Living Earth: Unit 3

Evidence of Evolution

Background for Teachers and Instructional Suggestions

Evolutionary scientist Theodor Dobzhansky made the now famous quote "Nothing in biology makes sense except in the light of evolution". The topics and concepts in this instructional segment can be referred to throughout the course. To understand the evidence for how evolution has shaped life over time, students need to think about processes in both the biosphere and geosphere.

Observations and analysis of ***patterns*** of ***change*** that support evolution were introduced at the middle grade level, including noticing patterns in the fossil record (*MS-LS4-1*) **analyzing data** and **constructing explanations** of the evolutionary origins of anatomical similarities (*MS-LS4-2*) and embryological similarities (*MS-LS4-3*). This instructional segment also relates to some of the statistical and **mathematical modeling** of natural selection that students did in middle school (*MS-LS4-6*). Before these tools can be developed, students need to understand a bit more about fossils so that they will be able to understand the evidence they help provide.

Fossils as a Part of the Geosphere

Evolution requires changes that span many generations of a population, so it can only be directly observed in populations that reproduce very quickly such as bacteria in petri dishes. For the rest of organisms, scientists have sought out other lines of evidence. In particular, the fossil record allows them to peer back over a very long time interval and discover transitional life forms as well as indications of organisms that no longer exist. The finding of fossils in layers of deep valleys or mountaintops leads to a question about how fossils form and are preserved for millions of years. This instructional segment begins with understanding the ways in which past events are recorded by the rock record.

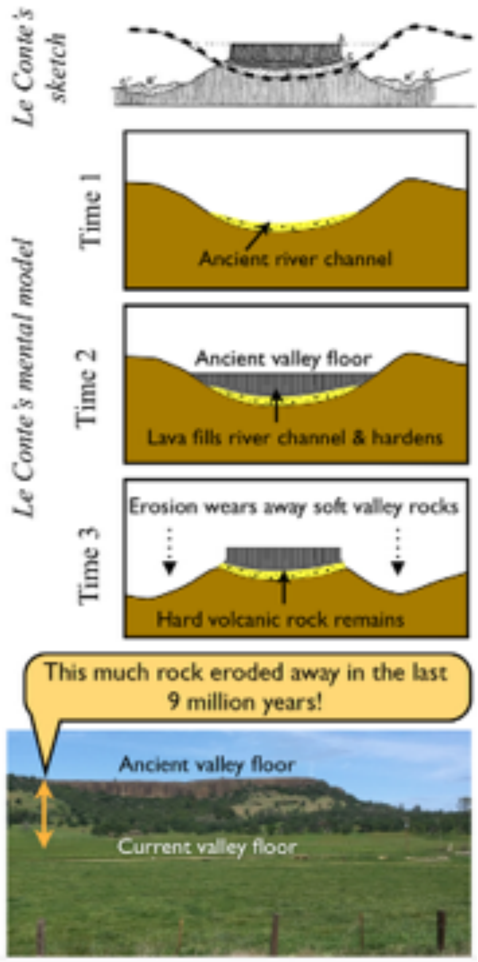

Figure 4. Tuolumne Table Mountain near Jamestown, CA reveals how much soil and rock has eroded. Joseph LeConte sketched the drawing on the top for a textbook he wrote in 1882. LeConte was one of the first faculty at the University of California and a charter member of the Sierra Club. There are several schools in California named after him, including ones in Los Angeles and Berkeley. (LeConte 1892) Photo by Kirk Brown, illustration by Matthew d'Alessio.

Just as evolution changes populations, a variety of processes shape the physical landscape on Earth. All of these processes require a sense of how change is recorded over time. In the 1850's, geologists in California like Joseph Le Conte, one of the first faculty members at the University of California, began to look at landscapes and construct mental models of how landscapes developed and changed by erosion (Figure 4). These mental models need to be put to the test, so Earth scientists began to conduct small experiments of erosion in laboratories. A stream table (a sloped table or plastic bin covered with sand and other earth materials and flooded with water) is a platform for exploration about erosional processes that is an example of both a hands-on **investigation** and a physical **model** that can be used to predict possible outcomes. Teachers can use stream tables to help meet some of the PEs of CA NGSS, including having students **ask their own questions**, and construct their own experiments (*HS-ESS2-5*). Students can recreate California landforms such as the Sierra Nevada and Great Valley in a stream table and watch as sediment slowly accumulates in deep layers in the Valley or even be given a range of materials that they must choose from to see if they can produce the mesa-like features of Table Mountain. This will give the students a hands-on **explanation** for why there are layers in the mountains and valleys and how those layers are placed down and accumulate over time. Each layer that gets deposited preserves a record of what the physical environment was like at the time. Even after the climate of this region has changed and millions of years have passed, we can get a glimpse of what the ecosystem was like at this spot because the ancient river channel in Time 1 of Figure 4 may preserve fossils of organisms that once drank from or swam in it. Like a little time capsule, these fossils have been protected from erosion by the solid cap of lava above.

