Table 7.2 also reveals that the single largest reservoir of carbon is not in the air or water, but in rocks. How does it get there? After students learn about the chemical composition of life (LS1.C), they are able to explain why carbon is so important for so many of life's **systems [CCC-4]** (HS-LS1-6). Living organisms are therefore a large reservoir of carbon. When those organisms die, the carbon stored in their bodies can accumulate in layers that are buried over geologic time (discussed more in IS3). Heat and pressure, caused by burial, speed up chemical reactions that slowly reorganize the carbon and other elements into new, easily combustible molecules that we call fossil fuels, including oil (petroleum) and natural gas (including methane). To ensure that students see the connection between past life and oil formation, students can draw the stages of oil formation to summarize an article (The National Energy Education Development Project 2012, 13, 57). Extracting oil and gas from deep within the Earth and burning it harnesses energy that ancient plants and animals collected millions of years ago and that has been stored as chemical potential energy in materials trapped underground for millions of years. These materials are incredibly valuable for generating electricity, fueling our vehicles, and generally enabling modern society to thrive. Unfortunately, fossil fuels form very slowly and only under specific conditions and therefore are considered non-renewable because we consume them more quickly than they form. Access to fossil fuels occurs in specific places on Earth and California has large deposits, though extracting them can often leak or spill toxic chemicals into the air, land, and water (EP&C II, IV). While they are very convenient (EP&C V), they also disrupt the natural carbon cycle (EP&C III). Students weigh the cost and benefits of these fuels in the Physics of the Universe course.

IS3 Living Earth Instructional Segment 3: Evidence of Common Ancestry and Diversity

Evolutionary scientist Theodor Dobzhansky made the now famous quote, "Nothing in biology makes sense except in the light of evolution." Therefore, one option is for evolution to occur early in this course and much of the rest of the course explains the detailed mechanisms that **cause [CCC-2]** the **patterns [CCC-1]** introduced in this instructional segment.

LIVING EARTH INSTRUCTIONAL SEGMENT 3: EVIDENCE OF COMMON ANCESTRY AND DIVERSITY

Guiding Questions

- How do layers of rock form and how do they contain fossils?
- Why do we see similar fossils across the world from each other but living organisms that are very different?
- What evidence shows that different species are related?
- How did modern day humans evolve?

Performance Expectations

Students who demonstrate understanding can do the following:

HS-LS4-1. Communicate scientific information that common ancestry and biological evolution are supported by multiple lines of empirical evidence. [Clarification Statement: Emphasis is on a conceptual understanding of the role each line of evidence has relating to common ancestry and biological evolution. Examples of evidence could include similarities in DNA sequences, anatomical structures, and order of appearance of structures in embryological development.]

HS-LS4-2. Construct an explanation based on evidence that the process of evolution primarily results from four factors: (1) the potential for a species to increase in number, (2) the heritable genetic variation of individuals in a species due to mutation and sexual reproduction, (3) competition for limited resources, and (4) the proliferation of those organisms that are better able to survive and reproduce in the environment. [Clarification Statement: Emphasis is on using evidence to explain the influence each of the four factors has on number of organisms, behaviors, morphology, or physiology in terms of ability to compete for limited resources and subsequent survival of individuals and adaptation of species. Examples of evidence could include mathematical models such as simple distribution graphs and proportional reasoning.] *[Assessment Boundary: Assessment does not include other mechanisms of evolution, such as genetic drift, gene flow through migration, and co-evolution.]*

HS-LS4-4. Construct an explanation based on evidence for how natural selection leads to adaptation of populations. [Clarification Statement: Emphasis is on using data to provide evidence for how specific biotic and abiotic differences in ecosystems (such as ranges of seasonal temperature, long-term climate change, acidity, light, geographic barriers, or evolution of other organisms) contribute to a change in gene frequency over time, leading to adaptation of populations.].

HS-LS4-5. Evaluate the evidence supporting claims that changes in environmental conditions may result in: (1) increases in the number of individuals of some species, (2) the emergence of new species over time, and (3) the extinction of other species. [Clarification Statement: Emphasis is on determining cause and effect relationships for how changes to the environment such as deforestation, fishing, application of fertilizers, drought, flood, and the rate of change of the environment affect distribution or disappearance of traits in species.]

