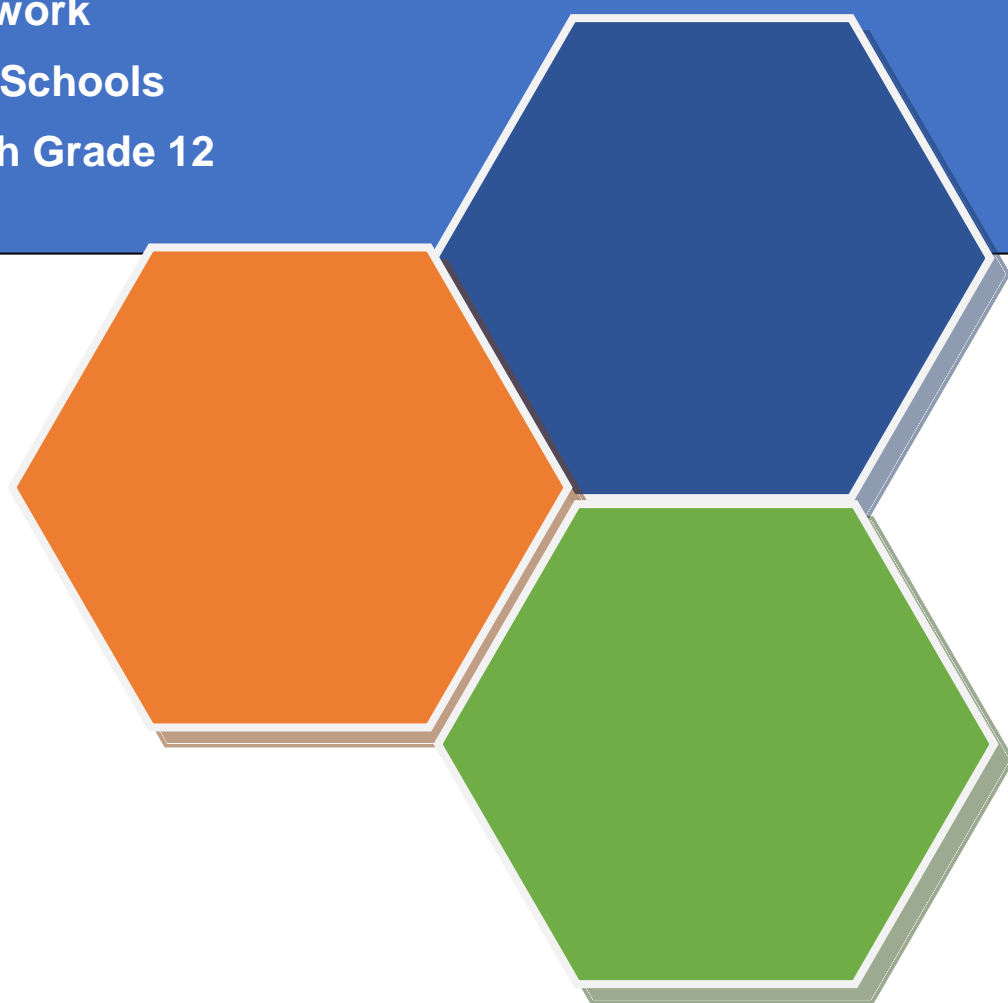# Chapter 7
High School Three Course Model

2016 Science Framework

for California Public Schools

Kindergarten through Grade 12

Chapter 7

High School Three-Course Model

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References

For an additional high school course model see appendix 4 – High School Three-Year Model: Every Science, Every Year

Introduction to Grades Nine Through Twelve

The *National Research Council's A Framework for K–12 Science Education: Practices, Crosscutting Concepts, and Core Ideas (NRC Framework)* outlined a significant new vision for science education. The Next Generation Science Standards for California Public Schools, Kindergarten Through Grade Twelve (CA NGSS), aided by the *Science Framework for California Public Schools: Kindergarten Through Grade Twelve* (*CA Science Framework*), are the first step toward translating that vision into practice.

Before schools and districts can fully implement the CA NGSS, they must organize the high school grade-banded performance expectations (PEs) into courses. This chapter describes ways in which the PEs for high school could be bundled together into units to form an appropriate sequence of courses. This chapter describes one of two high school course sequences: the High School Three-Course Model. The High School Four-Course Model is described in chapter 8. Additionally, appendix 4 in this *CA Science Framework* outlines an integrated three year high school model called "Every Science, Every Year."

