IS3

Integrated Grade Eight Instructional Segment 3: Evolution Explains Life's Unity and Diversity

IS3 focuses on Earth's extremely long geological history and the changes in Earth's web of life over billions of years. When Earth scientists observe Earth's current landforms, they are usually looking at the results of Earth processes that occurred over millions of years and involved thousands of square miles of area. These time and distance scales [CCC-3] are too slow and too large to reproduce in a lab. Imagine trying to do a reproducible experiment by selectively changing one variable at a time at those time and distance scales! Instead, investigations in Earth science often begin with carefully observing what the Earth looks like today, and then trying to reproduce similar features in small-scale laboratory experiments or computer simulations. Scientists can even apply these models of Earth processes to other planets like Mars to understand their history. On Earth, these tools have allowed scientists to recover a remarkable history of life on Earth.

INTEGRATED GRADE EIGHT INSTRUCTIONAL SEGMENT 3: EVOLUTION EXPLAINS LIFE'S UNITY AND DIVERSITY

Guiding Questions

- What can we infer about the history of Earth and life on Earth from the clues we can uncover in rock layers and the fossil record?
- What evidence supports Darwin's theory of biological evolution?
- How do evolution and natural selection explain life's unity and diversity?

Performance Expectations

Students who demonstrate understanding can do the following:

MS-LS3-1. Develop and use a model to describe why structural changes to genes (mutations) located on chromosomes may affect proteins and may result in harmful, beneficial, or neutral effects to the structure and function of the organism. [Clarification Statement: Emphasis is on conceptual understanding that changes in genetic material may result in making different proteins.] [*Assessment Boundary: Assessment does not include specific changes at the molecular level, mechanisms for protein synthesis, or specific types of mutations.*]

MS-LS4-1. Analyze and interpret data for patterns in the fossil record that document the existence, diversity, extinction, and change of life forms throughout the history of life on Earth under the assumption that natural laws operate today as in the past. [Clarification Statement: Emphasis is on finding patterns of changes in the level of complexity of anatomical structures in organisms and the chronological order of fossil appearance in the rock layers.] [*Assessment Boundary: Assessment does not include the names of individual species or geological eras in the fossil record.*]

MS-LS4-2. Apply scientific ideas to construct an explanation for the anatomical similarities and differences among modern organisms and between modern and fossil organisms to infer

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evolutionary relationships. [Clarification Statement: Emphasis is on explanations of the evolutionary relationships among organisms in terms of similarity or differences of the gross appearance of anatomical structures.]

MS-LS4-3. Analyze displays of pictorial data to compare patterns of similarities in the embryological development across multiple species to identify relationships not evident in the fully formed anatomy. [Clarification Statement: Emphasis is on inferring general patterns of relatedness among embryos of different organisms by comparing the macroscopic appearance of diagrams or pictures.] [*Assessment Boundary: Assessment of comparisons is limited to gross appearance of anatomical structures in embryological development.*]

MS-LS4-4. Construct an explanation based on evidence that describes how genetic variations of traits in a population increase some individuals' probability of surviving and reproducing in a specific environment. [Clarification Statement: Emphasis is on using simple probability statements and proportional reasoning to construct explanations.]

MS-LS4-5. Gather and synthesize information about the technologies that have changed the way humans influence the inheritance of desired traits in organisms. [Clarification Statement: Emphasis is on synthesizing information from reliable sources about the influence of humans on genetic outcomes in artificial selection (such as genetic modification, animal husbandry, gene therapy); and, on the impacts these technologies have on society as well as the technologies leading to these scientific discoveries.]

MS-LS4-6. Use mathematical representations to support explanations of how natural selection may lead to increases and decreases of specific traits in populations over time. [Clarification Statement: Emphasis is on using mathematical models, probability statements, and proportional reasoning to support explanations of trends in changes to populations.]

MS-ESS1-4. Construct a scientific explanation based on evidence from rock strata for how the geologic time scale is used to organize Earth's 4.6-billion-year-old history. [Clarification Statement: Emphasis is on how analyses of rock formations and the fossils they contain are used to establish relative ages of major events in Earth's history. Examples of Earth's major events could range from being very recent (such as the last Ice Age or the earliest fossils of *Homo sapiens*) to very old (such as the formation of Earth or the earliest evidence of life). Examples can include the formation of mountain chains and ocean basins, the evolution or extinction of particular living organisms, or significant volcanic eruptions.] [*Assessment Boundary: Assessment does not include recalling the names of specific periods or epochs and events within them.*]

**The performance expectations marked with an asterisk integrate traditional science content with engineering through a practice or Disciplinary Core Idea.*

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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-2] Developing and Using Models [SEP-4] Analyzing and Interpreting Data [SEP-5] Using Mathematics and Computational Thinking [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	LS3.A: Inheritance of Traits LS3.B: Variation of Traits LS4.A: Evidence of Common Ancestry and Diversity LS4.B: Natural Selection LS4.C: Adaptation ESS1.C: The History of Planet Earth	[CCC-1] Patterns [CCC-2] Cause and Effect [CCC-6] Structure and Function [CCC-7] Stability and Change

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

CA CCSS Math Connections: 6.RP.1, 6.SP.5, 6.EE.6, 7.RP.2, MP.4

CCSS for ELA/Literacy Connections: RST.6–8.1, 4, 7, 9, WHST.6–8.2, 8, 9, SL.8.1, 4, 5

