PATTERNS IN TIME

by Larry Flammer

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 and football fields. They also learn to associate the earliest fossils of specific groups of vertebrates with the geologic time of their emergence, on the now-familiar scale of relative distances from their school. From this, they discover the pattern of gradual vertebrate emergence and how well it consistently fits vertebrate phylogeny.

PRINCIPAL CONCEPT:

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

ASSOCIATED CONCEPTS:

1. The vast dimensions 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 emergence of each major vertebrate group.
3. Each successive vertebrate group possesses characteristics of the previous group, plus a few key modifications unique to the new group.

ASSESSABLE OBJECTIVES (Students will be able to…)

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 (6 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 time spans separating the emergence of each major vertebrate class, proportional to familiar dimensions, e.g., time between first fishes and first amphibians, between amphibians and first reptiles, etc.

MATERIALS

Real fossils and/or models and/or pictures of fossils, from a variety of organisms, including different classes of vertebrates
Pictures of modern fishes, amphibians, reptiles, mammals and birds.
Animals of the Past: Patterns in the Fossils (for overhead or PowerPoint) - illustration
Calendar, with squares for each day of the week. Calendar with 1" wide days provided (makes for easy scaling)
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
Stack of 10 $1-bills, and a stack of 100 $1-bills (optional)
"Jumbo" size paper clip (wire = 1mm thick)
Map of your area in a 40 mile radius of your school - with scale (try GoogleMaps or MapQuest)
Map of your region or state (within about 280 miles of your school) - with scale (ditto)
Chalkboard compass, or length of string (for finding point of interest at particular distance from school)
Geologic Time Scale Chart (spreadsheet)
Sample "Time Map" of San Francisco Bay Area

TIME
One 45 minute period (possibly two periods)

STUDENT HANDOUTS
Scale Events Worksheet
Vertebrate Fossil Record (chart): 1 chart per team
Accumulating Traits in the Vertebrate Fossil Record (table)

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.

PROCEDURES
ENGAGE:
Introduce students to fossils:

Have some real fossils (and/or plastic copies) of a variety of organisms for students to handle and share.
Show pictures of fossils

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). 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? How longer are these time spans than *your* lifetime?
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.

ALTERNATE OPENER:
To Teachers: [As you and many students may know, birds are now considered as a group of dinosaurs, closely related to *T. rex* and *Velociraptor*, that somehow survived the KT extinction 65 mya (millions of years ago). So technically, dinosaurs are actually still with us! However, for

purposes of convenience, in this lesson, we will use “dinosaurs” for the *non-bird* dinosaurs, the last of which became extinct 65 mya]

Show some pictures and/or models of dinosaurs.
Ask: “Has anyone seen any live dinosaurs anywhere?” “Why not?” [extinct, except for birds!]
“How do we know there were dinosaurs?” [fossils]
“When did they live?” “How do we know this?” [we can date the rocks around them]
“Were there any mammals alive then?” [yes] “How do we know that?” [mammal fossils of that age]
“Were there any birds alive then?” [yes] “...amphibians...?” [yes] “...fishes...?” [yes]
“Any whales alive then?” [no - earliest whale fossils appeared about 50 mya]
“Were there any humans alive then? [no – earliest human fossils appeared less than 7 mya]
“How can we tell when the first dinosaurs appeared?” “mammals?” “birds?” etc. [ages of their fossils]
“How old were the first dinos....mammals....birds..... amphibians...”
[Students may (should) be using words like “millions” of years ago.]

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EXPLORE

Introduce the use of length or distance for time:

Preparation: See materials

Presentation: Ask probing questions in order 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.]
Could we compare *distances* to explain “1 million years?” [yes]
Show calendar, where each day is about 1 inch wide (show on overhead or LCD projector, with ruler, showing each **day-length** as **one inch** wide on the calendar).
If we use one inch here as a convenient length for comparison, 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: 364/12=**30.3 feet**]
Roll out the tape to the 30.3 foot mark (~10 yards), or show that dimension in your classroom.

