PATTERNS IN TIME 5

Staggered Origins of Vertebrate Fossils in Familiar Time

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www.indiana.edu/~ensiweb/lessons/pat.in.time.html

SYNOPSIS

Students gradually build a realistic sense of deep, geological time from familiar linear analogs, e.g., calendars, millimeters and football fields, relative to their short lifetimes. They learn that if we equate 10 years of their life to 1 mm, a million years will equal a football field, and 500 million years will equal 30 miles - all distances with which they are familiar.

They also learn to associate the earliest member of each group of vertebrates with the geologic time of its emergence, on their "familiar scale" of relative distances from their school. The stair-step pattern of emergence revealed by this activity leads naturally to an inquiry for an explanation, with the hypothesis that each group (class) originated from a preceding group. In order to test this idea, students are guided to seek further clues, e.g., the possession of common features, with a few new features added with each new class, and some of the many transitional fossils showing gradual changes of features. And they find them.

PRINCIPAL CONCEPT:

The fossil record shows a pattern of increasing diversity and large-scale gradual changes through time.

ASSOCIATED CONCEPTS:

1. The vastness of deep geological time can be understood on a recognizable scale of familiar dimensions.
2. There are vast periods of time (tens of millions of years) that separate the gradual emergence of each major vertebrate group. Vertebrate groups did *not* appear suddenly or over any short period of time.
3. Each successive vertebrate group emerges with the characteristics of the previous group, plus a few key modifications unique to the new group.
4. There are many transitional fossils showing gradual changes over time.

ASSESSABLE OBJECTIVES (Students will…)

1. recognize the sequence of emergence of the major vertebrate classes.
2. recognize the basic vertebrate characteristics, common to all vertebrates.
3. recognize the special modifications new to each successive class.
4. recognize the time/distance back to key geological time markers proportional to familiar dimensions, e.g., the time since humans emerged as a unique family (7 mya), the time since whales emerged from four land-dwelling animals (50 mya), the time since the extinction of non-avian dinosaurs (65 mya), the time back to the first fish (500 mya)
5. recognize the relative approximate time spans separating the emergence of each major vertebrate class, proportional to familiar dimensions, e.g., time between first fishes and first amphibians, between first amphibians and first reptiles, between first reptiles and first birds, and between first reptiles and first mammals.
6. recognize examples of transitional fossils, showing evidence of gradual change over time.

MATERIALS for Teacher Demo

Pre/Post Quiz for lesson (short, w/ key; version showed ~90% improvement in 8th grade LS classes)

Real fossils and/or models and/or pictures of fossils, from a variety of organisms, including different classes of vertebrates (fishes, amphibians, mammals , reptiles and birds,) (PowerPoint 5,6)

Pictures of modern fishes, amphibians, mammals, reptiles and birds. (See our collection of pictures of living and earliest fossil vertebrates - link under Materials in the onsite lesson); Do Web search for additional illustrations if needed, or have students do this.

Animals of the Past: Patterns in the Fossils diagram (for overhead or PowerPoint) - (PP 8 & 42)
Version of **Animals of the Past** showing phylogenetic connections (PP 43)
Calendar, with squares for each day of the week. (1" wide days provided for easy scaling PP 10-11)
Football field picture - awkward scale (PP 14)
Football field picture - useful scale (PP 17)
Register tape (strip of at least 10 yards). Mark off 1 inch, 7 inches, and 30' 4" (about 10 yards).
Meter stick (and enough metric rulers for students to observe in pairs), and a **yardstick**
Big Map of your area in a 40 mile radius of your school - with scale (try GoogleMaps or MapQuest)
Big Map of your region or state (within about 280 miles of your school) - with scale (ditto)
Large Circle Compass, or length of **string** (for finding point of interest at particular distance from school)
Geologic Time Scale Chart (spreadsheet) PP 25
Demo **TimeMarker Scale** strip on Map
Sample "Time Map" of your area (or another area as an example, e.g.,...)
Sample "Time Map" of San Francisco Bay Area (PP 18)
Sample "Time Map" of Middle California (PP 19)
Teacher Guide for using TimeMarker and Preparing Scaled Map
Teacher Guide for Students Calculating Scale Dimensions
Vertebrates Over Time (Key for checking student chronology)
Stack of 10 $1-bills, and a stack of 100 $1-bills (= 100 years - **optional**)
"Jumbo" size paper clip (wire = 1mm thick)

TIME
One 45 minute period for the time concept and map layout. Building the **Vertebrates Over Time** chart, and using inquiry to show how this chart suggests the evolutionary connectedness of the groups, will require an additional period (or two).