HS-ESS1-5. Evaluate evidence of the past and current movements of continental and oceanic crust and the theory of plate tectonics to explain the ages of crustal rocks. [Clarification Statement: Emphasis is on the ability of plate tectonics to explain the ages of crustal rocks.

LIVING EARTH INSTRUCTIONAL SEGMENT 3: EVIDENCE OF COMMON ANCESTRY AND DIVERSITY

Examples include evidence of the ages oceanic crust increasing with distance from mid-ocean ridges (a result of plate spreading) and the ages of North American continental crust increasing with distance away from a central ancient core (a result of past plate interactions).] (Introduced, but assessed in High School Chemistry in the Earth System course)

HS-ESS2-5. Plan and conduct an investigation of the properties of water and its effects on Earth materials and surface processes. [Clarification Statement: Emphasis is on mechanical and chemical investigations with water and a variety of solid materials to provide the evidence for connections between the hydrologic cycle and system interactions commonly known as the rock cycle. Examples of mechanical investigations include stream transportation and deposition using a stream table, erosion using variations in soil moisture content, or frost wedging by the expansion of water as it freezes. Examples of chemical investigations include chemical weathering and recrystallization (by testing the solubility of different materials) or melt generation (by examining how water lowers the melting temperature of most solids).]

HS-ESS3-1. Construct an explanation based on evidence for how the availability of natural resources, occurrence of natural hazards, and changes in climate have influenced human activity. [Clarification Statement: Examples of key natural resources include access to fresh water (such as rivers, lakes, and groundwater), regions of fertile soils such as river deltas, and high concentrations of minerals and fossil fuels. Examples of natural hazards can be from interior processes (such as volcanic eruptions and earthquakes), surface processes (such as tsunamis, mass wasting, and soil erosion), and severe weather (such as hurricanes, floods, and droughts). Examples of the results of changes in climate that can affect populations or drive mass migrations include changes to sea level, regional patterns of temperature and precipitation, and the types of crops and livestock that can be raised.]

HS-ESS3-4. Evaluate or refine a technological solution that reduces impacts of human activities on natural systems.* [Clarification Statement: Examples of data on the impacts of human activities could include the quantities and types of pollutants released, changes to biomass and species diversity, or areal changes in land surface use (such as for urban development, agriculture and livestock, or surface mining). Examples for limiting future impacts could range from local efforts (such as reducing, reusing, and recycling resources) to large-scale geoengineering design solutions (such as altering global temperatures by making large changes to the atmosphere or ocean).]

HS-ETS1-3. Evaluate a solution to a complex real-world problem based on prioritized criteria and trade-offs that account for a range of constraints, including cost, safety, reliability, and aesthetics, as well as possible social, cultural, and environmental impacts.

LIVING EARTH INSTRUCTIONAL SEGMENT 3: EVIDENCE OF COMMON ANCESTRY AND DIVERSITY

The bundle of performance expectations above focuses on the following elements from the NRC document *A Framework for K–12 Science Education*:

Highlighted Science and Engineering Practices	Highlighted Disciplinary Core Ideas	Highlighted Crosscutting Concepts
[SEP-3] Planning and Carrying Out Investigations [SEP-6] Constructing Explanations (for science) and Designing Solutions (for engineering) [SEP-7] Engaging in Argument from Evidence [SEP-8] Obtaining, Evaluating, and Communicating Information	LS4.A: Evidence of Common Ancestry and Diversity LS4.B: Natural Selection LS4.C: Adaptation ESS2.B: Plate Tectonics and Large-Scale System Interactions ESS2.C: The Roles of Water in Earth's Surface Processes ESS3.A: Natural Resources ESS3.B: Natural Hazards ESS3.C: Human Impacts on Earth Systems PS1.C: Nuclear Processes ETS1.B: Developing Possible Solutions	[CCC-1] Patterns [CCC-2] Cause and Effect: Mechanism and Explanation [CCC-6] Structure and Function [CCC-7] Stability and Change

Highlighted California Environmental Principles and Concepts:

Principle I The continuation and health of individual human lives and of human communities and societies depend on the health of the natural systems that provide essential goods and ecosystem services.