CA ELD Connections: ELD.PI.6.1, 5, 6a–b, 9, 10, 11a

While the evidence that a giant impact triggered the extinction of the dinosaurs is strong, there are a few loose ends of evidence that do not quite fit the claim. As an anchoring phenomenon for this instructional segment, students will consider that very few dinosaur fossils are found in rock layers slightly below the layer formed at the time of the major asteroid impact (implying that they may have declined before the major impact). The most compelling piece of evidence supporting the impact claim is that the dinosaurs died out at the same time a layer formed during a giant impact. It's important to define what the "same time" means—layers of rock may take thousands or even hundreds of thousands of years to form. Scientists are not proposing that dinosaurs were instantly obliterated, but instead died out over time in the years following the impact. There should be evidence of this die off in the layers of rock. In one of the rock layers with the most prolific dinosaur fossils, the Hell Creek

Formation in Montana and surrounding states, dinosaur fossils are common below the impact layer, but become sparse several meters below the impact layer. In geologic layering, *below* means before. Did dinosaurs start going extinct before the impact? Or is the scarcity just due to the fact that dinosaur fossils are rare? At this point in grade eight, students are ready to contend with these challenges. According to the progressions in appendix 1 of this framework, middle grades students **analyze data [SEP-4]** with a more critical eye, considering limitations and possible errors in the data themselves. To resolve the dinosaur dilemma, students need a better understanding of how to read the layers of rock like geologists.

While geologists use phrases like "66 million years ago," nobody can realistically experience how long that time span really is and the kinds of changes that can happen over that **scale [CCC-3]** of time. Anchoring the unit in a perspective of geologic time helps students conceptualize such scales. One model that educators often use to help us get a handle on how Earth and life have changed over such an immense period of time is to condense all of Earth's history into an imaginary calendar year (table 5.11). Each day on that calendar represents about 12.5 million years. An alternative is to have students construct a scale model of geologic time using adding machine tape that is then hung in the classroom for the duration of the unit.

Table 5.11. One-Year Calendar Model of Geological Time Scale

EVENT	ACTUAL DATE	ONE YEAR CALENDAR
Earth Formed	4,550,000,000 years ago	January 1
First single-celled organisms	3,500,000,000 years ago	March 24
First multicellular organisms	1,200,000,000 years ago	September 22
First hard-shelled animals	540,000,000 years ago	November 18
First land plants	425,000,000 years ago	November 27
First reptiles	350,000,000 years ago	December 3
First mammals	225,000,000 years ago	December 13
Dinosaur extinction	66,000,000 years ago	December 26
First primates	60,000,000 years ago	December 27
First modern humans	200,000 years ago	11:33 p.m. on December 31

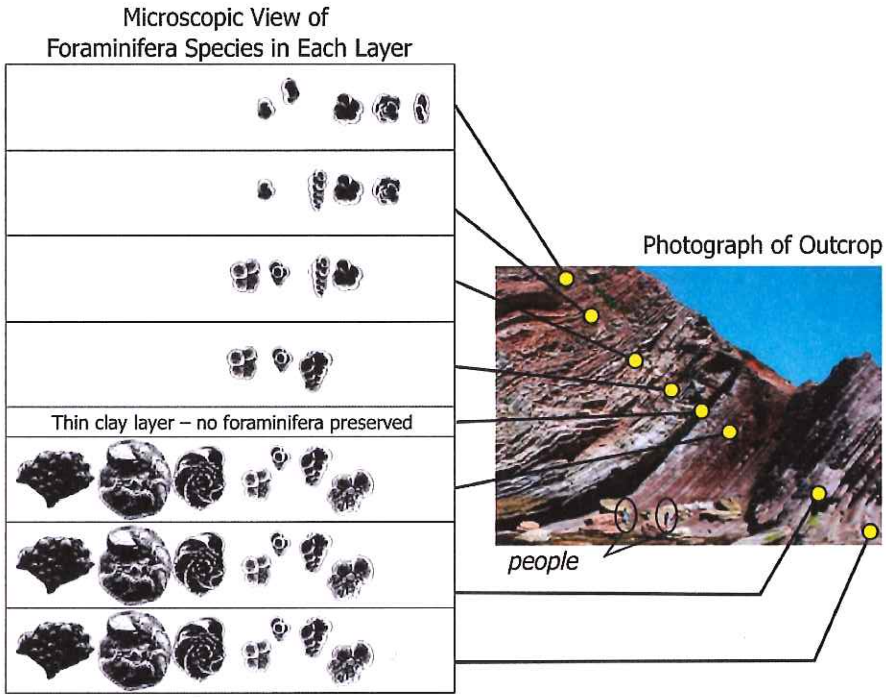
Source: Information from Sussman 2006.

The clarification statement for MS-ESS1-4 indicates that the emphasis of this performance expectation is not on the geologic timescale itself, but rather how different evolutionary and geologic events are put into a sequence using evidence from rock strata.

Students identified patterns in rock layers and used them to interpret fossils back in grade four (4-ESS1-1). In grade seven, students developed a model of rock cycle processes such as erosion and sedimentation (MS-ESS2-1) that form sequences of rock layers that have preserved fossils. One geologic application of the CCC of **stability and change [CCC 7]** is that geologists assume that processes we observe today operated the same way in the distant past. In other words, we can use the present as a key to interpret the past. Students must be able to use this overarching principle to **explain [SEP-6]** how they can use rock layers to determine the sequence of events in the past such as those in table 5.11 (MS-ESS1-4). The evidence statement for MS-ESS1-4 provides a complete list of the types of reasoning students should be able to use in their explanation, including the ordering of layers with the most recent material being deposited on top of older material, the presence or absence of fossils of certain species that lived only during certain time intervals, and the identification of layers with unique chemical or structural signatures caused by major events such as lava flows and impacts with high iridium concentrations. In essence, geologists use clues in the rock layers to reconstruct a sequence of events much like a detective determines the timeline surrounding a crime. In fact, one way to introduce these principles is through a murder mystery (USGS, http://www.cde.ca.gov/ci/sc/cf/ch5.asp#link22). Students then need to practice reconstructing sequences from simple diagrams of layers to ensure that they have mastered the principles of relative dating.

