Grade 8 Instructional Segment 3

Teacher Background and Instructional Suggestions

Instructional Segment 3 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 miles of area. These ***time and distance scales*** 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.

Students in Integrated Grade 7 experienced some of these Earth Science practices as they investigated rock cycle processes such as erosion and sedimentation. Also in learning about continental drift and plate tectonics, students analyzed and interpreted continental shapes and data on the distribution of fossils and rocks (MS-ESS2-3). In Integrated Grade 8 they now build on those learning experiences to use evidence from rock strata to explain how the geologic time scale organizes Earth's 4.6-billion-year-old history (MS-ESS1-4).

While we can readily say phrases such as "4.6-billion-years," most of us cannot realistically experience how long that time span really is and the kinds of changes that can happen over that ***scale*** of time. 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). Each day on that calendar represents about 12.5 million years.

Geologists organize this immense time scale in a variety of ways, mostly based on data from fossils that were found in layers of sedimentary rock. Earth scientists read these layers of rocks like the pages of a history book. The composition and texture of each layer of rock reveals a snapshot of what the world looked like when that layer formed, and the sequence of layers reveals how environmental conditions and organisms changed over time. Generally the higher layers correspond to later periods of time.

TABLE 5: ONE YEAR CALENDAR MODEL OF GEOLOGIC 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 pm on December 31

(Information from *Dr. Art's Guide to Science*, courtesy of WestEd)

Much of science resembles a crime science detective activity, and this analogy is especially true with respect to Earth history. "What Killed the Dinosaurs?" is one of the most famous of these crime stories, and, as illustrated in the vignette below, it provides a very engaging way to learn about Earth's history and the science practices that scientists use to discover what happened many millions of years ago.

Vignette: The Day the Mesozoic Died

Introduction

Like most of his students, Mr. Rex is fascinated by dinosaurs, how they lived and dominated ecosystems in the air, ocean and land for about 135 million years, and, of course, that they became extinct. He enjoyed using the asteroid impact theory in Instructional Segments 1 and 2 to introduce the physical science of forces, motions and collisions. Through that introduction he became familiar with the wealth of resources about extinction, evolution and the asteroid impact that are available for free from the Howard Hughes Medical Institute (HHMI) biointeractive.org website. In particular, he determined to teach about Earth's geological time scale, extinction, and evolution using the film "The Day the Mesozoic Died" and its associated resources and lessons.[1]

Act 1: An Earth-Shattering Hypothesis

The entire film is about 34 minutes long and the website includes a teacher In-Depth Film Guide. Before viewing the film, students individually and then in small groups discussed what they knew about the rock cycle, fossils, erosion, sedimentation, and the extinction of the dinosaurs. Mr. Rex facilitated the discussions with related images and concepts that students had encountered in the Earth Science embedded within Integrated Grade 7. In their notebooks, students made notes about key ideas and terms.

Mr. Rex provided a homework reading based on the first two pages of the short article resource from BioInteractive with the same title as the film. Students **obtained information** to answer questions about the timing of the Mesozoic Era and the K-T Boundary, what geologist Walter Alvarez was doing in Gubbio, Italy, which fossil organisms he was **gathering data** about in the rock layers, and what **science question** he was asking. The next day Mr. Rex showed the first 5 minutes of the film, then students in groups discussed the film and their homework, and, following student requests, he showed the next 5 minutes where they learned about a Dutch geologist who was gathering similar evidence. Students used their notes about both scientists to it to answer the main questions that Mr. Rex had posed, "Which science practice or practices were shown in these 10 minutes of the film? What is **your evidence**?"

The resulting small group and whole class discussion unearthed two key SEPs: **carrying out investigations** involving gathering data about forams (foraminifera: tiny ocean plankton that are major producers in ocean ecosystems) and **asking questions**. Students cited good science questions such as, "Why had the forams disappeared?" and, "Did the extinction of forams have anything to do with the dinosaurs?"

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[1]All accessed at < http://www.hhmi.org/biointeractive/day-mesozoic-died>. Film can be downloaded, ordered for free shipment, or streamed at https://www.youtube.com/watch?v=tRPu5u_Pizk&feature=youtu.be