Principle II The long-term functioning and health of terrestrial, freshwater, coastal, and marine ecosystems are influenced by their relationships with human societies.

Principle III Natural systems proceed through cycles that humans depend upon, benefit from and can alter.

Principle IV The exchange of matter between natural systems and human societies affects the long-term functioning of both.

Principle V Decisions affecting resources and natural systems are based on a wide range of considerations and decision-making processes.

CA CCSS Math Connections: MP.2; MP.4

CA CCSS for ELA/Literacy Connections: SL.11–12.4; RST.11–12.1, 8; WHST.9–12.2.a–e, 7, 9

CA ELD Connections: ELD.PI.11–12.1, 5, 6a–b, 9, 10, 11a

To understand the evidence for how evolution has shaped life over time, students need to think about processes in both the biosphere and geosphere. Students need to understand more about fossils so that they will be able to interpret fossil evidence of evolution.

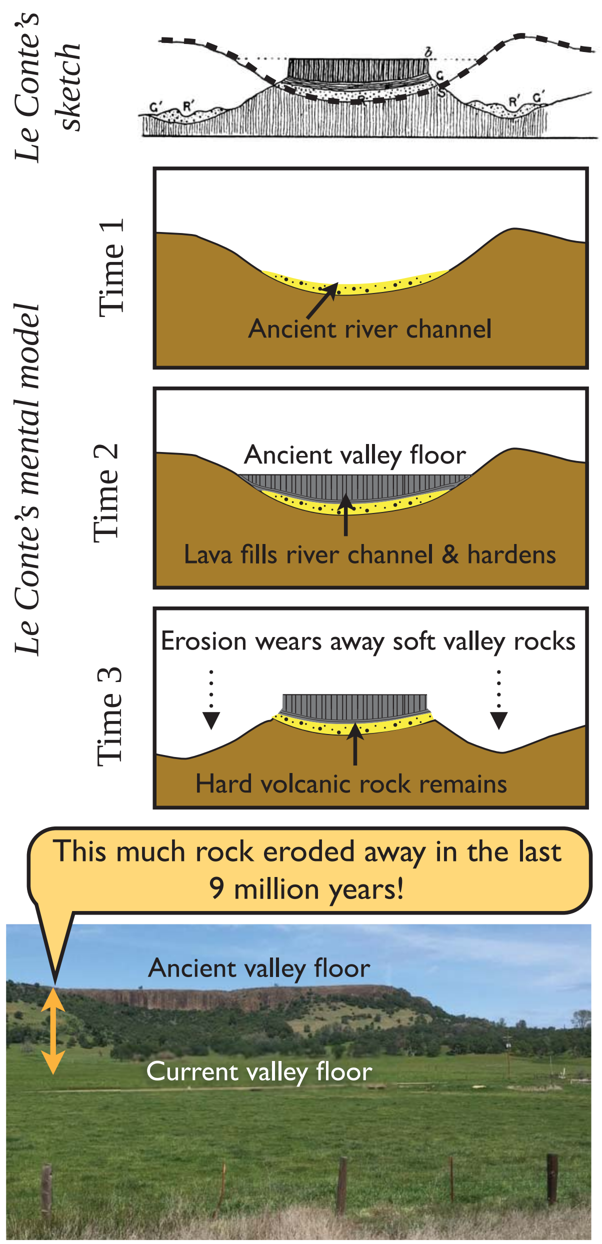
Fossils as a Part of the Geosphere

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, indications of organisms that no longer exist, and the absence of fossils of modern species in very old sediments. Finding of fossils in layers of deep valleys or mountaintops leads to questions about how fossils form and are preserved for millions of years. This instructional segment begins with students developing models of the ways that the rock record records past events.