Since dinosaur fossils are rare, the absence of dinosaur fossils in a layer is not reliable evidence of extinction. Other organisms, however, are much more common. Students next investigate a sequence of layers above and below the layer caused by the impact that may have killed the dinosaurs. Students will look at layers of rocks that formed at the bottom of the ocean, and they can tell that they are marine rocks because they formed in continuous flat layers out of calcium-rich material and contain fossils of microscopic organisms called foraminifera. An astonishing variety of foraminifera live in the ocean today, each species with a different size and shape shell. Students examine the diversity of foraminifera in each of these ancient rock layers. Using cards with pictures of the view through a microscope of foraminifera shells extracted from a single layer, students document the species in that layer and compare them to the next layer upwards (figure 5.47). Which species from the lower layer survived into the next layer, which went extinct, and which new species appeared? They **analyze [SEP-4]** all the layers together from the class and create a graph showing how the number of species changed over time. To **interpret [SEP-4]** their findings, students must remember that the progression of layers represents the progression of time. A sudden decrease in the number of species represents a major extinction event, and students see evidence of this extinction occurring right up to the layers immediately above and below the clay layer from the impact.

Figure 5.47. Microscopic Views of Fossil Foraminifera from Different Rock Layers



Source: M. d'Alessio with foraminifera data from National Research Council 1995 and image from Meléndez and Molina 2008

Whatever the exact cause, the majority of foraminifera species went extinct at the time of the impact, though some did survive. The number of species increases again in layers above the impact, and many of the species that survived the impact go extinct as these new species appear. What traits did the species that died share and how did they differ from the species that survived? Why did many of the species that survived eventually die off? To fully understand these phenomena in the fossil record, the focus of this instructional segment shifts to life science DCIs about natural selection and their implications for evolution.

Opportunities for ELA/ELD Connections

Students read two articles that outline some of the possible climatic changes that could have accompanied a major impact, one review by a scientist (Cowan 2000) and one reporting the results of a scientific study in a newspaper (Netburn 2016). They **evaluate [SEP-8]** the differences between the articles. How do the tones of the articles differ? What sort of information is included in each? Students then **ask questions [SEP-1]** about how these climate changes would affect populations.

CA CCSS for ELA/Literacy Standards: R.I.8.2, 8, 9

CA ELD Standards: ELD.PI.8.6, 7

While it is not possible to go back in time to monitor how the impact would affect the Earth systems and interactions between them, scientists do study modern changes to ecosystems and how they affect populations. The snapshot below illustrates how scientists track modern changes.

Integrated Grade Eight Snapshot 5.8: Making Sense of Natural Selection

How do climatic changes (ESS3.D) lead to the predominance of certain traits in a population over generations? To gauge what students already knew about how environmental changes impact living things, Ms. Q started the learning sequence with a brief pre-assessment probe about what happens to individuals when there is such a dramatic change that all of the animal's food supply dies off (Keeley, Eberle, and Tugel 2007). Will it change its diet? Hibernate for the first time ever? Die? Change in some other way?

Anchoring phenomenon: Finches on the Galapagos Islands have different size and shape beaks.

Ms. Q introduced the anchoring phenomenon for this sequence—images showing differences between Galapagos finches—the same birds that intrigued Darwin during his voyage on the HMS Beagle. She asked students to record observations of the finches and questions they have about them. She then presented students with a page from Darwin's ornithological notes (where Darwin describes his confusion over the birds). She asked students how Darwin used **cause and effect [CCC-2]** to frame his thinking. What effects did he recognize and what causes was he considering?

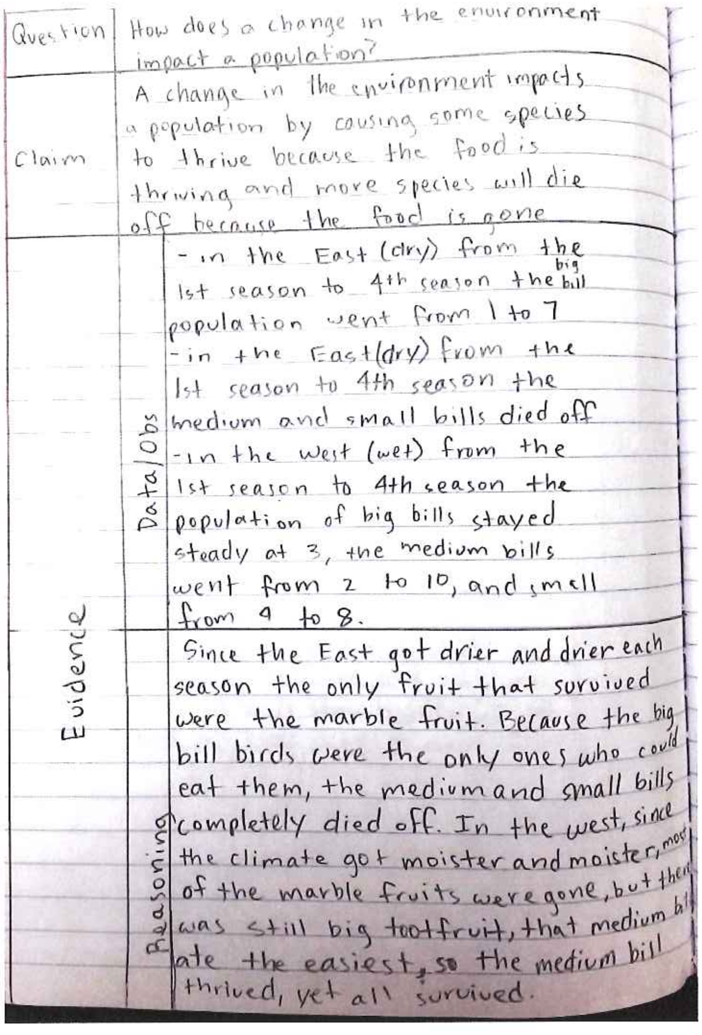
Investigative phenomenon: In a simulation, birds with different size beaks die off when the climate changes and causes a change in food supply.