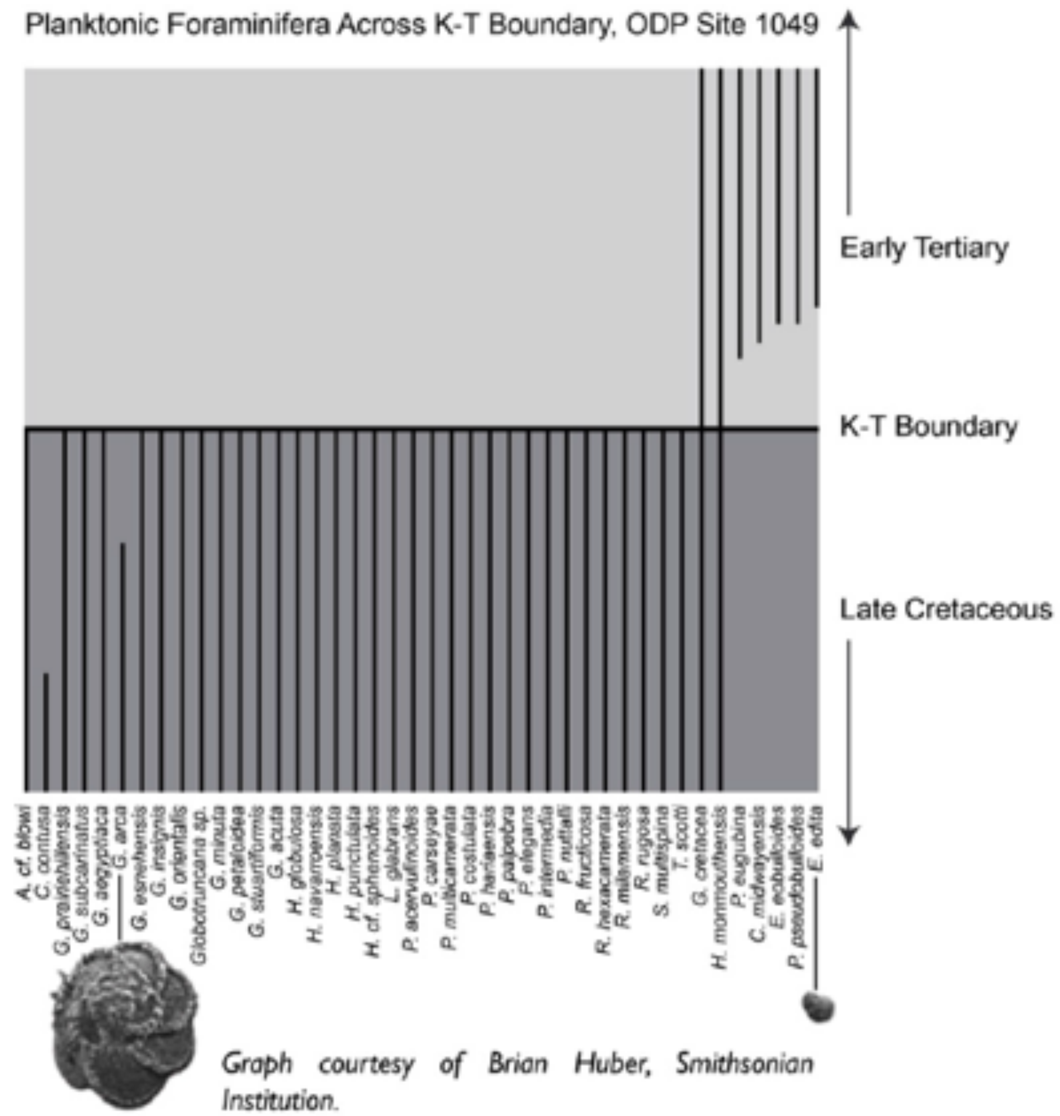

Figure 17: Species of forams that existed before and after the K-T Boundary at a location. (From student lesson accessed at BioInteractive website, courtesy of HHMI)

The next day students did an investigation based on the BioInteractive lesson, “Weighing the Evidence for a Mass Extinction Part 1: In the Ocean.” They **measured** lengths of forams based on illustrations all at the same scale of about 10-fold magnification, and **concluded based on that evidence** that Tertiary forams were much smaller than the forams that had existed before the K-T time boundary. They also **calculated based on data** from geologists that more than 90% of the forams at “ODP Site 1049” became extinct at the time of the K-T Boundary (Figure 17). Each vertical line within Figure 17 represents a foram species and which rock strata contain fossils of that species. Students can **analyze that data** to conclude that only 2 of the Cretaceous foram species survived whatever had happened at that time Boundary. Looking at what happened afterwards in time during the Early Tertiary, students can **conclude** that 5 new foram species appeared after the K-T time Boundary.

The following day, students watched the next 5 minutes of the film until the end of Act 1. Mr. Rex had provided a list of key questions based on those 5 minutes. Once the students started discussing those questions, they asked for opportunities to watch the 5 minutes again. Mr. Rex showed it this time in even briefer segments giving them time to take notes and talk about each of those shorter sections. By the end of the class, they had made some progress answering his questions but they still needed more time.

Mr. Rex had anticipated this situation, and provided an illustrated homework reading that summarized the key points. The next day in class they watched the last 5 minutes of Act 1 again, and progressed much faster in their class discussions. Now students identified in the film situations where scientists engaged in the practices of:

Asking questions: For what length of time did the clay layer at the K-T Boundary represent?

Planning and carrying out investigations: measuring the amount of iridium in the clay layer and in the sedimentary rock strata above and below it.

Analyzing and interpreting data: finding out that the iridium amount was way higher in the K-T Boundary clay layer than in the rock strata above and below it; interpreting that data to mean that an outer space catastrophic event had occurred.

Planning and carrying out investigations: measuring the amount of plutonium in the clay layer.

Analyzing and interpreting data: not finding the plutonium in the clay layer, and interpreting that absence to mean that the hypothesized outer space event was not a supernova explosion.

Using mathematics and computational thinking: Luis Alvarez, Walter's famous physicist father, **calculating** based on the amount of iridium that if the outer space event was an asteroid collision, the asteroid would have been as big as Mount Everest and traveling at 80,000 kilometers per hour when it slammed into Earth.

Asking questions: what other kind of data could be gathered as evidence of an asteroid impact?

Mr. Rex made sure that students noticed and commented that the practices kept being revisited and repeated, that scientists do not engage in the practices in a linear manner. Following this discussion of science practices, Mr. Rex posted a slide listing the 7 NGSS crosscutting concepts, and asked students to discuss and give evidence for which of these CCCs were most connected with the film so far. After much small group discussion and whole class sharing, students voted for three main CCCs:

***Patterns*:** the geologists had found the same foram fossil patterns in rock strata that are in very distant parts of the Earth. Cretaceous rock strata had many diverse species including many larger forams, and after the K-T Boundary the Tertiary rock strata had very few species and they were all small.