STUDENT HANDOUTS
Scale Events Worksheet (1 per student)
Accumulating Traits in the Vertebrate Fossil Record (chart): 1 chart per team (PP 32)
TimeMarker Scale strip (1 per team) - cut from sheet of 4 TimeMarker strips
Scaled Map of your area (1 per team)
Vertebrate Patterns (information and Practice Procedures) (1 per team)
Vert. Over Time blank grid (horiz. lines mark every 20 my back to 600 mya) (1 per team) (PP 33-35)

TEACHING STRATEGY (PREPARATION/CONTEXT)
This lesson would fit nicely as an introduction to fossils, or geological time (earth science or life science). It might also be helpful when introducing the diversity of life. While getting familiar with different groups of vertebrate animals, it's always helpful to consider the fossil record in this context, and how it relates to modern animals. This very valuable experience should prove vital to subsequent studies of classification and evolution. Most important for students is to note the *total absence* of fossils for each vertebrate group *prior* to its emergence (earliest fossils of that group). It's also important to note that each class does *not* just suddenly appear with all its traits fully formed, rather there are series of transitional fossils in the preceding class and early in the new class, showing the gradual development of those new traits.

Special PowerPoint is provided for teachers to get a feel for the presentation. Feel free to use excerpts of the PPT to build your own presentation, but use it sparingly, since direct and dramatic teacher-student interaction works best.

Pre-Post Test: Consider giving this to measure effectiveness of the lesson. (see teachers materials above). Used in several 8th grade Life Science classes showed average 90% improvement! Short - 6 items.

Skipping Parts? Whether you walk your students step-by-step through the scaled measurements, or just jump to the essential scale (thickness of dollar bill = one year, so football field = one million years) depends partly on the age and experiences of your students, and the amount of time you can devote to this. Don't feel bad if you decide to skip the gradual development of the scale, but be prepared to help students confused by the scale-up - maybe offer to go over it with a small group after school or during lunch break.

PROCEDURES

ENGAGE: Fossils over time

Introduce students to fossils:

Have some real fossils (and/or plastic copies) of a variety of organisms for students to handle and share, and/or show pictures of fossils; a few models of some prehistoric creatures, like dinosaurs and other early reptiles, would also make it fun.

Ask: "If you found these fossils in some rocks, what questions would you ask?
[list some of the questions asked, e.g., "what was it?" "when did it live?" "how old is it?"]
If possible, tell them the ages of some of the fossils. Brachiopods and trilobites were abundant from about 400 to 300 million years ago (mya). Some brachiopods are alive today, but trilobites must be older than 250 million years (the last of them died out in the Great Dying – end of Permian - when 96% of all marine species went extinct). Ammonite fossils were most abundant between 250 and 65 mya (died out when dinosaurs did). Dinosaur fossils must be older than 65 million years (last non-avian dinosaurs went extinct then). Earliest whale and pre-whale fossils would be less than 55 million years old. There are no known human fossils older than about 7 million years.

As part of this, show the class an enlarged version of the chart: "**Animals of the Past: Patterns in the Fossil Record**," point out how the different major groups of vertebrates did **not** all appear at once, but separately, over several 100s of millions of years. Emphasize that there are NO fossils of mammals prior to about 220 mya (millions of years ago), NO reptiles prior to about 310 mya, NO fishes prior to about 500 mya.

Ask "how long is 1 million years? Any idea? What about a billion years? A thousand years? (Try this engaging approach: show a dollar bill and ask "If one year = the *thickness* of this dollar bill, how high would a stack of a million dollar-bills be? To the ceiling? Top of two story building? Length of our building? Length of football field? Two miles? More than two miles?" If you didn't ask this in a pre-test, you might list these as "A, B, C..." choices on the board, and tally the number of hands for each guess. Or try a secret ballot in some classes. Chances are that the guesses will be wide-ranging, and students can see this in a quantitative way.}

Let's see if we can develop a better understanding of those big numbers, and some major events that happened so long ago, and to see if there are any interesting patterns in those events.