Just as evolution changes populations, a variety of processes shape the physical landscape on Earth. What evidence do these processes leave behind? In the 1850s, 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 7.6). These mental models required testing, so Earth scientists conducted 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 exploring erosional processes; it can be used for hands-on **investigation [SEP-3]** and as a physical, conceptual **model [SEP-2]** that can predict possible outcomes. Teachers can use stream tables to help meet some of the performance expectations of the CA NGSS, including having students **ask questions [SEP-1]** and plan their own **investigations [SEP-3]** (HS-ESS2-5). Students can recreate California landforms such as the Sierra Nevada and Central Valley in a stream table and watch as sediment slowly accumulates in deep layers in the Valley. These sediments are rich in nutrients, so students can construct an **explanation [SEP-6]** of how erosion has fueled the California agricultural economy (HS-ESS3-1). Or students can be given a range of materials to see if they can produce the mesa-like features of Table Mountain. With this hands-on experience, students should be able to **explain [SEP-6]** why there are layers of rock and how those layers are deposited and accumulate over time.

Each layer that is deposited preserves a record of what the physical environment was like at the time. Even after the climate of the region has changed and millions of years have passed, we get a glimpse of what the ecosystem was like at this spot because the ancient river channel in Time 1 of figure 7.6 may preserve fossils of organisms that once drank from or swam in it. Like a little time capsule, the solid cap of lava protected these fossils from erosion.

Figure 7.6. Tuolumne Table Mountain Near Jamestown



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. *Source*: LeConte 1892; photo by Kirk Brown; illustration by M. d'Alessio

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 [CCC-6]**. 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 (the structure) 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 (the function).

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 [CCC-7]** for decades. Students can **investigate [SEP-3]** actual coastal erosion rates 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 7.7 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 can preserve fossils because they immediately cover and protect remains of entire organisms, rather than allowing them to be torn apart by scavengers. For example, famous dinosaur fossils of two dinosaurs fighting (for example, see American Museum of Natural History, Fighting Dinos exhibition notes, http://www.cde.ca.gov/ci/sc/cf/ch7.asp#link7) or mother dinosaurs sitting on 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 are recorded by the layers of rock. Processes that appear to occur at a **stable [CCC-7]**, constant rate may actually be periodically **changing [CCC-7]** when viewed at the right **timescale [CCC-3]**.

Figure 7.7. Coastal Bluff Changes Over Time

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 arrow 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. *Source*: California Coastal Records Project 2017. Copyright © 2002–2015 Kenneth & Gabrielle Adelman, California Coastal Records Project, www.californiacoastline.org

Engineering Connection: Coastline Erosion

When coastline erosion affects humans, it becomes a natural hazard. Students can explain some of the common impacts of erosion in California (HS-ESS3-1). They can also engage in an engineering design problem to reduce these impacts (HS-ESS3-4). Students can design and build erosion control measures using stream tables as well as read about actual measures that are taken in places like Pacifica 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 and tradeoffs that account for a range of constraints, including cost, safety, reliability, and aesthetics. (HS-ETS1-3; EP&C V). Sometimes, technologies that reduce the impact of erosion on people can have adverse impacts on ecosystems (EP&C III). Students should consider and evaluate the environmental impacts of their design and refine it to reduce those impacts (HS-ESS3-4). Students can **obtain information [SEP-8]** about different California coastal communities and **explain [SEP-6]** why they have chosen to develop or not develop their coastlines (HS-ESS3-1).

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. Sequences of layers reveal a sequence of time like pages in a book (as students discovered in the middle grades with MS-ESS1-4). In this way, scientists can examine fossils and look at how organisms change over time.

Evidence for Evolution

Students can begin by obtaining examples of evidence supporting evolution that they learned about in the middle grades: patterns in fossils (MS-LS4-1), anatomical similarities (MS-LS4-2), and embryological similarities (MS-LS4-3). In each case, they can find more detailed evidence. The goal for high school is to have enough conceptual understanding to communicate these lines of evidence effectively. To help students meet HS-LS4-1, curriculum can focus on the SEP of **communicating information [SEP-8]**, which includes writing, oral presentations, and especially visual displays (diagrams, charts, annotated photos, etc.). Students can compare multiple depictions and **evaluate [SEP-8]** which ones illustrate the common ancestry most effectively. What are the elements of an effective communications product?