So, on this scale, a **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 a little 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 about **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]
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!:**

DIFFERENT SCALE: [Here's where you might want to use the dollar connection - see Extensions and Variations below, item #4].
How about shrinking **10 years** of your life down to **1 mm**? [have them find this on their metric rulers]. 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 soccer field or football field]
Now, **if your lifetime so far is about 1mm**, then **a million years** is about **a football field long**, right? Does that help to visualize a million? So, when we talk about a million, think of a football field (if 10 years of your life were shrunk to 1mm ... *"I'm shrinking...!")*. Write down (or show) this scale equivalence so the whole class can see it as you proceed [show that thickness of wire in a "Jumbo" paper clip = 1mm]:

ACTUAL TIME	TIME "DIST. from SCHOOL"	TO SPECIAL PLACE
Ten year lifetime	1 mm	"Jumbo" paper clip wire
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	

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

TO TEACHER: 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 our area to give you some idea of the vastness of time involved. You will find that all fossils, on this scale, will be less than about 40 miles, a distance that your kids have probably traveled. [You will want to have a large map of your area and a large 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).

ASSIGNMENT: Using the **Scale Event Worksheet** table, students insert the missing information wherever they can. Most important is finding a familiar "special place" located at the distance from school indicated for each Scale Distance. This could be a friend's or relative's house, a familiar store, or park, etc. For larger distances, it could be a town, amusement park, theater, stadium, etc. Use a map and ITS scale, and a proportional equation to find the actual dimensions on the map. Set a compass (or string) for that dimension, then move it around the school's location, looking for familiar reference points at that distance. If no special building, park, etc., just give names of two streets that cross at that distance. If done collectively as a class, let class decide which "Special Place" to use to mark the map (identifying the mark with the particular mya - distance from school that it represents).

See sample of "Time Map" done for the SF Bay Area, with San Jose as the focus.

CALCULATING SCALE DISTANCES: This provides an excellent opportunity to use some fairly basic algebra to show how a "scale factor" is derived from a simple scale equation. In the formula below, D = Scale Distance desired; T = Actual Time back to event of interest. The **0.6 mi. / 10 mya** fraction is the Reference equivalent determined from building the scale used in this lesson.

<u>EVENT</u> : <u>REFERENCE</u>

$$\frac{D}{T} = \frac{0.6 \text{ mi.}}{10 \text{ mya}}$$

Dividing 0.57 mi. by 10 mya = 0.06 mi/mya
Multiplying both sides of the equation by T cancels T on the left, and results in:

D = T x 0.06 mi/mya (Scale Distance Calculation)

Therefore, to find the map-scale Distance backwards in time to a desired event, just multiply that Actual Time (T) in mya by 0.06 mi/mya
The product will be the map-scale Distance (D) in miles (mya units cancel out).

If your students can handle the "scale factor" derivation, ask them to see if they can figure it out, and compare results with each other. Show them how the Event D/T is proportional to the Reference ratio, then let them do the derivation.

If they have no algebra experience, just show them the proportion equivalence equation, and explain that the "scale factor" was calculated from that. Then have them use the Scale distance Calculation for each T (Actual Time) that they need to find, then enter that into the table.

Once the scale distance (D) is determined, translate that distance (miles) into the map measurement (in inches or cm) that corresponds to D. This will require a second calculation, using the *map's* scale: D x MD/MM. Carefully measure (in cm, to nearest tenth of a cm) the actual length of the map scale for (say) 5 miles, then divide that measurement (MD = Map Dimension) by the miles (MM = Map Miles), 5 miles in this case, then multiply by the desired scale distance (D). Then set your compass for that map distance. Placing the compass center point at your school location, scribe a light circle for that distance. Look for familiar places of interest that lie on or close to that scribed arc, and pick one to remember as being associated with the special event in time that happened millions of years ago. Record that special place on your table on the line for that event.