EXPLORE: Time and Distance

Introduce the use of length or distance to show time:

Preparation: See **Materials** (and detailed information found in each approach used)

Presentation: Ask probing questions to get students thinking about time and distance:
How can you describe 1 million years to someone? [usually rather vague answers]
How do we measure time? [let students reply: counting seconds, clock, sun, **calendar**]
Can we look at certain distances for time? [distance from 11 to 12 on a clock, distance from Sunday to Saturday on calendar, etc.; show a big calendar or two]
Could we compare *distances* to explain "1 million years?" [yes]

"How about a **Time Machine**... like a calendar!" [show a big calendar]. Doesn't the calendar take you backwards in time - and forwards in time? Isn't that what a Time Machine does?"

Show on *our* calendar how each day is about an inch wide (show on overhead or LCD projector, with ruler, showing each **day-length** as **one inch** wide on the calendar).

[You may want to skip the following to save time; it just shows how useless a calendar would be for measuring deep time. If you do skip it, just point out that a calendar won't work for measuring "DEEP TIME!" - and skip down to "A Different, Better Scale"]

[The inch is used here for unity because it is more appropriately larger than a cm. If the days on your calendar are more than 1", tell class "let's assume that each day-square is 1 inch across."]

If we use one inch here as a convenient length, how long would a **week** be? [7"]
[Show one inch and 7 inches on the paper tape.

How many weeks in a year? [52], so how many inches for a **year**? [7 x 52 = **364 inches**]

Can you visualize 364 inches? [not easy] So, how could you do that?
[change to feet: 364" X 1 ft./12" = **30.3 feet**]

Roll out the tape to the 30.3 foot mark (~10 yards), or show that dimension in your classroom. (30.3 ft X 1 yd / 3 ft. = ~10 yards).

So, on this scale, one **year** is about **10 yards**, right? And, so, **10 years** is ....
[10x10= **100 yards**].

Ask "Where is there a place where you can see 100 yards easily?" [football or soccer field]

You are more than 10 years old...(you can probably remember events over the past 10 years, right?) So you were born about a football field (fbf) ago (if 1 day is 1"), right? You are each more than **a football field in age**!

How many fbf for 100 years? [10 fbf].... 1000 years? [100 fbf], etc. Can you visualize this very well? How far do you think that would be (say in miles)?
[100 fbf x 300' =30,000'/5280'=~5.7 mi.] Do you think a *million* years would be easy to visualize? How far do you think that would be (say in miles)? [~5,700 miles: SF to Berlin, or distance from SF to NY and back]

[By the way, inches, feet, yards and miles are used here (rather than metric units) because of their familiarity in the US, and the point here is to relate familiar dimensions with the unfamiliar numbers of deep time.]

As you can see, we are working with distances that are probably **not very familiar** with most of you. Therefore, **let's try a different scale**:

EXPLAIN: A DIFFERENT - BETTER - SCALE:

A calendar scale is just too big to help us understand really deep time - many millions of years. So, "How about shrinking **1 year** of your life (*'I'm shrinking...!')* down to the thickness of a $1 dollar bill [show them this]. If we do this, how thick is ten years (a stack of 10 $1 dollar bills)?" Show them that it is **exactly 1 mm** (especially impressive if you can use a digital micrometer to show this, but a metric ruler will suffice). Note that 1 mm is also the thickness of a paper-clip wire. "What about 100 years - a human lifetime? [show them a 1 cm stack]. Right; 10 x 1 mm = 10 mm."

Have them find 1 mm on their metric rulers, and look at the wire of a large paper clip]. Ask how many mm in a meter? [show meter stick.] If they don't know, have them count mm in 1 cm [10], and cm in the meter [100], so 10x100 = 1000 mm in a meter]. How many years would that be? [10 x 1000 = 10,000 years].