***Cause and Effect*:** an asteroid impact caused iridium to appear all around the planet in unusually high concentrations in a thin clay layer about 65-million-years-old. The impact would have caused huge fires, sunlight to be blocked, poisoned the oceans, and killed producers, all of which would disrupt ecosystems globally.

***Stability and Change*:** as evidenced by fossils in rock strata, the populations of forams during the Cretaceous were stable and then suddenly these populations changed drastically with a lot of extinctions.

Some students pointed out that the iridium in the K-T Boundary clay layer was indeed caused by the impact, but the iridium did not cause any extinctions. Instead of iridium being a cause, the iridium was strong **evidence for the claim** that an asteroid impact had occurred.

Act 2: Following the Trail of Evidence

Act 2 in the film is packed with information about the search for the impact site crater where the asteroid crashed into Earth. Before showing this section to students, Mr. Rex led a whole class discussion about the **science question** that had emerged at the end of Act 1, “What other evidence besides the iridium in the clay layer could prove whether an asteroid had crashed into Earth around 66 million years ago?”

Students discussed this question in groups and then shared as a whole class. Mr. Rex served as a facilitator charting key points, and helping to keep the conversation on task. He helped the class discussion coalesce around the concept of a crater. Mr. Rex then displayed the beginning part of Act 2 showing scientists discussing attempts to find a crater with the right age and size, worrying about the possibility that the asteroid had crashed into the middle of the ocean, and finally **concluding based on the evidence** of rocks with shocked quartz crystals that the asteroid ***must have*** crashed on or very near land.

To help students use science practices to engage with the “trail of evidence” about the crater, Mr. Rex used the BioInteractive materials to create an illustrated reading that summarized key points. He helped the class form small groups to use this resource to **research and then report** about six key aspects related to the crater:

• ejecta - all the material blasted outward (ejected) due to the collision

• spherules – glassy spheres embedded within ejected rocks

• tektites – irregularly shaped glassy melted rock located within ejected rocks

• spinels – a mineral rich in nickel that formed when the asteroid passed through Earth’s atmosphere

• shocked quartz – quartz grains that fractured due to the impact, and

• breccia – large chunks of broken-up rock

TABLE 6: Possible Evidence from Ejecta

	Close to Impact	Not Close, Not Far	Far from Impact
Thickness of Ejecta	> 10 cm	1 – 10 cm	< 1 cm
Breccia	Maybe	None	None
Spherules	Maybe	Maybe	Maybe
Shocked Quartz	Maybe large and small	Maybe large and small	Maybe small
Tektites	Maybe	Maybe	None

As the student teams presented their reports, all the students wrote key information in their notebooks. Mr. Rex advised them to pay special attention to how different kinds of ejecta could be used as **evidence** whether a location was close to or far away from the asteroid impact site. After all the reports and note-taking, students worked in groups to create a guide for **analyzing data** about 66-million-year-old rocks in a location. Student groups shared their ideas, and then the whole class created a guide that they would all use for the next activity (Table 6).

Students worked in pairs or small groups to locate10 different sites where scientists had obtained rocks and soil from about 65 million years ago. They used a world map marked with longitude and latitude lines spaced 5^0 apart. Using data, photos and illustrations for each of the sites, the students **analyzed and interpreted the data** to decide whether the ***pattern*** at each site indicated whether it was close to, far from, or at an intermediate distance from the impact site. They then used the global ***pattern*** to make an **evidence-based claim** about the probable location of the asteroid impact. This activity concluded with Mr. Rex showing the complete Act 2 of the video ending with the definitive identification of the Chicxulub Crater in the Yucatan region of Mexico as the asteroid impact site.

Next Steps

Mr. Rex planned to show “Act 3: Mass Extinction and Recovery” to introduce the major Instructional Segment 3 topic of evolution. However before making that transition, he wanted to help the students apply the crosscutting concept of ***Stability and Change*** to the topic of extinctions as a preparation for exploring evolutionary change. As a whole class discussion, he asked students what they remembered from the film or previous learning experiences about the pace of changes. Several students mentioned that fossil scientists had rejected the Alvarez impact hypothesis because they investigated ***slow but steady changes*** in the Earth. Other students remembered featured scientist Sean Carroll saying that “something had come from outer space and rewritten the history of life in almost an instant.” Other students described that the rock cycle features both slow and steady changes as well as sudden volcanic eruptions.

NGSS Connections and Three-Dimensional Learning

Performance Expectations		
MS-ESS1-4 History of Earth *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.* **MS-LS4-1 Biological Evolution: Unity and Diversity** *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.*		
Science and engineering practices	**Disciplinary core ideas**	**Cross cutting concepts**
Analyzing and Interpreting Data *Analyze and interpret data to provide evidence for phenomena.* **Constructing Explanations** *Apply scientific reasoning to show why the data or evidence is adequate for the explanation or conclusion.* **Obtaining, Evaluating and Communicating Information** *Evaluate data, hypotheses and/or conclusions in scientific and technical texts in light of competing information or accounts.*	**ESS1.C The History of Planet Earth** *The geologic time scale interpreted from rock strata provides a way to organize Earth's history. Analyses of rock strata and the fossil record provide only relative dates, not absolute dates.* **LS4.A Evidence of Common Ancestry and Diversity** *The collection of fossils and their placement in chronological order (e.g., through the location of the sedimentary layers in which they are found or through radioactive dating) is known as the fossil record. It documents the existence, diversity, extinction, and change of many life forms throughout the history of life on Earth.*	**Cause and Effect: Mechanism and Prediction** *Phenomena may have more than one cause, and some cause-and-effect relationships in systems can only be described using probability.* **Stability and Change** *Stability might be disturbed either by sudden events or gradual changes that accumulate over time.* **Patterns** *Patterns can be used to identify cause-and-effect relationships.* **Scale, Proportion, and Quantity** *Time, space, and energy phenomena can be observed at various scales using models to study systems that are too large or too small.*
Connections to the CA CCSSM:		