The fossil record provides much of the evidence to support evolution because it includes transitional life forms as well as organisms that no longer exist. In addition, many life forms alive today (including humans) are not found very far back in the fossil record, implying that they are newer and therefore evolved from other species. Effective communication of this evidence shows progressions of species and identifies where species appear or disappear in the fossil record.

Looking at structures that are *homologous* (features that originate from the same structure within a common ancestor) and *analogous* (features that arise because two species use a similar structure to accomplish the same function) also provides evidence of how, over time, parts of organisms have changed in both **structure and function [CCC-6]**. Effective communication of this evidence shows comparisons of structures side-by-side and highlights the similarities.

Students can look at a variety of skeletons of vertebrates from the major classes and identify **patterns [CCC-1]**, noting that all these animals share the same basic skeletal structure but with only small variations such as the placement and usage of forelimbs or hind limbs. For example, a dog foreleg, human arm, and seal forelimb are all forelimbs of mammals (homologous) but serve very different functions (so they are not analogous). On the other hand, a dog and a horse have homologous forelimbs that they both use to walk. Students should be able to **construct arguments [SEP-7]** that two organisms share a common ancestor using homologous structures as evidence. Similarly, they should use the observation that homologous structures are used in diverse ways as evidence that natural selection accentuates certain favorable traits over generations, leading to a gradual evolution.

Are all structures with similar functions caused by genetic similarity and common ancestry? In high school, students develop a nuanced understanding of **cause and effect [CCC-2]** when they evaluate evidence to determine which cause (or causes) most likely explains a given observation. For example, penguins and dolphins both have streamlined bodies that allow them to swim efficiently. This feature is not the result of common ancestry, but rather an example of convergent evolution. Both these organisms independently evolved their body shapes from separate ancestors. Students can identify examples from the plant kingdom as well. The modified leaves in a Venus flytrap and pitcher plant demonstrate a homologous trait used to help the plants catch insects (all of these plants share a common ancestor). Thorns and spines, however, are a common analogous trait that protects plants from herbivores; this trait evolved in a wide range of plants through convergent evolution. As students **develop arguments [SEP-7]** that two organisms share common ancestry, they need to consider whether to present evidence of homology, analogy, both, or neither.

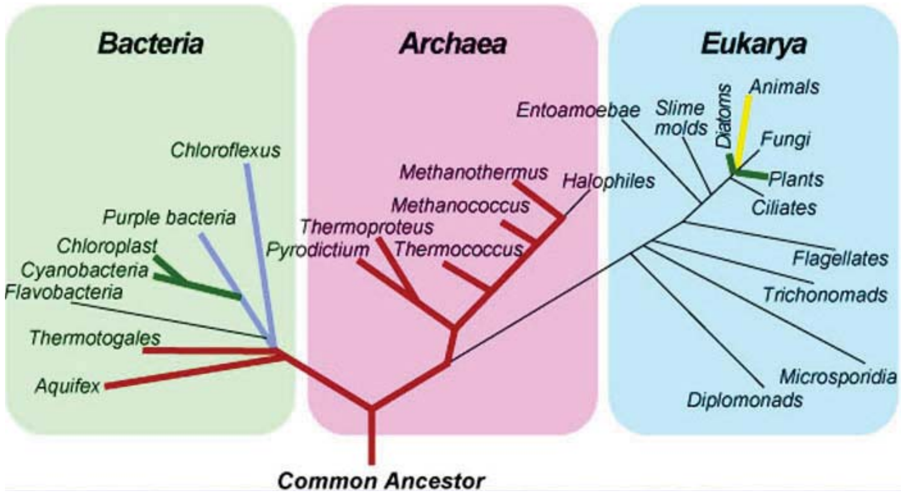
Because of the changes in organisms over time, some organs/structures no longer have a use in the modern day organism, although there is evidence that the structure was once functional in the ancestor; these traits are now called vestigial organs/structures. Some classic examples of *vestigial organs/structures* are the remnants of hipbones in snakes and whales and the remainder of the tip of a tailbone (the coccyx) in humans.