Over the next days, students engaged in the Clipbird activity (Janulaw and Scotchmoor 2011). In this hands-on simulation, students used the lens of **cause and effect [CCC-2]** to understand how a change in the environment over time impacts the ability of plants to reproduce (produce seeds), which in turn impacts birds' food supply and thus their survival. In this simulation, a mountain range separated two different populations of birds. Each population began with the same small variations in beak size and similar food supply in the first two rounds of the simulations ("seasons"). In seasons three and four, the "climate" diverged on the two sides of the mountains and the food supply changed. Before actually acting out the simulation each season, students predicted the outcome knowing the food supply. After season four, students **constructed an explanation [SEP-6]**, using **cause and effect [CCC-2]** evidence to address the question: How does change in the climate

Integrated Grade Eight Snapshot 5.8: Making Sense of Natural Selection

impact each population (MS LS4 4, MS-LS4-6)? They wrote in their notebooks, shared with their team, and finally revised their thinking as appropriate and constructed a single team explanation (figure 5.48).

Figure 5.48. Preliminary Student Explanation of the Clipbird Scenario



Source: Photo provided by Jill Grace.

The following day, Ms. Q asked her students to think of ways they could be more certain or "sure" that their **explanation [SEP-6]** was accurate. This eventually led to a discussion of sample size, and Ms. Q presented the students with data from all of her classes. She asked the students to consider ways in which the data could be displayed

Integrated Grade Eight Snapshot 5.8: Making Sense of Natural Selection

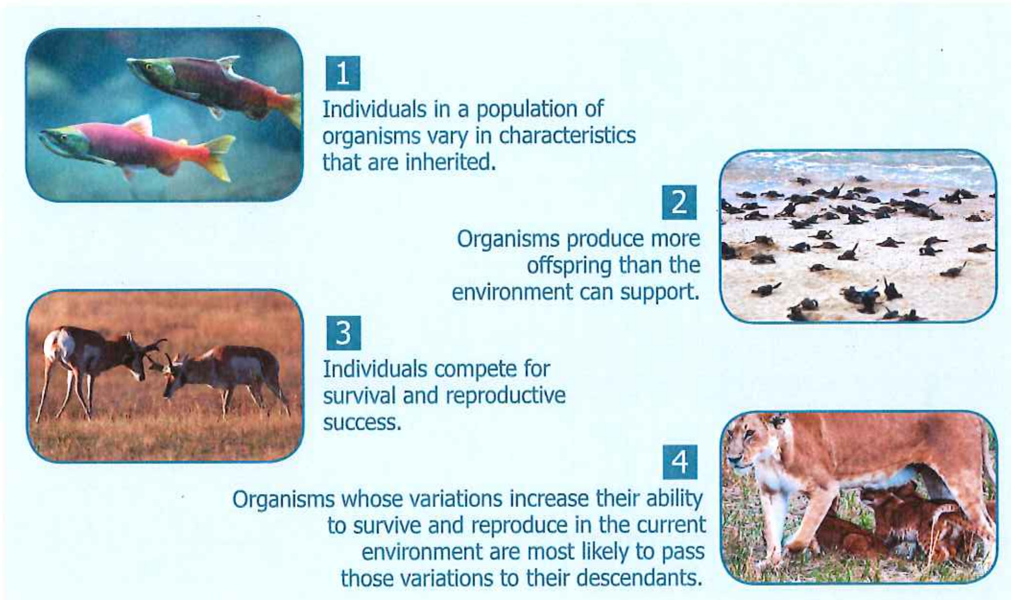
to better understand it, and students agreed they should combine and then graph the data. **Organizing and presenting the data [SEP-4]** in a visual form (graph) helped students make sense of the information and enabled them to discuss and work with their team to **review and revise their explanations [SEP-6]** through the lens of **cause and effect [CCC-2]**.

How would the populations change after 100 generations or even 1,000? Ms. Q informed the students that their simulation was based on an actual study by scientists who had observed the real-life effects. She spent the next several days exploring actual data from Grant and Grant (2014) and media resources (Howard Hughes Medical Institute 2014), including articles that described some of the changes that global climate change may bring to different species in the Galapagos and beyond (ESS3.D).