Connections to CA CCSS for ELA/Literacy: **RST.6–8.1, 4, 8, 9; WHST. 6–8.7, 8; SL.8.1, 4**
Connection to CA ELD Standards: ELD.PI.6-8.1, 9 **Connections to CA CCSSM:** MP. 3, MP.4; 8.EE.4

Vignette Debrief

The *CA NGSS* require that students engage in science and engineering practices to develop deeper understanding of the disciplinary core ideas and crosscutting concepts. The lessons give students multiple opportunities to engage with the core ideas in space science (moon phases), helping them to move towards mastery of the three components described in the *CA NGSS* performance expectation.

In this vignette, the teacher selected two performance expectations and in the lessons described above he engaged students only in selected portions of these PEs. Full mastery of the PEs will be achieved throughout subsequent units.

The inherently fascinating topic of the dinosaur extinction event connects major life science concepts of extinction and biodiversity with the major Earth science concept of the geologic time scale. The teacher used excellent free resources that dramatically showed scientists engaging in the science practices emphasized within NGSS. Mr. Rex used those examples to help students understand how specific practices actually play out in a complex research topic, especially that scientists apply them as they are appropriate rather than in a tightly programmed linear fashion.

During the vignette, the students observed very clear images of rock strata, and the fossils in different rock layers as the scientists explained what they were seeing. The students themselves engaged with science practices in uncovering and applying the clues about the asteroid impact event. Coming from lessons in the physical sciences where they could manipulate variables and immediately observe changes in results, these same practices looked quite different when they were used to investigate an event that happened 66 million years ago.

Throughout the impact lessons, students engaged with arguments based on ***cause and effect mechanisms.*** Ultimately the arguments that scientists used related to the phrase in MS-LS4-1 about “the assumption that natural laws operate today as in the past.” Scientists keep applying the same cause and effect arguments unless the phenomena ultimately demand that they consider new alternatives. Students also connected the asteroid impact event with the crosscutting concept of ***stability and change*** that they will soon explore in greater depth in succeeding lessons about evolution.

Resources for the Vignette

- < http://www.hhmi.org/biointeractive/day-mesozoic-died>

Instructional Segment 3 Teacher Background and Instructional Suggestions (continued)

After viewing and analyzing the asteroid impact DVD or other high quality educational resources, students will have very clear images of walls of sedimentary rock that are extremely stratified and very tall. They will know that each stratum of rock has fossils and other evidence representing the forms of life and environmental conditions during the time that rock layer was laid down. Students will also have learned that information from rock strata in different areas help provide a continuous record of Earth’s long ***geological scale of time***. The kinds of fossils in rock strata provide evidence of the relative age of different rock layers but they do not tell us absolute ages. For that information, scientists rely on radioactive dating, a concept whose details are generally not appropriate at the middle school level.

Act 3 of the Mesozoic extinction DVD raises the issue of how life has recovered over the millions of years after a period of mass extinction. These recoveries were evident in Figure 2, which shows an overall ***pattern*** of increasing marine biodiversity despite the five major extinction events. After the asteroid impact, the relatively few species of mammals increased tremendously in diversity, size, number and ecosystem prominence. Mammals had co-existed with dinosaurs for millions of years, but mammals flourished only after the dinosaurs had disappeared.

Natural Selection

The science process of natural selection **explains** how species change over time so they continue to survive and reproduce in changing environments (Figure 18). This ***cause and effect mechanism*** is based on four related science concepts. The first three of these concepts shown in the illustration are often readily observed. As students learned in Integrated Grade 7: organisms have variable traits that are inherited, most organisms produce for more offspring than survive, and individuals in a population compete with each other for resources. Darwin's genius consisted in linking these ideas together and adding a big inference: organisms that have traits that increase their success 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.