BACK TO THE FOSSILS: The History of Life on Earth

Students should know that most of the familiar animals they know about are **vertebrates**, and can be divided into five 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:

They all have a head and tail ends, vertebrae, dorsal nerve cord, and gill arches in their embryos (common to all vertebrates). **In addition**...

Fishes: have fins, gills and scales;

Amphibians: have four limbs, + lungs, and smooth moist skin, all teeth the same type, lower jaw with 3 bones, 1 ear bone;

Pre-Mammals: have four limbs, lungs, eggs with special membranes, different teeth types, lower jaw with fewer bones, and increasing number of ear bones;

Mammals: have four limbs, lungs, + fur, eggs with special membranes, different teeth types, lower jaw with only one bone, 3 ear bones, and mammary glands;

Reptiles: have four limbs, lungs, + scaly skin, and produce eggs with special membranes; all teeth the same type, lower jaw with 3 bones, one ear bone.

Birds: have four limbs, lungs, + feathers, eggs with special membranes, and hollow bones.

ACCUMULATING TRAITS: A chart of these major vertebrate groups "**Accumulating Traits in the Vertebrate Fossil Record**" is provided, summarizing the general vertebrate traits plus the particular traits that distinguish each group. Be sure students notice how each successive group (in time) possesses the same traits as the previous group, PLUS a few modifications. In other words, in general, the different vertebrate groups appear to have *accumulated* their traits from previously existing groups over long periods of time.

It would be useful to find out how far back in time each group lived... in other words, can we say when each group first appeared in the fossil record? This can be tricky, but paleontologists have found features that are fairly unique to each group, and appear in their teeth and bones, and therefore in their fossils. For example, there are certain bones, in certain patterns that are typically found in the skulls of mammals, but they are not quite the same in amphibians or reptiles.

Using those diagnostic features, paleontologists have found that the earliest **fish** fossils appear around **500 mya** (million years ago). Those fish had no jaws and no bones, and certain ones live today in the form of lampreys and hagfishes. These are the agnaths, or "jawless fishes."

The first **jawed fishes**, appeared about 60 my later, about **440 mya**. That means that, for about 60 my, there were *no* fishes with jaws. Most of today's fishes have jaws: most with bones (teleosts) and many with cartilage instead (sharks and rays)

The oldest **amphibian** fossils go back to about **365 mya**, about 75 my after those first bony fishes with jaws appeared.

Then, about 45 my later, we find fossils of the earliest **pre-mammals** (stem-mammals or synapsids) that began to appear about **320 mya**. About 100 my later, these pre-mammals accumulated more and more mammal-like features, (passing through stages known as pelycosaurs, therapsids, then cynodonts). Eventually, true **mammals** appeared (about **220 mya**). The pre-mammals all became extinct. Note there are no true mammals prior to 220 mya, so there were **no true mammals** during the 280 million years when fishes, amphibians, and reptiles gradually emerged.

About the same time the pre-mammals appeared, another group known popularly as the "**reptiles**" first appeared (**310 mya**). This entire group is more accurately known as "sauropsids." The earliest sauropsids to appear were anapsids, with some traits like modern day turtles and tortoises. Then, two other groups of sauropsids appeared: one with traits closest to lizards and snakes of today, and the other a widely diverse group that included the pterodactyls, crocodiles, and dinosaurs. About 226 mya, therapsid dinosaurs first appeared and many became increasingly bird-like. The earliest therapsid fossils showing feathers (now called **birds**) date back to about **150 mya**.

This is what the fossil record tells us today, so far. The fact that the earliest fossils in each group are preceded by fossils with intermediate traits (between previous group and the newly-formed group), strongly suggests that each group formed gradually from a previous group by gradual changes and modifications of some of the earlier traits. This pattern is repeated many times. You can show this by showing the **Fossil Record Patterns** diagram on the overhead, and adding connecting lines that show possible connections. Or you can just show **Fossil Record Patterns 2**, where likely pathways are shown. The branches between reptiles and mammals represent the pre-mammal groups (pelycosaurs, therapsids, and cynodonts. The last cynodonts went extince in the early Cenozoic. This would provide and excellent segue for an introduction to evolution, if this fits into your schedule at this time. If not, be sure to refer back to this diagram when you do study evolution.