The process of lava capping a layer is far less common than simply having layers of sediment deposited one on top of the other. The constant buildup of layers like in the Grand Canyon is the geologic example of ***structure and function***. In biology, the shape of objects gives clues about what they are used for, while in geology the shape of the landscape reveals the process that brought it into existence. Sedimentary rock layers tell us that material was eroded from one area and deposited in another, usually driven by water, wind, or gravity. Details about the layers and the arrangement of the materials in them reveal clues about the ancient environment such as the past climate because it affects the amount and speed of the water and the intensity of the wind.

While people often think of erosion and deposition as slow and steady processes, these processes are often much more dramatic, which turns out to be important for fossil preservation. Students can observe the rate for themselves in a stream table where slow and steady erosion is punctuated by rapid landslides. The slow movement of sediment from the base of a cliff eventually hits a critical point and a massive piece of the cliff suddenly falls. The erosion rate then slows down because the cliff erodes into a flatter hillslope. California's coastal bluffs repeatedly face this problem, often eroding many feet in a single storm and then remaining stable for decades. Students can relate this process to real coastal erosion by using online collections of historical photos as found in Google Earth and the California Coastal Record to measure the impact of waves on the coastline (*HS-ESS2-5*). Figure 5 shows oblique aerial photos of Pacifica, California, but the aerial photos in Google Earth are precise enough that students can measure the amount of coastline erosion as a classroom experiment. Such sudden land failures are excellent for the preservation of fossils because they immediately cover and preserve remains of entire organisms, rather than allowing them to be torn apart by scavengers. For example, famous dinosaur fossils[1] of two dinosaurs "fighting" or mother dinosaurs sitting on their nests of eggs are only possible because some depositional event covered them quickly. Even in places like the middle of the open ocean where there are no dramatic events like landslides, there are seasonal, decadal, and longer term variations producing changes in deposition rates that get recorded by the layers of rock. Processes that appear to occur at a ***stable,*** constant rate may actually be ***changing*** constantly when viewed at the right ***timescale***.

For students to be able to explain how this natural process becomes a natural hazard that affects human activities (*HS-ESS3-1*), they can engage in an engineering design problem to reduce the impacts (*HS-ESS3-4*). Students can explore analogs to those using stream tables as well as read about actual measures that are taken in places like Pacifica (Figure 5) and locations all along the California coastline. The engineering solutions either involve 1) increasing the strength of the hillside (by adding plants with root systems to stabilize the hillside, building support walls, or covering the cliff with concrete); or 2) reducing the driving forces (by placing rocks or sea walls to reduce the speed of waves when they hit the natural hillslope and through better drainage). Students should compare and evaluate solutions based on prioritized criteria

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[1] American Museum of Natural History, Fighting dinos exhibition notes, http://www.amnh.org/exhibitions/past-exhibitions/fighting-dinos.

and tradeoffs that account for a range of constraints, including cost, safety, reliability, and aesthetics. (*HS-ETS1-3*). Sometimes, technologies that reduce the impact of erosion on people can have adverse impacts on ecosystems. Students should consider and evaluate the environmental impacts of their design and refine it to reduce those impacts (HS-ESS3-4).

Figure 5. Changes over time in coastal bluffs in Pacifica California. They go for many years without much erosion and then erode more than a dozen feet in a single year. The yellow triangle shows the migration of the cliff top from year to year at a single position. By 2010, the cliff is located directly beside the apartment building. (California Coastal Records Project 2013)

With a better understanding of how Earth's geosphere changes at the surface, students are better equipped to interpret the fossil record. Because fossils are recorded in rock layers piled one on top of another, geologists look back in time as they dig deeper down. Sequences of layers reveal a sequence of time like pages in a book (as students explained in middle school with *MS-ESS1-4*). In this way, scientists can examine fossils and look at how organisms change over time.