If **1 meter** = **10,000 years**, how many meters would be equal to 100,000 years?
[100,000 / 10,000 = 10 meters]; 1,000,000 years (1 million years)? [100 meters]
Right... it would take **100 meters** to equal 1,000,000 years.... **1 million years**.
What unit is a meter closest to in English measurements? [1 yard; show them 1 yardstick next to meter stick]. So 100 meters is **about** .... [100 yards], which you can visualize as being the length of .... a FOOTBALL FIELD! [or soccer field if you prefer].
Now, **if your lifetime so far is about 1mm**, then **a million years** is about **a football field long**, right? Close your eyes and visualize a football field... Does that help to visualize a million? So, when we talk about a million, think of a football field of dollar bills! (if 10 years of your life were shrunk to 1 mm. You may want to write down (or show) this equivalence scale so the whole class can see it as you proceed:

ACTUAL TIME	TIME "DIST. from SCHOOL"	TO SPECIAL PLACE
Ten year lifetime	1 mm	xxxxxxxxx
1 million years ago	1 football field (fbf)	xxxxxxxxx
10 mya **	10 fbf = 0.6 mile *	
50 mya	50 fbf = 3 miles	
100 mya	100 fbf = 6 miles	
250 mya	250 fbf = 15 miles	
500 mya	500 fbf = 30 miles	
1000 mya = 1 bya	1000 fbf = 60 miles	
4.6 bya	4600 fbf = 276 miles	

**When we talk about "one million years ago" we can abbreviate that with "1 mya"
* Approximate distance in miles, based on 100 meter (yard) football field (0.6 km = 1 mile)

ELABORATE - APPLICATION: In order for students to build a familiarity with the time/distances used in this scale, they should actually plot those distances on a **scale map of their area**. You may want to demonstrate this first, as follows, then have students do the assignment. And the Student assignment can be fairly simple, with no calculations, or a bit more challenging, requiring students to calculate scale dimensions. For getting a properly scaled map of your area, see **TimeMarker and Preparing Scaled Map** in the Materials section.

TEACHER DEMO: Notice that we are now talking about 10s and 100s of millions of years, so we'll want to translate football fields into miles on a map of your area to give students some idea of the vastness of time involved. You will find that all the major fossils, on this scale will be less than about 40 miles away, a distance that your students have probably traveled. [You may want to have a large map of your area and a large circle-drawing compass or two, e.g., a standard pencil-compass and probably an old chalkboard compass for longer distances, or use a string.] Be prepared to mark off circles with radii that represent key "distances" in time, so the kids can find landmarks (towns, special places, buildings, etc.) that they may have visited, and therefore have some sense of their distances. A **Geologic Time Scale chart** with such distances for key events in the geological past, based on the football field = 1 mya scale, is provided for you with this lesson. Note especially the vertical "Miles" columns (colored) that you - or, even better, the students) can mark out on the map of your area (using the map scale for distances). Miles are used here, rather than kilometers, because most people in our country have resisted moving to metric, and are therefore unfamiliar with it.

STUDENT ASSIGNMENT: Using a properly **scaled map** of your area, showing a series of towns or other landmarks more-or-less aligned for about 40 miles in one direction from your school, students position a **TimeMarker Scale**, with its several key events in geological time, so that they can find familiar towns or other landmarks whose distances coincide approximately with those key events (mostly the earliest fossils for each major vertebrate group). The scale is based on 10 years = 1 mm (or 1 million years = a football field). Students then record the name of each town (or landmark) on their **Scale Events Worksheet** tables, and answer the Discussion Questions there.

If you would like students to work more closely with the simple math of scaling, and finding the map distances for whatever scaled map you can provide, then CLICK HERE.

ASSIGNMENT DETAILS:
To do this, students use copies of maps of their area that have been downloaded from the internet, at appropriate scales. For recent events (within about 4 miles, for 65 mya), a Google map with a scale (lower left corner) measuring about 2 cm for 2000 ft would probably work best. For earlier events (scaled to about 30 miles for 500 mya), use a map where the scale measures about 2 cm for 5 miles. For times reaching out to 4.6 billion years (276 miles), you'll need a map where the scale measures about 2-3 cm for 50 miles. You may want to have 1 or two teams (pairs) working on the "most distant" events, a couple more on the "most recent" events, and most of the pairs working on the 65-550 mya range. Or just show enlarged (or projected) maps with the extreme distances, so all teams will work with the 65-550 mya maps.

Detailed Teacher Preparation & Instructions for two approaches (Click on preference below):
1. Students use pre-made **TimeMarker** scales on pre-made maps (no calculations necessary).
2. Students **calculate** and plot the Time Distances for each event on pre-made maps.