Evolution itself is not a linear process, but rather a branching process in which the members of populations of an ancient species change and branch into two new descendant species from a common ancestor (see IS6). These descendent species underwent more changes and could have possibly branched again and again over geological time. Visual depictions of this tree of life (figure 7.8) summarize our understanding of how life evolved from single-cell organisms to the modern species we see on earth today. The tips of the tree represent these modern species. These trees were developed using studies of fossils and have been refined using investigations of the similarities and differences in DNA. What makes these diagrams effective at communicating evolutionary history? How can they be improved?

Students should be able to **communicate [SEP-8]** evidence both graphically and in writing. Students can design Venn diagrams or tables to communicate commonalities and differences.

They will have to revisit these comparisons later in the course as they add information about the common structure of DNA, cell structures, the process of cell division, etc.

Figure 7.8. Tree of Life



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 branches: bacteria, microbes known as Archaea, and a group of multicellular organisms called Eukarya, which includes humans. Longer branches indicate a more significant change in DNA from its common ancestor. *Source*: Farmer 2000

Living Earth Snapshot 7.2: Simulating Evolution of Antibiotic-Resistant Bacteria

Everyday phenomenon: When you get a prescription antibiotic from the pharmacy, the symptoms go away in a few days but the instructions always say to keep taking the drug for as long as two weeks.

Mr. K asked students if they had ever had an ear infection and had to take antibiotics. Did they have a nasty tasting liquid or a huge pill to swallow? But did they get better? How long did it take? He then asked them if they remember how long they took the medicine. He passed around an empty antibiotic bottle (with patient information removed) and projected a picture of the label on the screen so that everyone could see how long the instructions say to take the drug. Could they just stop taking the antibiotic when they start feeling better?

Investigative phenomenon: Bacteria can become resistant to antibacterial drugs.

Evolution appears to be slow because **changes [CCC-7]** happen in populations over many, many generations. Bacteria reproduce every few hours, so humans can actually observe their evolution. Mr. K's class simulated the effects of antibiotics on bacteria populations using colored index cards or foam packing peanuts (NSTA http://www.cde.ca.gov/ci/sc/cf/ch7.asp#link8). Each index card represented an individual bacteria organism; most cards were white, but two red cards represented individuals of the same species that were somehow resistant to the antibiotic. During each round, an antibiotic was applied that killed three out of four of the white cards but none of the resistant red cards. After each round, the bacteria reproduced, so students collected another card of the same color. Students graphed the number of bacteria and identified the **trend [CCC-1]** that the population had evolved to become resistant to antibiotics.

Mr. K asked students to formulate the rules of the index card game as a **computational algorithm [SEP-5]**. Students then wrote their own computer code and used it to predict what happened to the population of bacteria when a person with an infection stopped taking antibiotics before the end of the prescription. They culminated by constructing an **explanation [SEP-6]** about how the use of antibacterial agents can cause bacteria to evolve into superbugs (HS-LS4-4). They watched a video to **obtain information [SEP-8]** about how resistant bacteria are impacting behaviors and health at local hospitals. Mr. K then pretended to be one student's father who wanted to throw out his antibiotic when his symptoms went away but before the prescription ended. He asked the student to **convince him using evidence [SEP-7]** that he should keep taking the medication.

As students recognize the lines of **evidence [SEP-7]** supporting evolution they can connect it to what Charles Darwin postulated in the middle 1800s. 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. What Darwin noticed was that organisms have the potential to reproduce many more offspring (for example, a spider will lay hundreds 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. All these observations 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, then that population ceases to exist and any unique alleles within that population are also eliminated. Darwin originally summarized his findings into four postulates (table 7.3).

Table 7.3. 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 taproot
Some of this variation is passed from parent to offspring.	Seeds from plants with purple flowers grow into new plants with purple flowers; insects with long wings produce offspring with long wings.
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.