Evidence for Evolution

The specific evidence for evolution comes from comparing the ***structure*** of organisms over time (from fossils) and between different species (both in fossils and modern day organisms). Two ***patterns*** in structures are strong indicators that species have evolved over time: homologous (resulting from a common ancestor) and analogous (have the same function). Looking at structures that are homologous (which results in similarity from two species that evolved from a common ancestor) and analogous (which results in similarity because the two species use the structure for the same function) also provides evidence of how over time parts of organisms have changed in both ***structure and function***. Because of the changes in organisms over time, some of these organs/structures no longer have a use in the modern day organism but there is evidence that the structure was once functional in the ancestor; these traits are now called vestigial organs/structures. Some classical examples of vestigial organs/structures are the remnants of hip bones in snakes and whales and the remainder of the tip of a tail bone (the coccyx) in humans. Students can look at skeletons of vertebrates with representatives from the major classes and identify ***patterns*** in both the placement and usage of forelimbs or hind limbs so that they can make connections to homologous and analogous structures. For example, they can look at the forelimbs of vertebrates which are homologous and even though they have the same ***structure*** not all have the same ***function*** (a dog and a horse both use their forelimb to walk (so they are analogous and homologous) but a dog foreleg, human arm and seal forelimb do not function the same so therefore are not analogous but are homologous). Also, analogous structures or features are sometimes not homologous for example students can observe the streamlined body of a penguin or a dolphin which both swim in the water and recognize that this feature is the result of convergent evolution and not common ancestry. In other words, it is helpful to have a streamlined body if you swim regardless of whether you are a bird or a mammal but not all birds and mammals have streamlined bodies. For this reason, some texts are using the term convergent trait rather than analogous. ***Patterns*** such as those observed in vertebrates can also be found in other organisms and teachers are encouraged to show other types of examples. Looking at plants might be one way to connect the observations from above. Observing modified leaves in a Venus fly trap or a pitcher plant demonstrates a homologous trait used to help the plant catch insects (these plants share a common ancestor) (HS-LS4-1). Looking at thorns and spines in plants are examples of convergent traits in plants used to protect the plant from herbivores.

To elucidate more evidence supporting evolution students can identify commonalities found in all living organisms. Students can design Venn diagrams, charts, or tables that show the overlap of these commonalities. They should be able to **communicate** this **evidence** both graphically and in writing using what they have learned in their past Life Science courses. These lists/diagrams should include DNA, RNA, ribosomes, ATP, macromolecules, ability to use energy, cell division etc. Their evidence should be the result of what they have learned in middle school and will be confirmed by what they continue to learn in this course.

As students recognize the lines of **evidence** supporting evolution they can now connect it to what Charles Darwin postulated in the middle 1800's. In the early to middle 1800's Darwin spent his adult life collecting and analyzing data. Interestingly, he was a naturalist on a boat expedition (HMS Beagle) that was sailing the world to map landforms and geologists on this same expedition (and others like it) would contribute data to our understanding of plate tectonics (see below). The result of Darwin's work is the foundation for the study of evolution. Many of his observations were also noticed by others for example, Alfred Wallace. What Darwin noticed was that organisms have the potential to reproduce many more offspring (for example a spider will lay 100's of eggs) than will survive. He noticed that despite the potential for large numbers in a population most populations remain fairly constant in numbers over generations. Darwin concluded that there had to be competition for resources and that is part of what helped keep population numbers stable over time. He also noticed that while fossils and modern living organisms differed from place to place, the fossils and modern living organisms in the same area were very similar to one another. For example, Darwin saw that several bird species in the Galápagos Islands looked very similar to one species found on the continent of nearby South America. He also knew that offspring looked like their parents but there was slight variation. He understood how animal breeders manipulate the traits in the population of their livestock or dogs by selectively breeding to reinforce or eliminate certain traits. It was all these observations that helped him frame the Theory of Natural Selection which states that there is competition over resources and the individuals in a population that can get the resources they need are able to reproduce and pass on their traits to their offspring and therefore are the more fit individuals of the population. If no individuals reproduce than that population ceases to exist and any unique alleles within that population are also eliminated.

Darwin originally summarized his findings into four postulates Table 2. It is important to give examples in all living ***systems*** (*in the table there are examples in plants, fungi, animals, prokaryotes etc.*). Students can collect data on individuals in a population and look for the ***patterns*** that are present. This can be done by having students measure individual skulls or beaks or shells that have been gathered to represent a specific species. There are datasets available that extend from generation to generation and students can use this to mathematically **analyze** and **construct an explanation** of the changes they are noting. Extensions of this data collection can include some generations that survived after a change in their environment, for example, what happens to the size of beaks after a drought or what happens to the size of shells after the introduction of a non-native species that eats the shelled organism.