Natural Selection Based on Four Scientific Concepts

Natural selection is a **mechanism [CCC-2]** that explains how species change over time in response to changing environments. Students will need to develop a conceptual model [SEP-2] of natural selection that connects several DCIs (figure 5.49). Students observed evidence of the first three concepts in Integrated Grades Six and Seven: organisms have variable traits that are inherited (LS3.A, B), most organisms produce far more offspring than survive, and individuals in a population compete with each other for resources (LS2.A). Darwin's contribution was to link these ideas together and explain them: organisms that have traits that increase their success (survival and reproduction) in the current environment are more likely to pass their traits to their descendants than organisms that have traits that are not so well suited to the environment (LS4.B).

Figure 5.49. Four Key Ideas in Natural Selection



Source: Adapted from Sussman 2006.

Darwin lived in England in the mid- to late 1800s. His country led the world in advancements of geologic ideas, and provided evidence that Earth had an immensely long history and that changes generally happened very slowly. Darwin and his contemporaries also assumed that natural laws that governed biology would follow the same logic; evolution must also be very slow. We now know, however, that the rate with which changes occur depends on generation time. The traits common in a population shift each generation. These small-scale changes are measurable and can lead to a small increase in the ability to survive and reproduce. Given enough time, however (sometimes thousands of generations), these small changes can accumulate and lead to major change and can account for the diversity we see in life today. A population that appears stable might actually be slowly changing, and students will benefit from explicitly considering the CCC of **stability and change [CCC-7]**. By the end of the middle grades, students are expected to be able to recognize that processes can cause both slow and rapid changes, and this understanding feeds into an even more sophisticated view of dynamic equilibrium in high school where students will quantify feedback mechanisms that control the rate of change. Students can provide examples from their own lives where changes occur slowly and rapidly (grass grows slowly each day until it is suddenly cut; they make steady progress reading a book each night during the week and then race through to the end during a reading binge one weekend). The Clipbird snapshot (snapshot 5.8) provides a tangible example in which during seasons one and two changes were slow, but the sudden shift in food availability in seasons three and four (simulating major climate change over a compressed classroom timescale) caused more rapid population changes. Students can identify similar effects in real data sets, such as the *Geospiza fortis* and use **mathematical models [SEP-5]** to describe these changes (MS-LS4-6).

Linking Natural Selection and Evolution

To develop an understanding about how these changes in populations can add up to major differences between species, students need to track different examples. Darwin used **evidence [SEP-7]** from artificial selection (most notably dogs and pigeons) to support his claims about natural selection as the mechanism for evolutionary change. Artificial selection refers to how humans have consciously selected and bred plants and animals to have traits that humans wanted to exploit, taking advantage of naturally occurring random variations. Doing this keeps increasing the quantity and quality of a particular trait in a local population. In the example of dogs, exploited traits were those that helped hunters find prey or those that helped to control the behavior of other animals on the farm. There are numerous examples of humans artificially selecting for traits in animals and plants. Examples include selecting for the kind of sheep that give the best quality wool, trees that yield the biggest and sweetest fruit, crop plants that grow quickly or are resistant to pests, and cows that provide the most milk. Tapping into prior knowledge students have about such examples is a good entry point for students to start thinking about artificial selection.

Digging deeper, students could investigate a case study involving scientists' understanding of the history of modern maize (corn), which holds tremendous cultural significance. Scientists puzzled for a long time trying to reconstruct the ancestry of modern maize from what some claimed was the common ancestor, teosinte. Students obtain **information [SEP-8]** from resources (e.g., *Weed to Wonder: Domestication*, http://www.cde.ca.gov/ci/sc/cf/ch5.asp#link23) to discover the lines of evidence used to support the claim and to document questions they have about the evidence. Students can then **argue from evidence [SEP-7]** to evaluate the strength of the evidence to support the claim and view the Howard Hughes Medical Institute (HHMI) Video *Popped Secret: The Mysterious Origin of Corn* (http://www.cde.ca.gov/ci/sc/cf/ch5.asp#link24) to compare their research and arguments.

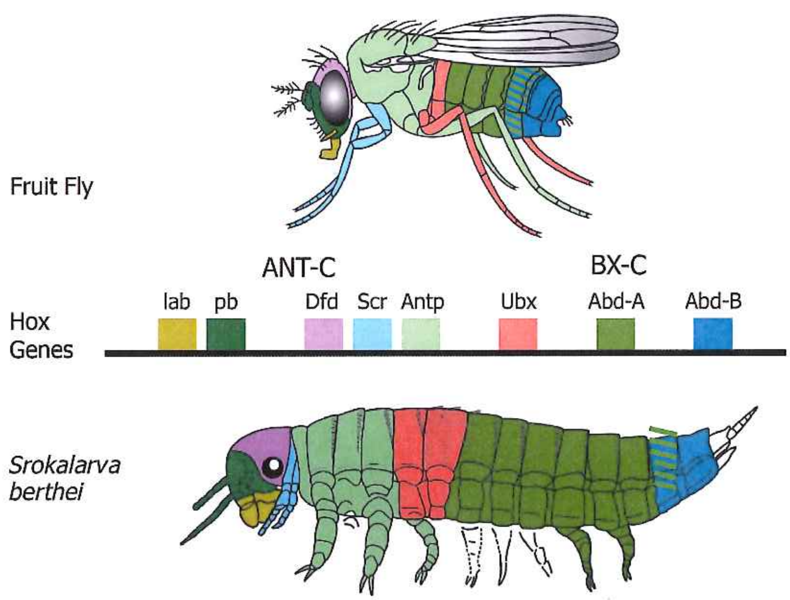
Students can compare and contrast the processes of artificial selection and natural selection. By selecting for specific characteristics over many generations, humans consciously take advantage of naturally occurring variations, and they keep increasing the quantity and quality of a particular trait in a local dog or plant population. In artificial selection, nature provides random variations in traits, and human beings select the traits that they want. In natural selection, nature provides both the random trait variations and the selection mechanisms (competition due to changing environments).