In either case, the object is to find a familiar "Special Place" located at the distance from school associated with each Time Distance. For nearby distances (recent times), this could be their house, or a friend's or relative's house, a school, a familiar store, or park, etc. For larger distances, it could be a town, amusement park, theater, stadium, etc. These landmarks don't need to be precise - just reasonably close to each Time Distance from school.

See example of "Time Map" done for the SF Bay Area, with San Jose as the focus, and also the Time Map done using the TimeMarker strip (for a school in the San Jose area). (By the way, don't worry if the scale bar on the TimeMarker Scale is not exactly 1.9 cm for 5 mi., or if the time-event points do not agree precisely with that scale, as these measurements may not always print out correctly. But that's ok; approximate dimensions are quite satisfactory for getting across the idea):

BACK TO THE FOSSILS: The History of Life on Earth

TO THE TEACHER: Students should know that most of the familiar animals they know about are **vertebrates**, and can be divided into five main classes: fishes, amphibians, reptiles, birds, and mammals. If not, it would be good to review those groups, what they have in common [vertebrate traits], and what makes them different. Show pictures and models or living examples of each group, and either provide the two-page "**Vertebrate Patterns**" handout for them to read (homework), or walk them through the "What Are They?" and "Accumulating Traits" material on that handout, based on the abundant fossil record. Those two pages can be printed back-to-back on a single sheet to hand out.

BUILDING A VERTEBRATES-OVER-TIME DIAGRAM

For students to engage more deeply with how vertebrate group origins are staggered over massive amounts of time (many tens of millions of years), have your students plot those beginnings (earliest fossils for each vertebrate class) on a time grid for the past 530 million years, shifting the tic mark about 2 cm to the right for each successive emergence, from the earliest to the most recent. A **bare grid** for **"Vertebrates Over Time"** is provided, or you could use the **prepared grid**, with tic marks already in place to save time. Instructions are given on the handout (and below). You may want to illustrate with the PowerPoint slides provided.

Next, students **label** each of those "firsts" with the name of that group. For example, the 500 mya mark would be labeled "**1st Jawless Fish**" - the 440 mya mark would be "**1st Jawed Fish**" - and so on. Use the "**Accumulating Traits**" table for this. In addition, if you like, students could add a few of the key **new** traits associated with each group. And have them notice how many millions of years passed between each new emergence.

To show that each group (except one) continues to exist to the present, have students draw **vertical lines** from each tic mark up to the most recent members of that group (top line). All but one will meet the "NOW" line at the top. Label each vertical line with the name of that class. For an example of this process, show your students slides 33, 34, and 35 in the **PowerPoint** presentation for this lesson.

USING INQUIRY TO ANALYZE THE VERTEBRATE FOSSIL PATTERN

THE PROBLEM:

Point out the stair-step pattern of the different times of emergence for each vertebrate class. Emphasize how there are NO fossils of any class prior to (below) those earliest fossils marking the time of emergence. Ask your class "**What does this staggered emergence suggest about the possible origin of each class?** Accept all reasonable ideas, but here are some possible responses (potential hypotheses):

HYPOTHESES:

1. "Could all the vertebrates originate at one time, but the early fossils of some just haven't been found?" [possible, but not likely, since fossil scientists have searched long and hard in sediments of those ages, and there is a consistently clear absence of fossils of each group prior to the earliest ever found].
2. "Could each just magically appear (or be created), one following the other?" [possible, but science can't use magic for an explanation, because true magic can't be tested.]
3. "**Could each class have come from one of the previous classes?** [Possible, and testable, so go with this one]. Ask "If so, what kind of evidence would strengthen that hypothesis?"

PREDICTIONS:
Again, accept all reasonable ideas. Students may suggest that new features in each class could just be modifications of similar features in a previous class, so we could look for 1) examples of stages of change in the fossils. They may also suggest 2) that we could look for examples of fossils with intermediate traits - so-called "transitional fossils." Or perhaps 3) some fossils may have a mix of features found in both a previous class and early in a later class, suggesting a gradual transition from one to the other. Provide hints of these if students have trouble making testable predications.

On the other hand, ask what they would predict if the hypothesis is *not* correct. Their responses may include: 1) no transitional fossils would be found; 2) no evidence of gradual changes in features of the fossils; 3) no examples of mixtures of old and new features in single fossils. If students are not forthcoming, drop some hints towards these ideas.