Table 2: Darwin's Four Postulates

Darwin's Postulate	Example
Individual organisms in a population vary in the traits they possess.	The size of their heads or the length of a tap root.
Some of this variation is passed from parent to offspring.	Flower color in peas, length of wings in an insect.
Individuals within a population have the ability to produce a lot of offspring.	Number of seeds produced by a flowering tree, the ability of some bacteria to reproduce every 20 minutes, the number of spores released by a mushroom.

The individuals that leave living offspring are the individuals that have certain traits that help them survive and reproduce, thus they are the individuals that are selected naturally by the environment.	Birds that can break open nuts that have grown harder in a drought year can acquire enough food and survive the environmental change (drought) so they then go onto reproduce.

Speciation events are the results of populations within a species changing to the point that they can no longer mate with other individuals from the same species. Isolation of the population is what allows for the changes in traits to occur and the isolation of land masses as discussed above were important to produce the biodiversity seen on our planet today.

Evolution itself is not a linear process but rather a branching process in which a historical species had members of populations change and branch off (this is described more fully in Figure 6) into two new descendant species from a common ancestor. These descendent species underwent more changes and could have possibly branched again and again over geological time. Evidence supporting evolution derives from this idea of common ancestry. The tree of life shown in Figure 6 gives a summary of our understanding of how life evolved from single cell organisms to the modern day species we see on earth today. The tips of the tree represent these modern day species. This also might be a good time to remind students of the conventions of scientific names. These are written italicized and are used throughout the scientific community as a common language (no matter what native language of the scientist is spoken).

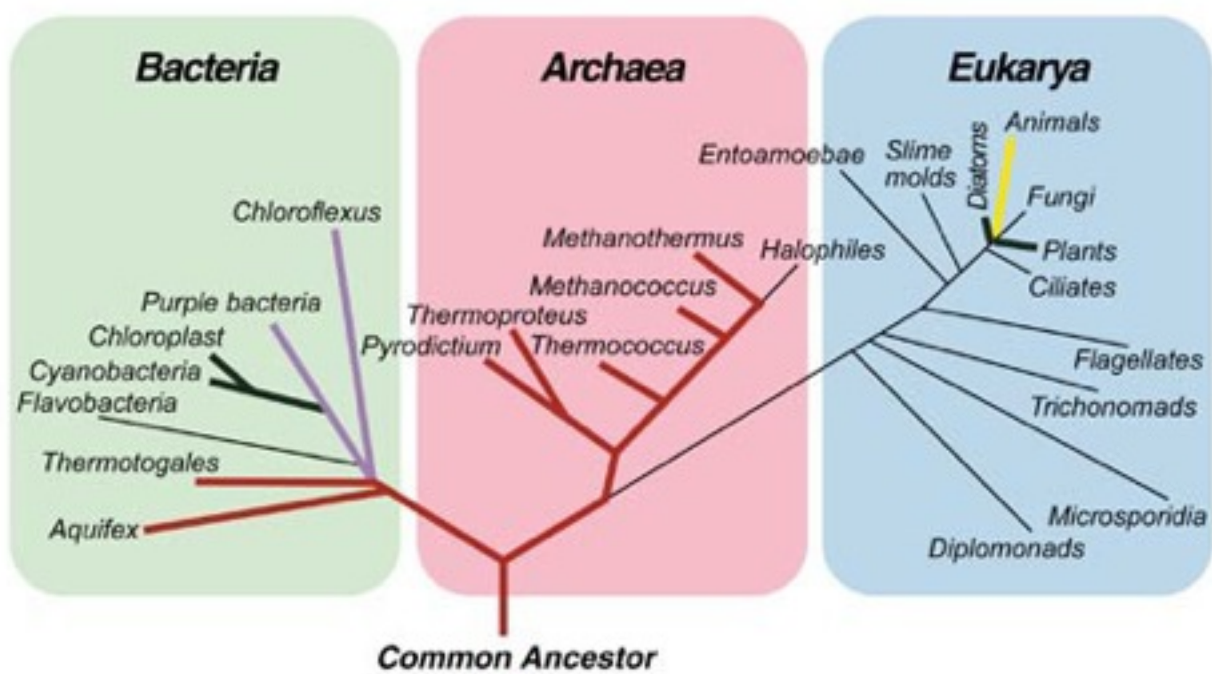

Figure 6. A tree diagram showing the relationship of all living species on Earth. All branches relate to the common ancestor at the base, which diverged into three main braches: bacteria, microbes known as archea, and a group of multicellular organisms called eukarya that includes humans. Longer branches indicate a more significant change in DNA from its common ancestor. (Farmer 2000)