What Causes Variation?

Both natural selection and artificial selection require random inheritable variations in traits. But, what exactly **causes [CCC-2]** these random variations in heritable traits? Darwin and his contemporaries at the end of the nineteenth century did not know the precise mechanism. The answers had to wait until great advances were made in biology about 100 years after Darwin published his theory of evolution by natural selection.

In grade six, students developed a model of how sexual reproduction results in genetic variation in offspring (MS-LS3-2), and they now extend that model to include variation by genetic mutation and the tie between genes, proteins, and traits. Specific molecular details of how this happens, including the discussion of DNA and mechanism for protein synthesis, are reserved for high school, HS-LS1-1. Students can begin with another case study identifying **patterns [CCC-1]** in the bodies of arthropods (figure 5.50). Are animals with similar body types closely related? Students can group animals based on similar body structures and lay these groups out on an evolutionary tree that reveals something about possible sequences (i.e., which came first, and when did the others diverge?).

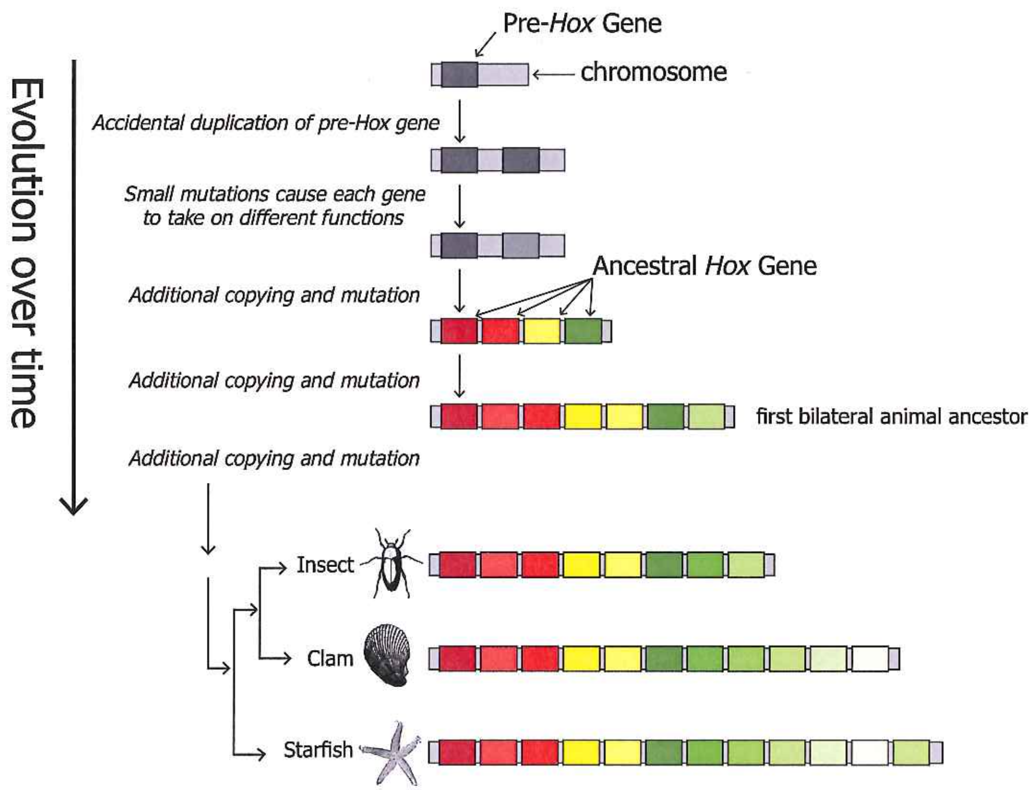
Figure 5.50. Arthropod Bodies Have Similar Structures



Source: M. d'Alessio with image from PhiLip 2007; adapted image from Haug et al. 2015, Fig. 4; and data from Haug et al. 2015.

Some scientists make an analogy between genetic code and programming computer code. If an organism has a specific gene sequence for creating a leg, it's easy to visualize how the body would create legs in different locations if the gene sequence gets moved, or how additional legs would grow if the segment is activated multiple times. The process is analogous to copying and pasting computer code to different parts of a computer program. When cells can copy their genetic code (for reproduction or other purposes), errors can occur that cause sections to get moved or duplicated. Students can see evidence of these mutations to the genetic code in arthropod bodies. In fact, the specific genes for body segments that show up in arthropods can be traced throughout all modern animals (figure 5.51). Slight variations in these body segment genes, called "*Hox* genes," provide genetic recipes for different body parts.

Figure 5.51. Animals Share Similar Genetic Code for Body Segments



Source: M. d'Alessio

With this conceptual framework linking genes and specific body structures, students now need to refine their models of mutations and link them more closely to the functioning of proteins and cells. By representing genetic codes of a virus as sequences of letters or colored bars, students can simulate random mutations and investigate their effects (see

Part Two: Evolution of the Mutants from HIV: Evolving Menace from the NSTA Publication, *Virus and the Whale: Exploring Evolution in Creatures Small and Large* (http://www.cde.ca.gov/ci/sc/cf/ch5.asp#link25). The assessment boundary of MS-LS3-1 highlights that the understanding is conceptual and does not require understanding of DNA, but it is reasonable to introduce genetic codes as specific sequences of letters or colors to help students visualize how a mutation can change the genetic code.