Natural Selection Based on Four Science Concepts

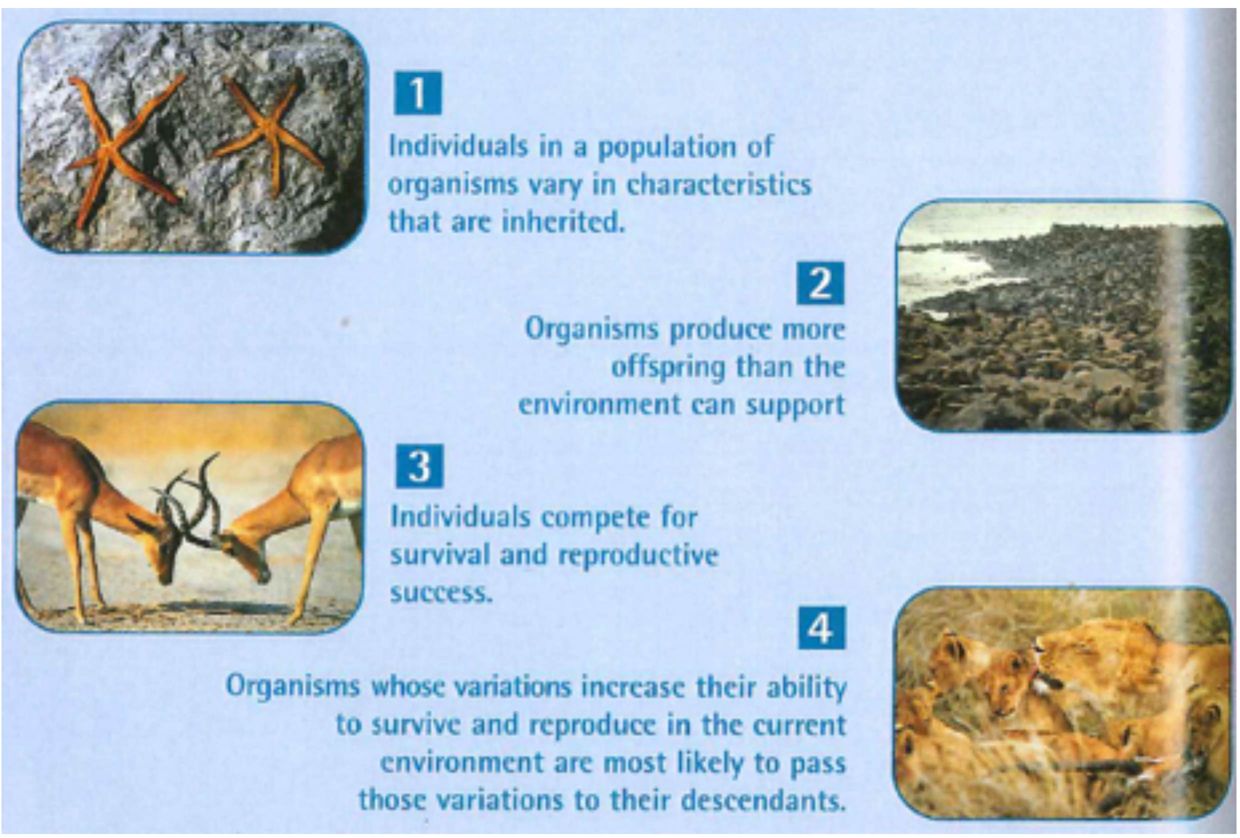

Figure 18: Darwin's theory of natural selection is based on four related concepts. (Illustration from *Dr. Art's Guide to Science*, courtesy of WestEd)

Darwin lived in England in the mid- to late 1800's. His country led the world in geology, and provided evidence for the major idea that Earth had an immensely long history, and that changes generally happened very slowly. Long periods of time enable a sequence of change at the species level of many small changes, each of which provides only a small increase in the ability to survive and reproduce, leading over time to a major change, such as the ability to see the world clearly, which provides a huge advantage.

Vision provides a very instructive example. Based on the fossil record and the anatomy of different kinds of eyes that exist today, scientists have **concluded** that eyes have independently evolved many times. Figure 19 illustrates a process of many small steps, each of which could provide a survival advantage, leading from lack of vision to increasing perceptions of light/shadows/shapes/movements to an eye that enables clear vision.

Natural selection works only if each of the kinds of changes shown in Figure 19 can be passed on through inheritance. Compared to their peers who do not have that heritable change, the descendants have a significant advantage that better enable them to survive and reproduce. The organisms themselves are not trying to change. Variations in the traits happen randomly and naturally. Those organisms that are lucky enough to have variations that improve their chances of success in the current environment are the ones that get to pass on their traits. As a result, the frequency of these advantageous traits increases in the population of that organism. The concept of adaptation works at the level of populations of a species. Teachers and students can use science language carefully by saying that species or populations adapt and avoiding saying that individual organisms adapt. To fully engage with this concept, students must **use mathematical representations** to help explain how natural selection can ***cause*** increases and decreases of specific traits in populations (MS-LS4-6).

