general (and evolution theory in particular) does not require one to be an atheist, but rather is simply agnostic in its methodological approaches to developing provisionally accepted, proximate causes (''how'') to natural phenomena. Science does not directly address the domain of ultimate, perhaps supernatural causes (''why'') that are the territory of religion.

Evolution, properly addressed as a theme that pervades an entire course of study, provides a perfect opportunity to engage students in critically analyzing the nature of scientific inquiry, including the scientific meaning of the term ''theory'' (Rudolph & Stewart 1998) and other commonly held ''myths'' about science (McComas

1996). The mistaken separateness of the numerous topics and chapters within textbooks belies the underlying unity that powerful, interlinked theories provide to science and science education (Duschl 1990). Science as an evolving product and process is inherently constructivist and economical in its efforts to explain the broadest range of phenomena in terms of the fewest number of unifying basic assumptions, concepts, and empirically supported laws and theories. The ''ever-evolving'' theory of evolution makes a perfect case study for this point.

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