Representing genetic codes as cookbook-style recipes is another useful **analogy [SEP-2]** for modeling how proteins influence traits. How would students represent a genetic mutation in this analogy? If a chef (the chef being an analog for proteins that do the "reading") misreads a recipe, the outcome will be different than intended. These mistakes can be adding something extra, leaving something out, or substituting an ingredient. The outcomes of such mistakes can be beneficial, neutral, or harmful (table 5.12). Random mistakes in genetic "recipes" (i.e., mutations) result in an enormous amount of potential variation in organismal traits. This potential has manifested in the great diversity of Earth's web of life.

Table 5.12. Possible Results of a Mutation

A CHANGE IN THE SEQUENCE OF DNA LETTERS		
Type of Mutation	**Effect on Protein Folding**	**Effect on Protein Function**
Neutral	No significant change	No significant change
Harmful	Protein can fold in a different way	Decrease in or loss of function
Beneficial	Protein can fold in a different way	Protein functions better or even helps in a new way

Source: Dr. Art Sussman, courtesy of WestEd

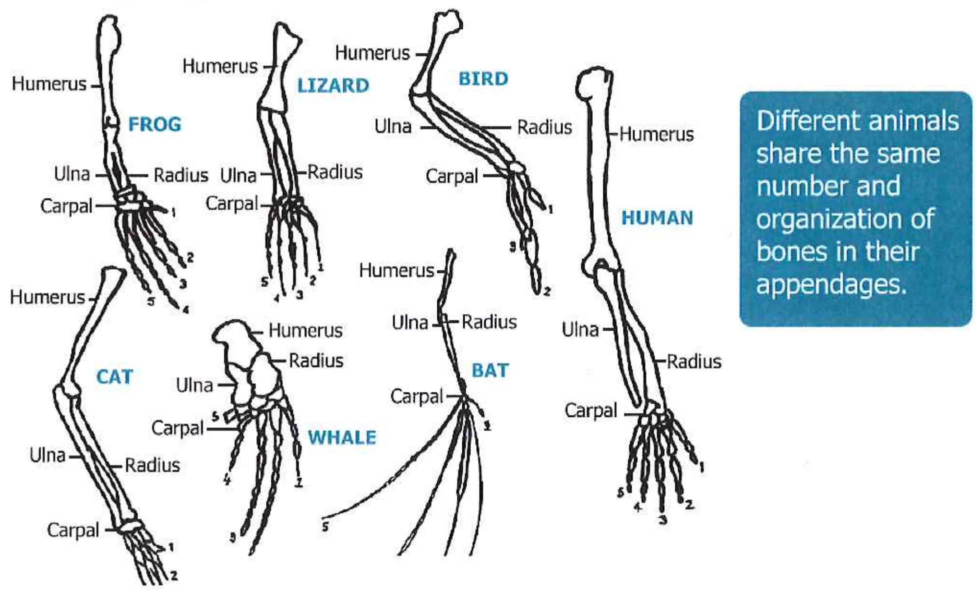
Just like artificial selection parallels natural selection, humans have developed technology to artificially introduce mutations. Students can return to their case study of corn and maize and **obtain information [SEP-8]** about how seed manufacturers have genetically modified some maize traits by inserting the Bt gene that produces a protein that can kill harmful insects (Gewin 2003). The applications of this genetic science to societal challenges such as the corn example are not "optional sidetracks," but part of an explicit performance expectation in the CA NGSS (MS-LS4-5).

Unity and Diversity of Life

An overview of Earth's biodiversity reveals two very different but also complementary features: unity of life and a diversity of species. With respect to unity, all of Earth's species share essentially the same genetic code described in the previous section because of common ancestry. In addition to the genetic code being the same, at the molecular level even very different organisms such as humans, sunflowers, and fruit flies have very similar molecules that perform vital life functions. Despite these fundamental similarities, there are also key differences. The grade eight performance expectations focus on these differences at the macroscopic rather than the molecular level.

With their new model of genetic mechanisms for mutation, students can now explain the linkage between evolution and natural selection from a new light. Like the arthropods, students can recognize **patterns [CCC-1]** in the structure of animal limbs that enable humans to throw, bats and birds to fly, dolphins to swim, frogs to jump, and lizards to run (figure 5.52). They can now **explain [SEP-6]** both the similarities and differences in terms of genetic inheritance, mutations, and natural selection (MS-LS4-2). They can also use the similarities to **construct an argument [SEP-7]** that these animals all share a common ancestor.