Evolution of an Eye Via Many Small Steps

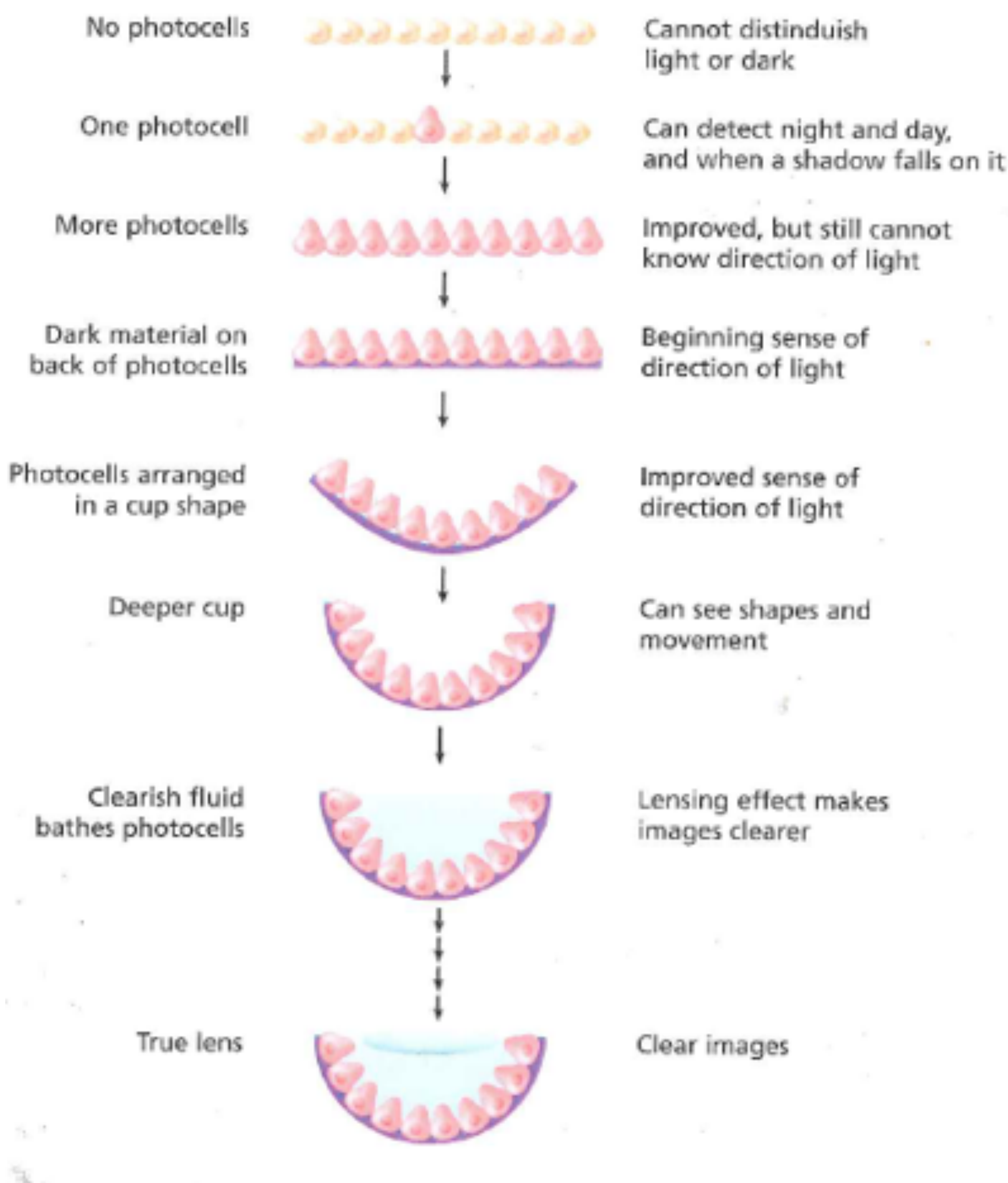

Figure 19: Overview of a process leading from lack of vision to the evolution of a clearly seeing eye. (Illustration from *Dr. Art's Guide to Science*, courtesy of WestEd)

Darwin used **evidence** from artificial selection **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 want. Examples from Darwin's time are dogs that help us hunt or that control the behavior of our farm animals such as sheep, the kind of sheep that gave us the best quality wool, trees that gave us the biggest and sweetest fruit, crop plants that grew quickly, and cows that gave us the most milk.

Student can individually or in small teams **research** different examples from pets, crops, farm animals, microscopic organisms such as yeast, and genetic engineering. Dogs provide a great example because students may know about or can easily get photos of many different kinds of dogs including tiny Chihuahuas, huge Great Danes, fierce pit bulls, smart sheep dogs, gentle pugs specifically bred to being companion dogs, and elongated dachshunds. All these types of dogs originated from an ancestral species that first transitioned from being wild to becoming a member of human communities. Student teams can **communicate** their finding in different ways, and the teacher can use these reports as a way to highlight key features of artificial selection.

Students can then 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 population. Nature provides random variations in traits and human beings select the traits that they want. In the case of natural selection, nature provides both the random trait variations and the selection. The traits are unconsciously and naturally selected on the basis of whether a trait variation helps that kind of organism to survive and reproduce in the current environment. Students can conclude that artificial selection and natural selection are similar but different kinds of ***causal mechanisms that result in*** Earth's biodiversity.

Engineering Challenge: Engineer a bird beak

Engineering Connection

Different animals eat different types of food, and their bodies must have the correct **structures** to enable them to eat that food effectively. Birds in particular have large variation in their beak shapes based upon their food source. Students can design a "beak" from a fixed set of materials that will allow them to eat as much "food" as possible[2]. They begin by defining the problem and establishing the criteria they will use to

[2] Curiosity Machine, Engineer a bird beak: https://www.curiositymachine.org/challenges/4/

measure success (*MS-ETS1-1, MS-ETS1-2*). Will they compare the amount of food in one bite or the amount of food in a set amount of time? Which of these criteria is probably a better approximation of what helps birds survive in nature? Are there any specific challenges that this particular type of food presents (powders, foods encased in hard shells, and foods that crumble easily all require different solutions)? Are there any obvious disadvantages to bigger or smaller beaks? (To represent the fact that bigger organisms require more ***energy*** to survive, the activity can be set up so that the amount of points a team receives depends on the ratio of food mass eaten to their beak mass.) After testing their design, students make improvements to improve their chance of survival (*MS-ETS1-4*). The students then compare their solutions to actual bird beaks, including the location and size of muscles (and attachment points) and the shapes of the beaks. They discuss the process of iterative improvements that they used and then compare and contrast it with evolution by natural selection and also with artificial selection. What was the source of the variations? What or who did the selecting?

Life is Bilingual

Both natural selection and artificial selection require random inheritable variations in traits? What ***causes*** these random variations in heritable traits? Darwin and his contemporaries at the end of the nineteenth century did not know. 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 the second half of the twentieth century scientists discovered that life on Earth is bilingual, and that all Earth organisms – from bacteria to mushrooms to plants to humans – at the level of molecules essentially speak the same two languages. This language analogy aims to convey major understandings about living systems.