TESTING the PREDICTIONS:
Students can go online to search for "Transitional Fossils" - or you can provide a selection of appropriate sites (see below) for students to study. Students will find that some sites will claim that there are no transitional fossils, or if there are, they only indicate changes within species. These are nearly always sites associated with Biblical or creationist interests, with their particular motives, so students should be wary of the unscientific approach followed by such groups. You could point out that their views could be true, but they're usually not testable, therefore using them is not a productive way to go.

Different groups of students could be assigned different sites to study (good homework assignment), but be sure to provide a few specific points to look for and think about, e.g., 1) Find 2-3 good examples of series of fossils that apparently show transition from one class to another. Record the source of the information, the names of the two classes in each case, and list the particular features that show step-wise change. 2) Be critical: Can you think of any reasons why those features might *not* actually be transitional features? 3) Be prepared - as a team - to discuss your findings and conclusions with the class, It would be helpful to have a large diagram or two to illustrate your brief presentation (always makes it more interesting). Perhaps team members could prepare a large drawing or two based on the most impressive examples found.

Here are some useful sites to suggest:
Transitional Fossils: http://www.talkorigins.org/faqs/faq-transitional.html
A few transitional fossils: http://www.transitionalfossils.com/
29+ Evidences for Macroevolution: http://www.talkorigins.org/faqs/comdesc/section1.html
(click on item 4. Intermediate and transitional forms - for good examples).
Taxonomy, Transitional Forms and the Fossil Record:
http://www.asa3.org/ASA/resources/miller.html
Transitional Fossils: http://en.wikipedia.org/wiki/Transitional_fossil

There are also a few examples showing series of transitional vertebrate fossils near the end of the PowerPoint presentation with this lesson.

Evidence of the gradual accumulation of traits: Give students a chance to study the handout sheet: "**Accumulating Traits**" to see how each new class simply adds a few new traits.

CONCLUSION:
After students have looked over the resources about transitional fossils, have a representative from each group give a brief summary of their findings to the class, along with diagrams where possible. Afterwards, lead a class discussion about whether there is sufficient evidence (convincing examples of transitional forms) to support the hypothesis - or not. Ask, "Is the hypothesis supported by the evidence, or not?"

FAMILY TREE: PHYLOGENY - A Graphic Display of the Conclusion
Using the **Vertebrates Over Time** diagram, have your students draw a dashed line from each tic mark to a slightly earlier point in time on the immediately preceding vertical line, suggesting how each successive group may have come from the preceding group due to **modifications** of some features (as documented in the fossil record). Showing slides 36 to 43 in the PowerPoint would help to illustrate those likely connections. Be sure to emphasize that **we have many transitional fossils** that clearly show gradual changes between the earliest members of each group and in certain slightly older members in the previously existing group, so their inferred connectedness is not mere speculation. You could show the **Animals of the Past** diagram with the connections that suggest their phylogeny (see Teacher Materials).

QUESTIONS ABOUT the RELIABILITY of GEOLOGICAL TIME
If you can take the time, it's important that students recognize the high level of confidence we have in the actual ages of fossils. See items 4 and 5 under the "Extensions and Variations" section below. Also, if students challenge you on these issues, be sure to have them read the items found HERE.

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EVALUATE: ASSESSMENT

A Pre/Post Quiz is provided (see teacher materials), or you can modify to match the particular experience in your classes.

Use the Assessable Objectives as a basis for formative and summative assessments. Create test questions that require students to recognize particular sequences of a few key vertebrate groups, and relative periods of time, using a few of the most notable key events in geological time that were studied. They should identify such "time spans" as linear dimensions on the scale used in class (10 years = 1 mm, and 1 football field = 1 million years), applied to a familiar map of the area. They should also recognize that the major vertebrate groups emerged over 100s of millions of years, with each successive group modifying some features possessed by the previous group. Perhaps most important is that students get a clear picture of the vastness of geological time, the confidence that scientists have in those numerical time spans, and the fact that the major vertebrate groups did not appear at the same time or even over a short period of time.