Figure 5.52. Comparing Limb Bone Structures in Different Animals

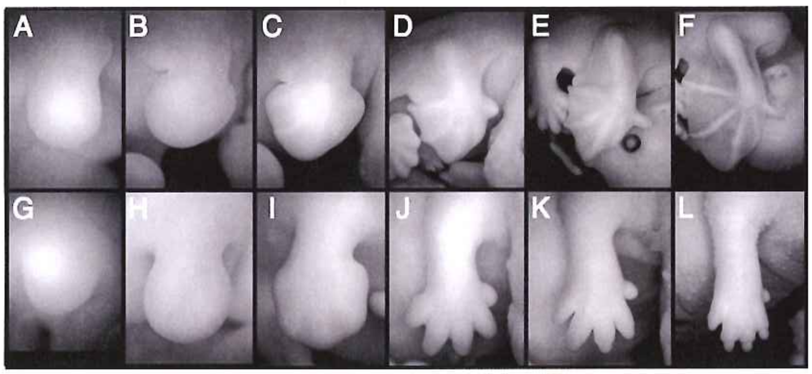


Anatomy reveals both the unity of basic bone structures and the diversity of organisms. *Source:* Lawson 2007

There are of course differences in the relative and absolute sizes of each bone compared across these very different organisms. The differences make sense because the **structure [CCC-6]** of the bones relates to the **function [CCC-6]** of the arm. In an organism like a bat that uses its front appendage for flight, longer, lighter bones are naturally selected. Organisms that walk on four legs must have bones sturdy enough to support weight, while those that walk on two legs tend to have front arms that have been naturally selected for lighter weight-bearing since they aren't supporting the body.

Further evidence that supports the evolutionary relationship of these different organisms comes from examining how structures develop in the embryo. For example, the limbs and hands of bats and mice start off developing in the embryo nearly identically but differentiate later during the embryo's development (figure 5.53). Students should be able to analyze pictorial data of embryos to identify patterns [CCC 1] in the development of these organisms (MS-LS4-5).

Figure 5.53. View of Embryo Development in Bats and Mice



(Top Row, A-F): Bat; (Bottom Row, G-L): Mouse. *Source:* Cretekos et al. 2008, © Cold Spring Harbor Laboratory Press

These and similar examples from anatomy (MS-LS4-2) and embryology (MS-LS4-3) provide data that students can analyze [SEP-4] and use as evidence to construct evidence-based explanations [SEP-6] based on resemblances due to shared ancestry and differences due to the effects of natural selection in different environments (MS-LS4-2) as well as the role of mutation (MS-LS3-1). Students can explain [SEP-6] what caused [CCC-2] related species to look slightly different, or can use slight differences to identify possible relationships between species.

Integrated Grade Eight Snapshot 5.9: Simulating Mutant Hands

Anchoring phenomenon: People have hands. (How did they evolve?)

Darwin himself pointed to human hands and asked questions about how they came to be, and researchers are starting to answer these questions using a combination of fossil discoveries, embryological development, and artificial gene editing.

Investigative phenomenon: A transitional fossil shows a fish with fins that look more like limbs of a land-dwelling animal.

Ms. R's students began by **obtaining information [SEP-8]** from a news story documenting the work of scientists (Zimmer 2016). The scientists discovered a 370-million-year-old transitional fossil, *Tiktaalik*, a fish with fins that look more like the limbs of land-dwelling animals. How did arms and hands evolve from fins (the supporting rays of which are made from a completely different material than the rest of the fish's bones)? The article goes on to discuss how the same scientists used genetic experiments on zebrafish and mice and how these helped scientists isolate the specific genes responsible for our hands. The changes that allowed a few species of fish to make the environmental transition from water to land opened up whole new possibilities for life, and diversity exploded into the full range of limb functions we see today.

Investigative phenomenon: As specific genes are copied, moved, or deleted, an organism's body shape can change in specific ways.

To understand the evidence better, Ms. R's students explored an interactive simulator of a zebrafish. The computer screen provided students a control panel where they could copy, move, or delete different segments of the genetic code of the zebrafish. They could also insert special genetic code from a jellyfish to track the proteins built by each gene. After students modified a gene, they watched as the zebrafish developed. Through systematic **investigation [SEP-3]**, students isolated the effects of the individual genes. They tried to recreate the *Tiktaalik*'s arm-like fins in the engineered zebrafish.

Using the information obtained from the reading and their model of limb genetics from the simulator, students created a poster **communicating [SEP-8]** the evidence that explains how human hands slowly evolved from fish fins. Their posters included evidence from fossils (MS-LS4-2; ESS1.C), the embryological study (MS-LS4-3), and the genetic manipulation (MS-LS3-1).

While students engineered zebrafish embryos in the computer, the real scientists used modern technology to manipulate real living organisms. Ms. R helped lead a discussion with her students about the ethics of this form of scientific investigation.

Bringing the Unit Together

The similarity of organisms at molecular and macroscopic scales is best **explained [SEP-6]** by the idea that life originated as single-celled organisms that progressively became more complex as populations adapted to living in very different environments. Students can mark this history of life in the calendar of Earth's geologic time scale or the classroom scale model that they developed at the beginning of the instructional segment (table 5.11). The most prevalent and easy-to-find fossils come from animals that have hard body parts, such as bones and shells. These types of fossils first appear around 540 million years ago.

Students can focus on the evolutionary lineage of a local species of interest (such as the San Joaquin kit fox, the humpback whale, the California long-tailed weasel, etc.) or just about any other organism that captures their imagination. They can **obtain information [SEP-8]** about common ancestry, adaptation, and selection and then present their findings to the class.

Such a deep dive into the mechanisms and evidence for evolution will help students make sense of the diversity observed in the fossil record and the plausibility of larger extinction events as well as the subsequent diversification of life. Returning to the instructional segment phenomenon of an unexplained mystery in the geologic record, students can recall their comparison of fossilized foraminifera before and after the mysterious extinction event. What traits did the animals have that survived the climate change following the impact? Would these traits still have provided an advantage thousands of years after the catastrophe when the environmental conditions had stabilized (or possibly returned to their pre-impact conditions)? What factors explain the subsequent diversification of foraminifera (and other species) in the millions of years following the impact? What happened to the traits and genetic code for the organisms that became extinct?