DARWIN'S POSTULATE	EXAMPLE
The individuals that leave living offspring are the individuals with 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 grew harder in a drought year could acquire enough food and survive the environmental change (drought) so they then could go on to reproduce.

Students should observe examples of evolution in all living systems (e.g., plants, fungi, animals, prokaryotes, etc.). Students can collect data on individuals in a population and look for the **patterns [CCC-1]** that are present. They can 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 (HHMI 2014; Grant and Grant 2014) and students can use these to mathematically **analyze [SEP-4]** the changes they observe. They can begin to **construct an explanation [SEP-6]** based on this evidence of the conditions that are necessary for evolution to occur (HS-LS4-2). Extensions of this data collection can include some generations that survived after a change in their environment (e.g., 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). From these observations, students notice that interactions in the environment influence evolution (EP&Cs I, II). The vignette in IS6 provides an example of this sort of data analysis.

Ideally, students should do an in-depth investigation of one species and obtain information about the evidence of its evolutionary history. One possible example is the history of modern humans (the vignette in IS6 illustrates another). Using genome studies on DNA sequences as well as fossil evidence, scientists estimate that the common ancestor for humans and great apes lived over seven million years ago. Since that time, each branch has undergone further evolution. Students can use interactive tools to examine fossils and arrange them on a timeline based on **patterns [CCC-1]** that document human evolution.[2] How exactly did these changes happen?

2. HHMI-Howard Hughes Medical Institute http://www.cde.ca.gov/ci/sc/cf/ch7.asp#link165. This Web site 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.

High School Three-Course Model Living Earth Snapshot 7.3: Human Evolution

Anchoring phenomenon: Several other species of hominin existed, but our species, *homo sapiens*, is the only one that survived to today.

Evolution is driven by natural selection favoring some new traits over others. But which new traits or selective pressures allowed our species, *Homo sapiens*, to thrive while several other early hominin species died off? Mrs. B recently saw the September 2014 issue of *Scientific American* http://www.cde.ca.gov/ci/sc/cf/ch7.asp#link9) that addresses that very question. Each article offers a different argument supported by different evidence. One article focuses on specific anatomical features (*structure and function, LS1.A*), several articles on group behavior (LS2.D) including mating for life, cooperative hunting, and the power of culture, one article on information processing (LS1.D), and one article emphasizes the role of ancient climate change on evolution (ESS2.E, ESS3.D).

Mrs. B assigned different students to read different articles in a classic jigsaw. Then she organized the students so that each group discussed a common article. Each student group created a collaborative presentation about its article that summarized the argument made in the paper. Students had to identify the claim, describe the evidence, and tie it all together with reasoning. The students needed to pay particular attention to fossil evidence (ESS1.C), which was described more in some articles than others. Then, the student groups were reorganized, with one expert on each article in each group. Each expert presented the collaborative presentation about the article to his or her small group. Then, the group laid out a large sheet of butcher paper and created a comprehensive concept map illustrating the possible explanations of how humans evolved and then connected those explanations to other key course ideas. For example, students knew that the pace of present-day climate change is much faster than a climate shift 160,000 years ago that one article mentioned may have been a selective pressure that favored larger brains. It is unlikely that humans or other species can adapt quickly enough to keep pace with modern changes happening on the scale of decades. Mrs. B emphasized the fact that today we do not have enough evidence to distinguish between these different possibilities, but one day somebody might discover key evidence that allows us to rule out some of the possibilities or provides direct evidence of a cause and effect relationship for others. Mrs. B added, “And the person who will make that discovery might be in this room right now.”

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. In the middle grades, 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, as a result, better understand why the fossil evidence for plate 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 location tracked 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 IS2 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 IS4 of the Physics of the Universe course and can address the basic principles here (HS-PS1-8). By determining 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 [SEP-7]** for other well-known species that spanned across continents around the same time (i.e., *Mesosaurus*, *Cynognathus*, *Lystrosaurus*, etc.) (HS-ESS1-5, though students are assessed on this performance expectation in the Chemistry in the Earth System course). None of them existed as the same species on two different continents after the continents broke apart, as demonstrated by the ages of the fossils. 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 IS6.