Precise times (in millions of years ago) are *not so important*. It would be helpful to learn approximations of a few of the key reference points in time, e.g., the earliest fish - about 500 mya, earliest mammals about 220 mya, and most other vertebrate groups emerged roughly 40-60 million years apart, staggered over about 300 million years. It's also important to know that each successive group is defined by a few new features, modified from previously existing features found in their predecessors, and that there are "transitional fossils" that document those gradual modifications over time. These are examples of the "Patterns in Time" that tell us that life has evolved over time.

EXTENSIONS & VARIATIONS

1. If you feel that your students are sufficiently computer competent, let them search for the "first mammals," first amphibians," etc. Remind them the *Wikipedia* site is a good place to start, but that results should be compared to information on other sites. They should try to use university or professional science society sites as much as possible. An excellent source for "first xxx" in each vertebrate class is the list of "**Transitional Vertebrates**" on *TalkOrigins.com*. Students will find a fair amount of variation (note comments above on the cause of this), but differences in ages of first members of a major group shouldn't be huge. Earlier sources (20+ years ago) or non-academic / non-professional sources, could be way off the mark, for various reasons. You and/or your students can prepare a table for them to post their findings, or let them create their own tables. Be sure that you let each team share its findings with the class, and come up with a class consensus to serve as basis for building the scale to be used for plotting out the time spans (to scale) on the map.

2. For ongoing reinforcement, consider installing a large horizontal **time scale chart** in your classroom, either around the room (perimeter = age of solar system), or along one side or across the front of the room. Having this handy throughout the year allows convenient reference to geological or biological events in time that you can point to when discussing them. It's a memory aid that will stay with students for a long time. See The **Time Machine** lesson on the ENSI site for details and suggestions for making this room-size time scale AND taking your class on a dramatic voyage back in time.

3. You might also consider making a big enlargement of the **Animals of the Past** figure that you could post permanently on the wall for ongoing reinforcement and reference. You could do this on a large scale enlarging copier at Kinko's or similar copy place, or have an artistically talented student do it for you (for extra credit).

4. An interesting extension would be to ask students to figure out how far away (in miles) it would be (using our scale of 30 miles = 500 million years) for the distance representing the age of our planet (and our solar system) - about 4.6 bya, or 276 miles in our scale, or the **age of the known universe** (13.7 bya), about 822 miles with our scale. Have them find a spot on a larger scale map that shows those distances from their school/city. [For example, Los Angeles is about 280 miles from San Jose, CA, and Tucson, AZ is about 823 miles by road from San Jose, CA].

5. GEOLOGICAL TIME SCALE - VARIATIONS
When you or your students look for the ages of specific fossils, or the earliest members of a particular group, the time is sometimes given in the name of a geological period and/or epoch. The numerical ages of those named time periods may be slightly different in different resources. This could be confusing, until you realize that those ages are periodically revised by an international organization to reflect the latest research and improved dating techniques (see Resources below). Most of the adjustments (since 1982) have been relatively minor in geological terms (varying less than about 5-10 million years up or down in most cases). Charts showing this can be found in the **PowerPoint** presentation on slides 48-50. Each age value used in this lesson is the closest multiple of 5 to the latest numerical age to make time differences and scale calculations easier.

6. GEOLOGICAL TIME - RELIABILITY: Furthermore, the numerical ages used are based on a variety of radiometric dating methods, all based on the reliably measured time it takes for particular isotopes of certain elements to decay to new isotopes. The physics of this process are well-known and the techniques are extremely reliable, giving fairly consistent results when all sources of possible error are critically accounted for. There is even a technique known as the "**Isochron**" method, where ratios of different isotope pairs are compared in the same crystals that formed in the molten rock when it cooled. This technique

automatically provides a form of "proofreading" that virtually eliminates significant errors. For a fascinating tutorial on radiometric dating, especially the isochron method, you (or your students) can go to the **interactive tutorial**: **Virtual Age Dating** (linked to from the ENSI site) where simulations of the dating process are run, and formative assessment questions are asked along the way. A certificate of completion is printed out for each person who completes the tutorial successfully (good homework assignment).

7. BILLIONS OF YEARS AND BILLIONS OF DOLLARS
A useful application of this scale for personalizing deep geological time, into millions and billions of years, is to relate it to money. Instead of equating a $1 bill with a year, just keep it in dollars! A million dollars would stack about a football field's length; a billion bills would stack about 60 miles high!