In order to appreciate the huge periods of time between the times of emergence for each major group, review those distances on your map.

PRACTICE: Students should practice showing their team mates how long ago the earliest member of each vertebrate group appeared by pointing to its scale distance-equivalent on the map, relative to the location of your school (and to the 10-year period of their lives as 1mm).

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. Most of the adjustments (since 1982) have been relatively minor in geological terms (varying no more than about 5-10 million years up or down in most cases). 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.

GEOLOGICAL TIME - RELIABILITY: Furthermore, the numerical ages used are based on a variety of radiometric dating methods, all based on the regular and reliable 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 isotope pairs are compared in the same crystals formed when those crystals formed in molten rock. 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** (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.

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ASSESSMENT

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 vertebrates, 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), 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.

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 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. They 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 their 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 time scale 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. An interesting extension would be to ask students to figure out how far away (in miles) it would be to a scale distance representing the age of the known universe (13.7 bya). Using our scale, it would be about 822 miles. Have them find a spot on a larger scale map that is that far from their school/city. [Tucson, AZ is about 823 miles by road from San Jose, CA]

4. **Billions of Years = 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**. It just so happens that a stack of ten $1 bills is exactly 1 mm thick (same as thickness of the wire in a "Jumbo" - 47mm long - paper clip), and a stack of 100 $1 bills is exactly 1 cm thick. These are the same dimensions we used for our **time scale**, so a stack of $1000 would be 10 cm thick, and a million $1 dollar bills, stacked face-to-face, would extend one football field high! Five hundred million dollars would stack about 30 miles high, and a billion dollars would reach about 60 miles high! All of this based on the scale that the thickness of a one dollar bill (0.1 mm) represents 1 year of your life!

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.]

Another engaging introduction to the "football field" time scale might be to have a bundle of 10 $1-bills, and another bundle of 100 $1-bills. Tell students that we will take $1 for each year of the last ten years of their life. Count out the ten $1-bills - and then measure their combined thickness (calipers are helpful here) - very close to 1 mm. Ask "how many bills for 100 years?" "And how thick would that be?" [10 mm, or 1 cm]. Pull out the stack of 100 $1-bills to wave around. Say "There's 100 years of your life! Pretty close to a maximum human lifetime." Then you can launch into increasing multiples of ten with the class, so they discover that one million $1 bills would stack about a football field high (100 meters - ~ 100 yards - or 100,000 mm, where each mm = 10 years)! [RETURN TO "DIFFERENT SCALE" INTRO].

5. See the other lessons on this site that deal with geological and paleontologoical patterns (EVOLUTION 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.
Talk Origins - Transitional Vertebrate Fossils: http://www.indiana.edu/~ensiweb/lessons/c.bkgrnd.html
Tree of Life - Vertebrates: http://tolweb.org/Vertebrata
There are several excellent articles on **transitional fossil series** and the proper use of phylogenetic trees and cladograms, all in the **June 2009** issue of *Evolution Education & Outreach Online*. They are written by professional scientists, but in relatively non-technical language for use by teachers and students. They are freely accessible and downloadable. For reviews and access information, go to http://www.indiana.edu/~ensiweb/EvoEd.v2n2.html.

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.
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.
See http://www.palaeos.com/Vertebrates/Units/Unit390/000.html for an excellent phylogenetic tree of the synapsids (pre-mammals) over time
See http://www.gcssepm.org/special/cuffey_05.htm for jaws showing teeth, especially the increasing variety of teeth that gradually characterize pre-mammals and is so typical of true mammals.

If you would like to have a nice big 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
Created and developed by Larry Flammer, posted on the ENSI site April 2008. Enhanced July 2009.

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Meets California Science Education Standards:
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