One of the languages is a protein language. Proteins are huge molecules that can bend into a wide variety of shapes. Proteins are involved in practically everything that organisms do. All organism traits essentially ***result from*** the work that proteins do at the molecular level.

The other language of life is what scientists call nucleic acids, especially a huge type of molecule called DNA. Nucleic acids are the basis of heredity. DNA stores the information so an organism can make each of its proteins. Genes are made of DNA. In sexual reproduction, an offspring gets half of its DNA information from each of its parents (the molecular basis of MS-LS3-2 taught in Integrated Grade 6).

Proteins and DNA are huge, very long molecules. They are examples of extended molecular structures that students learned about in Grade 6 physical science (MS-PS1-1). The reason we can talk about these molecules as being languages is that both proteins and DNA are made of molecules that we can call building blocks. There are 20 different building blocks that are used to make proteins. DNA is made of four different building blocks that are a different kind of molecule than the protein building blocks.[3] Each protein can be thought of as a giant chain of 20 different "letters," one letter after the previous letter in an order that is specific to that kind of protein. Each of the proteins folds into a shape that enables it to perform its functions, and that shape is determined by the order of its building block letters. In this analogy, the DNA is like a computer hard drive that has a file corresponding to each of the proteins. That file is a sequence of the four DNA building block "letters" that somehow encodes the information for assembling one or more specific proteins. Each of those DNA files corresponds to a gene.

Notice that because there are two different languages with two different sets of letters, there must be a code that connects the DNA language with the protein language. In fact, that code is called the genetic code. The Integrated Grade 8 Performance Expectation related to genes and heredity (MS-LS3-1) does not specify the nature of proteins or DNA. However, the concept of random mutations is best understood in the context of these two languages of life. The recommendation here is to introduce these concepts at an appropriate level for Grade 8, and not get into details that are best learned in high school biology.

MS-LS3-1 specifies that, "structural changes to genes (mutations) located on chromosomes may affect proteins and may result in harmful, beneficial or neutral effects

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[3] Teachers and students are more likely to have heard of protein building blocks (amino acids) compared with DNA building blocks (nucleotides).

to the structure and function of an organism." Using our language metaphor, students can understand mutations as ***resulting from*** changes in the sequence of DNA letters that make up a gene. That change in the DNA could cause a change in one or more of the letters that make up a protein. As a result (Table 7), the protein could fold in a variety of ways that either result in no change (neutral mutation), a bad change so the protein can no longer function properly (harmful mutation) or, much less likely but possible, a good change so the protein performs its function better or even does something new that helps the organism survive and reproduce (beneficial mutation).

TABLE 7: 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
Benficial	Protein can fold in a different way	Protein functions better or even helps in a new way

(Table developed by Dr. Art Sussman, courtesy of WestEd)

Sickle cell anemia provides a very instructive example of the nature of genes, mutations and natural selection. Hemoglobin is a protein in red blood cells that binds oxygen and carries it from the lungs to cells. Hemoglobin consists of 177 amino acids (the letters of the protein language) joined together in a very specific order. The disease of sickle cell anemia is ***caused by*** a change in just one of those amino acids. That amino acid change ***results from*** a change in one of the letters in the gene (DNA) that codes for that amino acid in the hemoglobin chain. This single change ***reduces the ability*** of hemoglobin to carry oxygen, and ***results in*** episodes of pain, chronic anemia, and severe infections. Based on Table 7, students would classify this change in the DNA as a harmful mutation.

People have severe sickle cell anemia if they have two copies (alleles) of the bad gene (one from each parent). The disease is much less severe if the person has only one sickle cell allele (called sickle cell trait rather than disease). It turns out that sickle cell mutations have an unusually high frequency in areas of the world where malaria is a common disease. This mutation actually provides significant protection against dying from malaria. If the person has just one sickle cell allele and malaria is very prevalent, then the benefits of the mutation can outweigh its disadvantages. As a result, in some areas of Africa as much as 40% of the population has at least one sickle anemia allele.[4] As a result of this heritage, about 1 in 13 African American babies is born with sickle cell trait (having one sickle cell allele), and sickle cell disease is significantly prevalent in black American populations.

How do mutations happen such as the change in one DNA letter in the hemoglobin gene? Many different kinds of events can cause changes in the letter sequence of the DNA code. These events include mistakes in copying the code during germ cell division; damage caused by cosmic rays, radioactivity, X-rays, UV-radiation, or environmental chemicals; and viruses and other parasitic elements within the cell nucleus cutting and splicing DNA sequences. The key feature of all these damages is that the mistakes just happen: mutations are not designed to lead to any specific outcome. Nonetheless, these random mistakes do have an extremely important general outcome. Random mistakes result in an enormous amount of potential variation in organism traits. This potential has manifested in the great diversity of Earth's web of life. We can celebrate that life has diversity built into its very core!

Unity and Diversity of Life

An overview of Earth's biodiversity reveals two very different but also complementary features: a unity of life and a huge diversity of species. With respect to unity, all Earth organisms share essentially the same genetic code described in the previous section. In addition to the genetic code being the same, at the molecular level even vey different organisms such as humans, sunflowers and fruit flies have very similar molecules that perform vital life functions.