In these times of trillion dollar deficits - or costs of dealing with global warming - it would be interesting to have your students figure out how far away a trillion dollars would stack. That's 1000 x 1 billion [so on our scale, that would be 60,000 miles]. Then have them find something that is that far away (from the Earth, or around the Earth). [They may discover that the Earth's circumference at the equator is about 24,900 miles, so ONE trillion dollars would stack 60 / 24.9 = ~2.4 times around the world! Or, with about 2564 miles between San Francisco and New York, ONE trillion dollars would stack 60 / 2.564 = ~ 23.4 times across the USA.]

8. See the other lessons on this site that deal with geological and paleontological patterns (INDEX - click on "Synopses" there).

RESOURCES
An excellent source for the **latest geological time scale charts** is:
The International Commission on Stratigraphy: http://www.stratigraphy.org/
Also, (same site): Time Scale Chart and Timescale comparison charts (to scale - 1937-2004) - These are useful to show **changes in the Time Scale Charts** over the past 50 years. These are also shown in the **PowerPoin**t presentation for this lesson, slides 48-50.
Talk Origins - Transitional Vertebrate Fossils: http://www.talkorigins.org/faqs/faq-transitional.html
Tree of Life - Vertebrates: http://tolweb.org/Vertebrata
Several excellent articles on transitional fossil series and the proper use of phylogenetic trees and cladograms are available freely online in the June 2009 issue of Evolution Education & Outreach. For links to these and other resources, see **Resources area** in the **Patterns in Time** lesson.

Pre-Mammal Jaws: For a great series of jaws, with color-coded bones and and names and the periods they represent, clearly showing gradual change over time, see: **29+ Evidences for Macroevolution** at http://www.talkorigins.org/faqs/comdesc/section1.html Scroll down to see the beautiful sequence of skulls and jaws, in color, 8 species, from pelycosaurs to mammals, from the Carboniferous to the Jurassic. This would make a great visual to show students on overhead or PowerPoint. Or have an artistically talented student make an enlarged copy of this for the wall (for extra credit).
A simpler version (3 skulls) is shown further up, but this doesn't carry the strong impression of gradual change over time that the larger illustration does.
For an excellent **phylogenetic tree of the synapsids (pre-mammals)** over time see http://www.palaeos.com/Vertebrates/Units/Unit390/000.html
For **jaws showing teeth**, especially the increasing variety of teeth that gradually characterize pre-mammals and is so typical of true mammals, see http://www.gcssepm.org/special/cuffey_05.htm.
If you would like to have a nice sharp (8.5 x 11) jpg version of any of the illustrations mentioned here, let me know. I'd be happy to send it to you. Please be specific. Contact the webmaster.

ATTRIBUTIONS

1. Created and developed by Larry Flammer, posted on the ENSI site April 2008
2. Enhanced July 2009
3. Major Revision February 2010.
4. Major Revision - adding inquiry - August 2010

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SCIENCE STANDARDS MET WITH THIS LESSON

Meets these California Science Education Standards (2003):

7th grade LS: evolution 3c; earth and life history 4d, e, g
7th Investigations: 7d
HS Biology/LS: evolution 8e, g
HS Investigations: 1d, g, i, k, l

Meets these National Science Education Standards (1995):

UNIFYING CONCEPTS AND PROCESSES
 Evolution... : The general idea that the present arises from materials and forms of the past.
CONTENT: Grades 5-8
 155: Life Science (content standard C)
  Diversity and adaptations of organisms
   Biological Evolution accounts for diversity of species developed through gradual processes over many generations....
 158: Earth and Space Science (content standard D)
  Earth's History
   Fossils provide important evidence of how life and ... conditions have changed
CONTENT: Grades 9-12
 181: Life Science
  Biological Evolution (185)
   Natural selection and its evolutionary consequences provide a scientific explanation for the **fossil record**... as well as for the striking molecular similarities observed among the diverse species...
   The millions of different species ... are related by descent from common ancestors
   Biological classifications are based on how organisms are related.
 187: Earth and Space Science (189)
   The early Earth was very different from the planet we live on today.
   Geologic time can be estimated by observing rock sequences, ... using fossils, ... [and] using known decay rates pf radioactive isotopes ... to measure the time since the rock was formed.