Overall High School Three-course Model Introduction

The three-course model combines all high school performance expectations (PEs) into three courses. To highlight the nature of Earth and space science (ESS) as an interdisciplinary pursuit with crucial importance in California, each of the three courses present an integration of ESS and one of the other high school disciplines. In each course, the integration adds value to both disciplines in the pair, with each providing an engaging motivation for and a deeper insight into the other. ESS phenomena can serve as an engaging motivation for studying the other disciplines while understanding of each discipline provides deeper insight into processes in ESS. The three courses have been explicitly titled to emphasize this synergy:

- Living Earth: Integrating Biology and Earth Science
- Chemistry in the Earth System: Integrating Chemistry and Earth Science
- Physics of the Universe: Integrating Physics and Earth & Space Science

This model has its origin with the Modified Science Domains model presented in Appendix K of the NGSS. The choice of which ESS PEs would be included with biology, chemistry, and physics courses was based on their conceptual fit. Individual districts can integrate PEs between courses differently as long as they strive to ensure that all students meet all the standards.

Organization Within Courses

The PEs are the expected outcomes resulting from a sequence of Instructional Segments (IS) that reinforce one another as students develop the underlying knowledge of each topic. Individual PEs should not be used to develop individual lessons or activities, as they are insufficient to specify the full organization of a coherent curriculum. Rather, a bundle of selected PEs provides the breadth and depth required to address the key content ideas that students need. PEs within each course in this document are therefore bundled into instructional segments, and an effort is made to provide an expanded description of the science concepts indicated in the Disciplinary Core Ideas (DCIs) that underlie the specific set of PEs. Furthermore, the Clarification Statements and Assessment Boundaries associated with the PEs in the bundle were used to suggest student investigations aligned with the vision of three-dimensional learning: students engage in Science and Engineering Practices (SEPs) to learn DCIs that are understood better when linked together by Crosscutting Concepts (CCCs). The SEPs, DCIs, and CCCs grow in sophistication and complexity throughout the K–12 sequence. While this chapter calls out examples of the three dimensions in the text using color coding, each element should be interpreted with this grade-appropriate complexity in mind (Appendix 1 of this *Framework* clarifies the expectations at each grade span in the developmental progression).

This *CA Science Framework* provides examples and suggestions, it does not dictate requirements. The selections of PEs in each IS bundle presented in this chapter are only one example of the way PEs could be coherently organized. There are a variety of possible alternative paths and different interplays among overarching themes identified in each IS bundle. Educators should consider their local context as they reflect upon these examples. Instructional sequences are most effective when they are designed to meet the need of the specific students that will be participating in them.

The teaching of science and engineering content should be integrated with the teaching of the practices of scientists and engineers. It is through the integration of content and practices "that science begins to make sense and allows students to apply the material" (NGSS Lead States 2013c). The CA NGSS encourage teachers and

students to engage with specific topics in depth, emphasizing critical thinking along with primary investigations such as in the context of case-studies.

Essential Shifts in the CA NGSS

A cursory review of the CA NGSS PEs and the 1998 California Science Standards reveals a significant change in emphasis. With the exception of the Investigation and Experimentation standards, all of the standards in the 1998 Science Standards start with the phrase "Students will know…" By contrast, the performance expectations of the CA NGSS emphasize higher level reasoning through phrases directly linked to the eight SEPs such as: "plan and conduct…", "develop models…", "communicate…", "support the claim…" etc. Although the number of PEs in the CA NGSS is smaller than the number of standards in the 1998 Science Standards, they require a deeper understanding. It is critical that teachers look at the verbs embedded in each PE to understand what students are expected to do. It is no longer sufficient for students to simply "know" facts about science, they need to be able apply science and engineering practices to uncover and elucidate CCCs that have applications across many DCIs. In addition to this *CA Science Framework*, the NGSS Evidence Statements offer a concise overview of the pieces that students must know and be able to do in order to meet the PEs.

All Standards, All Students

The PEs of the CA NGSS for the high school level are the assessable statements of what *all* students should know and be able to do by the end of twelfth grade. In other words, the PEs represent the minimal assessable standards for which all high school students should be held accountable. Each of the PEs have "assessment boundaries" to guide those who construct standardized assessments. Thus, the PEs set a minimum goal, and high school science teachers should include additional expectations as appropriate for the goals of their courses. Teachers should pay close attention to the

DCIs, SEPs, and CCCs and develop each to the depth appropriate for the goals of their class using the resources in the NGSS Appendices.