Ending this instructional segment by studying how modern day humans evolved can show students how all of the above types of evidence have helped determine how hominids evolved. The great transitions that happened between ancestral chimps and ancestral humans leading to modern day humans are bipedalism, use of tools, and a bigger brain. Using genome studies on DNA sequences as well as fossil evidence it is estimated that the common ancestor for humans and great apes lived over 7 million years ago. Since that time each branch underwent further evolution and today we have modern day humans (*Homo sapiens*) off the human evolution branch and chimpanzees (*Pan troglodytes)* and bonobos (*Pan paniscus*) off the chimp evolution branch. Looking further at the human evolution path 1000's of fossils have helped us make the connections to how humans evolved. The first major transition was moving from walking on all fours (quadrupedal) to walking on our two hind legs (bipedal). Fossil evidence indicates that over 4 million years ago an early hominid *Ardepithecus* walked on hind legs but still had an extended big toe and also was a climber. Next, the *Australopithecus* were shown to also be bipedal but with all five toes face forward. The next transition in human evolution was the use of tools and though chimpanzees also use tools, humans began to use tools in different ways (for example to cut and remove meat from bones of prey). Tool use first appears in the fossil record of humans with the more recent *Australopithecus* species and continues to evolve in complexity with the *Homo* species. The last transition (growth of the brain cavity) in the skulls of early hominids is shown to have begun with early *Homo* species with the ratio of the brain cavity to the body size of the humans increasing over time. Students can look at this time line and extract the evidence through looking at ***patterns*** to support human evolution using many of the interactive tools available at such sites as Howard Hughes Medical Institute (HHMI).[2] An extension of this lesson can be done by looking at human population studies on the inheritance patterns of lactose intolerance or sickle cell anemia or any other genetic syndrome that originated in certain human populations (races) and how these syndromes have shaped human culture. There are EEI units that would be excellent choices for curriculum for this instructional segment, which includes lesson plans for isolation of species and differential survival.

Isolated Species as Evidence of Plate Tectonics

When scientists around the world collected fossils that showed evidence of systematic progressions of species within the biosphere, they also discovered something surprising about changes in the geosphere over time. At the middle grade level, students explained how spatial patterns in the fossil record provide evidence that plates are moving (*MS-ESS2-3*). They can now revisit this understanding in light of evolution and populations and better understand why the fossil evidence for plate

[2] HHMI-Howard Hughes Medical Institute http://www.hhmi.org this website is free, kept up to date and has excellent resources for evolution as well as other science topics designed by experts in the field for use by teachers and students.

tectonics is so compelling. Take, for example, fossils of a specific species of fossil fern, *Glossopteris* that grew in narrow geographic regions on South America, Africa, India, and Australia. It is virtually impossible that the same species would evolve independently in different places at the same time. If it had been transferred to all these separate continents by some hypothetical wind current, then these new populations would have existed in isolation and would have been free to change and evolve providing a foundation for many speciation events (*HS-LS4-5*). While it did develop and change over the 40 million years or so that it dominated the vegetation of the southern continents, the changes in one part tracked to the changes in others. This could only happen if they were part of a single, interconnected population. And that could only happen if the continents were once together and have since moved. Students learn about the mechanisms that drive plate motion in instructional segment 2 of the chemistry course.

The exact timing of these events can be tracked because of advances in radiometric dating techniques. Students learn about the details of these techniques in instructional segment 4 of the physics course and can address the basic principles here (*HS-PS1-8*). By dating the age of each rock layer, scientists can determine when the fossils contained within them were alive. The oldest seafloor in the Atlantic Ocean is 200 million years old, which indicates that the Americas began to be pulled away from Europe and Africa about 50 million years after the last *Glossopteris* went extinct. Students can evaluate the **evidence** for other well-known species that spanned across continents around the same time (i.e., *Mesosaurus*, *Cynognathus*, *Lystrosaurus*, etc.) (*HS-ESS1-5*). None of them existed as the same species on two different continents after the age data shows that the continents broke apart. In fact, many of them went extinct around the same time at the end of the Permian period, which is an interesting mass-extinction story in and of itself that could be discussed in instructional segment 6.