[4] http://www.pbs.org/wgbh/evolution/library/01/2/l_012_02.html

The Grade 8 Performance Expectations focus on the macroscopic rather than the molecular level. At the macroscopic level, the same underlying bone structures enable humans to throw, bats and birds to fly, whales to swim, frogs to jump, and lizards to run (Figure 20). Students can recognize the ***pattern*** that even though all these organisms look very different from each other, they share the exact same bone structure (including the number of bones and their relative position). Students can use as **evidence for this claim** the data that these "arms" all have a single upper bone (Humerus) that is attached at a joint to two different bones (Radius and Ulna) that is then attached in the wrist area to the Carpal bones and then radiate outward through many-boned fingers.

Comparing Limb Bone Structures in Different Animals

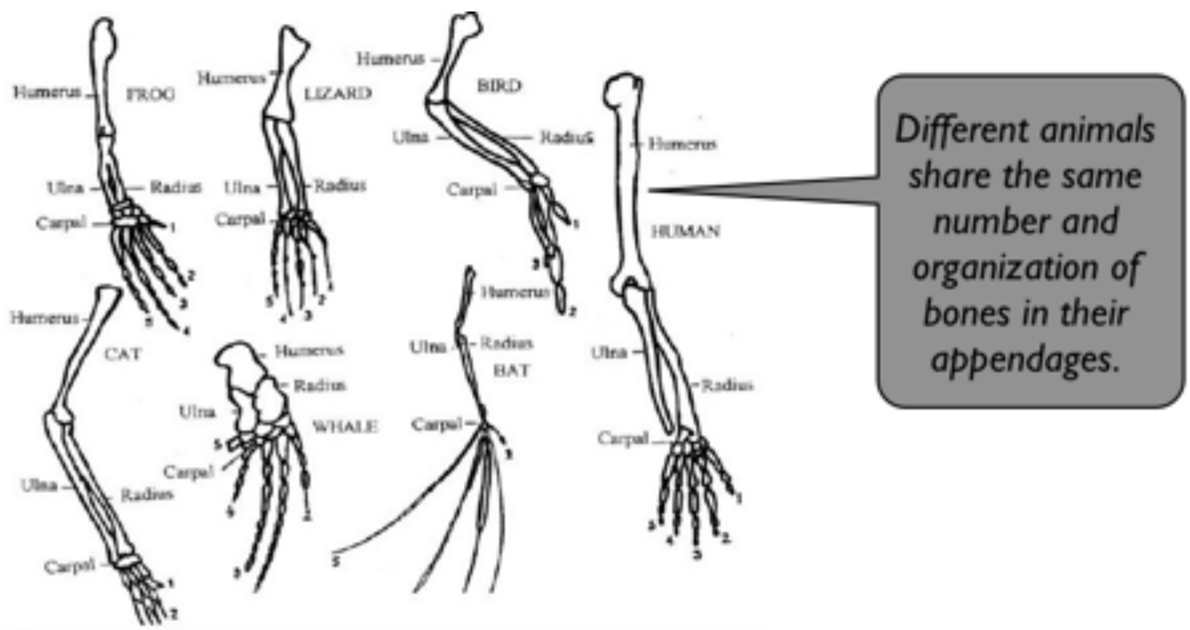

Figure 20: Anatomy reveals both the unity of basic bone structures and the diversity of organisms. (Wikibooks 2015)

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*** of the bones relates to the ***function*** of the arm. In an organism like a bat that uses its front appendage for flight, certain bones must be much longer. Organisms that walk on four legs must have bones sturdy enough to support weight, while those that walk on two legs can have front arms that are much lighter in weight than their back legs.

The similarity of organisms at molecular and macroscopic scales is best **explained** by the idea that life originated as single-celled organisms that progressively became more complex as organisms adapted to living in very different environments. Students can trace this history of life in the calendar of Earth's geologic time scale (Table 5). 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. However, life existed for about three billions years before that time, mostly as single cell organisms. Microscopic fossils are as important a part of the fossil record as more visible and dramatic fossils of larger organisms.

In addition to this unity of life, evolution accounts for life's diversity. Species are different because their locations and ancestral histories have diverged over the ages. A few fruit flies were blown to the Hawaiian islands where fruit is abundant. In this new environment, natural selection enabled fruit flies to diversify into 600 different species to take advantage of all the different island locations that had no insect like them to compete with. As a result, there are almost as many different fruit fly species in Hawaii as in the rest of the world combined. On a much bigger scale, mammals diversified to succeed in new ways of life that became available after the dinosaurs disappeared (Act 3 of the BioInteractive Mesozoic DVD).

Students can explore life's unity and diversity by **gathering and synthesizing information** about the anatomical features and the ancestral histories of a particular class of organisms or a specific species. For example, students can find patterns in the fossil record (MS-LS4-1) related to many whales whose history include land mammals that diversified and adapted to living deep in the ocean. The anatomy of Boa constrictors reveals a simple pelvis and leg bones hidden, unused within their bodies. A five-week human embryo has a beginning tail that is about 10% of its length. Very rarely, a human baby is born with an external tail. These and similar examples from anatomy (MS-LS4-2) and embryology (MS-LS4-3) provide data that students can **analyze** and use as evidence to **construct evidence-based explanations** based on resemblances due to shared ancestry and differences due to the effects of natural selection in different environments (MS-LS4-2).

Evolution and extinction are ongoing, not just processes that happened in Earth's deep past. Populations continue to evolve today, and unfortunately, the rate of extinctions appears to be rapidly accelerating due to human actions. Instructional Segment 4 explores how human actions harm biodiversity and also how humans can help sustain Earth's biodiversity.