Course Sequencing Discussion

California's high schools operate largely under local control. As such, course offerings and the order courses are offered for high school science are district decisions. As a result, this framework prescribes neither the courses to be offered nor the order in which they are offered. Instead, districts may consider multiple course sequences. The proposed Every Science, Every Year integrated model has a set sequence but the four-course discipline specific and three-course integrated Earth and space science models do not.

As decision makers, you have several factors to consider when deciding what will best meet your students' needs. Try not to let tradition and staffing be the only factors you consider as you make these choices. Since students learn the same eight SEPs and seven CCCs in all science classes, we are focusing on DCIs in this discussion.

The order in which high school science courses have traditionally been offered, Biology – Chemistry – Physics, has been in place for more than 100 years since the Committee of Ten first met, and may not make the most sense in our 21st century world. As you and your colleagues decide among the twenty four permutations for course sequence in the four-course model and six for the three-course model you need to be thoughtful about your choices and consider carefully the implications of the selected sequence. Strong arguments can be made for any of the sequences.

The questions and prompts below are meant to help your team with the decision.

- Is your goal to get students to take more science and science, technology, engineering and math (STEM) classes? If so, consider placing the most engaging and exciting classes as the first courses in the sequence. That may recruit more students into STEM and science classes (and possible STEM related careers and college majors).

- What course(s) are viewed as most important to your community? Put those classes first because some percentage of your students will take the minimum requirements for graduation.

- How many science classes are students in your district required to take in order to graduate? How many science classes do students in your school typically take? What science concepts and ideas do you want to be sure that all students have if they do not take the full scope of NGSS? These questions all have implications for choosing which classes (and ideas) come earliest.

- What science ideas do you think juniors and seniors are more developmentally ready to learn than freshmen and sophomores?

- What concepts and ideas do you think are more concrete so should be placed earlier in the sequence, with more abstract ideas coming later in the learning process?

- As you consider individual discipline focused classes, look at the Performance Expectations. Are there PEs from other disciplines that should be mastered for students to be successful in your particular course? If so, that has implications for sequencing.

The decision you are being asked to make is nontrivial. We urge you to spend time on the decision. Ultimately, your department/district needs to determine a two-, three- or four-year sequence of courses offerings. Whichever course sequence you select needs to consider the learning that takes place in earlier classes that will support and impact learning that comes later. The purpose of science classes is not merely to prepare students for other courses, but they are interconnected and disciplines overlap (think

about those crosscutting concepts which underpin all of science). Ideas and concepts learned in one content area come into play when learning a new science discipline. These should be considered as you determine what order to place courses.

Living Earth Early or Late in the Sequence?

Biology has a better track record of interesting girls in science (AAUW 2010; Baram-Tsabari and Yarden 2011), some teachers are more comfortable with its earlier placement in the sequence, and kids are generally interested in themselves, so a course that helps them understand themselves could be a good starting point. However, modern biology requires understanding and applying chemistry and physics–much of biology today explores and explains things at the molecular or cellular level. How could topics in a high school biology course be taught differently if chemistry, for example, were taken prior to biology as opposed to afterwards?

Chemistry in the Earth System Early or Late in the Sequence?

As mentioned above, modern biology is heavily influenced by chemistry. Having chemistry prior to biology may be instructionally efficient. For example, concepts already studied in a chemistry class should require less emphasis and subsequently less time leaving room for more in-depth biology concepts. On the other hand, chemistry is rather abstract, dealing with phenomena unseen to the naked eye and frequently not intuitive to students. Knowing your students and community will help you decide if they can handle the more abstract science ideas earlier in their academic career. An understanding of physics prior to chemistry could help students better understand atomic structure, electron shells and orbitals, and bonding. Just as comfort with mathematics is an argument used for determining where physics should be offered, it can be argued that chemistry also requires a level of mathematical competence.

Physics of the Universe Early or Late in the Sequence?

Physics has traditionally been offered late in the sequence to a small population of students (it tends to be an elective course with most students electing not to take it). Many argue physics later in the course sequence allows concepts to be introduced through a more mathematically rigorous lens. Others argue physics earlier in the sequence is approachable to students as the concepts are concrete and relate to students' everyday life. Physics prior to chemistry means students bring an understanding of the mechanisms for much of the physical world to their studies. Physics after chemistry allows the opportunity to revisit ideas learned earlier. Physics early in the sequence, taken by all students, might attract more students to pursue the physical sciences – especially girls and underrepresented populations who traditionally avoid the physical sciences (Institute of Physics 2006).

Credential Information

The California Commission on Teacher Credentialing authorizes the majority of high school science teachers to teach courses that integrate the sciences across content areas. (See the California Commission on Teacher Credentialing, Specialized Single Subject Science Credentials and Alignment with the CA NGSS at http://www.ctc.ca.gov/commission/agendas/2014-08/2014-08-4C.pdf.) This includes course models that integrate Earth and Space Science with the domains of Biology, Chemistry, or Physics. While many teachers will need additional professional development, their understanding of the SEPs and CCCs should provide them with a firm foundation to teach courses in this sequence. For specific information, contact the California Commission on Teacher Credentialing at http://www.ctc.ca.gov for questions about authorization to teach integrated courses.

High School Three-course Model

The Living Earth

The interactions between the biosphere and the rest of Earth's systems influence students every day from the food that they eat to the air that they breathe. In high school, students finally have enough understanding to explain patterns that they identified and asked questions about during their K–8 education. Some of these mechanisms occur in the blink of an eye while others take millions of years to unfold. Despite the extreme spans in scale, students have tools to use evidence, evaluate claims, and develop models to interpret the unseen. Students begin with phenomena and use them to enhance their understanding of core ideas in biological science and Earth and space sciences.

The Next Generation Science Standards for California Public Schools, Grades Kindergarten Through Grade Twelve (CA NGSS) do not specify which phenomena to explore or the order to address topics because phenomena need to be relevant to the students who live in each community and should flow in an authentic manner. This chapter illustrates one possible set of phenomena that will help students achieve the CA NGSS Performance Expectations (PEs). Many of the phenomena selected illustrate California's Environmental Principles and Concepts (EP&Cs), which are an essential part of the CA NGSS (see chapter 1 of this *CA Science Framework*). However, the phenomena chosen for this statewide document will not be ideal for every classroom in a state as large and diverse as California. Teachers are therefore encouraged to select phenomena that will engage their students and use this chapter's examples as inspiration for designing their own instructional sequence. For example, the course could be restructured around contemporary issues of health or ecosystem change faced by a local community.

This example course is divided into instructional segments (IS) centered on questions about observations of a specific phenomenon. Different phenomena require different amounts of investigation to explore and understand, so each IS should take a different fraction of the school year. As students achieve the PEs within the IS, they

uncover Disciplinary Core Ideas (DCIs) from Life Science and engineering. Students engage in multiple practices in each IS, not only those explicitly indicated in the PEs. Students also focus on one or two **Crosscutting Concepts (CCCs)** as tools to make sense of their observations and investigations; the CCCs are recurring themes in all disciplines of science and engineering and help tie these seemingly disparate fields together.

This chapter clarifies the general level of understanding required to meet each PE, but the exact depth of understanding expected of students depends on this course's place in the overall high school sequence. Teachers could modify the content and complexity so that the course serves as a basic freshman introduction to science, serves as a senior capstone that integrates and applies science learning from all previous science courses, or aligns with the expectations of Advanced Placement or International Baccalaureate curriculum.

Example Course Mapping for an Integrated Life and Earth Science Course

This section presents the life science and selected Earth science CA NGSS PEs organized into six embedded units (table 7.1). The sequence presented here spirals in scale (figure 7.1), starting with ecosystems as a whole (looking at both living and non-living components), progressing into connections within ecosystems describing the cycling of matter in two important life processes: photosynthesis and respiration while also emphasizing the non-living parts of these cycles. Then the course moves into evolution (where evidence is based in both living and non-living systems) and then links evolution to the study of heredity. From there the course zooms in more (progressing to smaller scales) to what defines characteristics of life from the cell to multicellular organisms. The course ends by coming back full circle to ecosystems and the impacts that humans have on them especially in relationship to climate change. A culminating project for this course should present a synthesis of how life on Earth is dependent on both biotic and abiotic factors.

Table 7.1. Overview of Instructional Segments for High School Living Earth

	1 Ecosystem Interactions and Energy	Students use mathematical and computer models to determine the factors that affect the size and diversity of populations in ecosystems, including the availability of resources and interactions between organisms.
	2 History of Earth's Atmosphere: Photosynthesis and Respiration	Students make a model that links photosynthesis and respiration in organisms to cycles of energy and matter in the Earth system. They gather evidence about the linked history of Earth's biosphere and atmosphere.
	3 Evidence of Evolution	Students develop a model about how rock layers record evidence of evolution as fossils. Building on their learning from previous grades, they focus on effectively communicating this evidence and relate it to principles of natural selection.
	4 Inheritance of traits	Students develop explanations about the specific mechanisms that enable parents to pass traits on to their offspring. They make claims about which processes give rise to variation in deoxyribonucleic acid (DNA) codes and calculate the probability that offspring will inherit traits from their parents.

	5 Structure, Function, and Growth (from cells to organisms)	Students use models to create explanations of how cells use DNA to construct proteins, build biomass, reproduce, and create complex multicellular organisms. They investigate how these organisms maintain stability.
	6 Ecosystem Stability & the Response to Climate Change	Students use computer models to investigate how Earth's systems respond to changes, including climate change. They make specific forecasts and design solutions to mitigate the impacts of these changes on the biosphere.

Sources: Savery 1628; adapted from Caulfield 2012; Rafandalucia 2016; Grant 2010; adapted from Castro 2008; Peters 2007; adapted from d'Alessio 2013.

Figure 7.1. Conceptual Flow of Instructional Segments in Example High School Living Earth Course
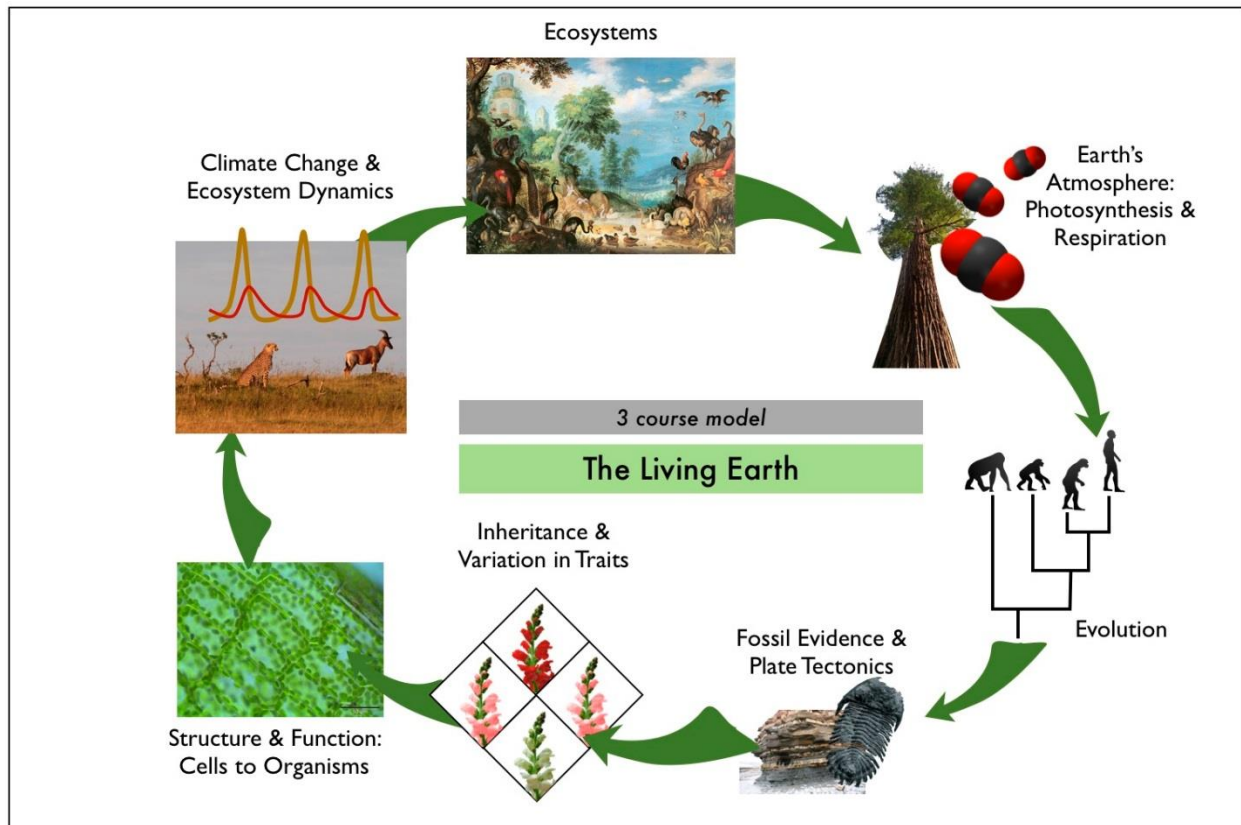
Sources: Savery 1628; adapted from Caulfield 2012; M. d'Alessio using image from Tkgd2007; Grant 2010; Rafandalucia 2016; adapted from Castro 2008; Peters 2007; adapted from d'Alessio 2013.

Living Earth – Instructional Segment 1: Ecosystem Interactions and Energy

An ecosystem is a biological system, and IS1 begins with a systems-based approach to ecosystems. Students focus on both biotic and abiotic conditions in a way that integrates LS and ESS DCIs.

Living Earth – Instructional Segment 1:
Ecosystem Interactions and Energy
Guiding Questions: • What factors affect the size of populations within an ecosystem?   • What are common threats to remaining natural ecosystems and biodiversity? How can these threats be reduced?
Performance Expectations
Students who demonstrate understanding can: **HS-LS2-1. Use mathematical and/or computational representations to support explanations of factors that affect carrying capacity of ecosystems at different scales.** [Clarification Statement: Emphasis is on quantitative analysis and comparison of the relationships among interdependent factors including boundaries, resources, climate, and competition. Examples of mathematical comparisons could include graphs, charts, histograms, and population changes gathered from simulations or historical data sets.] [*Assessment Boundary: Assessment does not include deriving mathematical equations to make comparisons.*]   **HS-LS2-2. Use mathematical representations to support and revise explanations based on evidence about factors affecting biodiversity and populations in ecosystems of different scales.** [Clarification Statement: Examples of mathematical representations include finding the average, determining trends, and using graphical comparisons of multiple sets of data.] [*Assessment Boundary:*

Assessment is limited to provided data.]

HS-LS2-4. Use mathematical representations to support claims for the cycling of matter and flow of energy among organisms in an ecosystem. [Clarification Statement: Emphasis is on using a mathematical model of stored energy in biomass to describe the transfer of energy from one trophic level to another and that matter and energy are conserved as matter cycles and energy flows through ecosystems. Emphasis is on atoms and molecules such as carbon, oxygen, hydrogen and nitrogen being conserved as they move through an ecosystem.] [*Assessment Boundary: Assessment is limited to proportional reasoning to describe the cycling of matter and flow of energy.*]

HS-LS2-8. Evaluate the evidence for the role of group behavior on individual and species' chances to survive and reproduce. [Clarification Statement: Emphasis is on: (1) distinguishing between group and individual behavior, (2) identifying evidence supporting the outcomes of group behavior, and (3) developing logical and reasonable arguments based on evidence. Examples of group behaviors could include flocking, schooling, herding, and cooperative behaviors such as hunting, migrating, and swarming.]

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	LS2.A: Interdependent Relationships in Ecosystems	[CCC-2] Cause and Effect

[SEP-3] Planning and Carrying Out Investigations [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-8] Obtaining, Evaluating, and Communicating Information	LS2.D: Social Interactions and Group Behavior	[CCC-3] Scale, Proportion, and Quantity [CCC-4] System and System Models [CCC-5] Energy and Matter: Flows, Cycles, and Conservation

Highlighted California Environmental Principles & Concepts:

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

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

CA CCSS Math Connections: N-Q.1-3; S-ID.1; S-IC.1,6; MP.2, MP.4

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

CA CCSS ELA/Literacy Connections: RST.9-10.8; RST.11-12.1,7,8; WHST.9-12.2a-e

A **system [CCC-4]** includes component parts, interactions between those parts, and exchanges of **energy and matter [CCC-5]** to the world outside the system. Ecosystems contain living and non-living components that influence one another. In a way, an ecosystem is a microcosm of the entire Earth, whose components are so complicated that it is often referred to as a "system of systems." To help organize thinking about these sub systems, scientists have divided up earth materials and processes into five general groupings, each of which is shaped by its own internal workings and its interactions with the other **systems [CCC-4]**:

- Atmosphere: gases around the Earth (i.e., our air)
- Hydrosphere: all the water (sometimes ice is separated out into the cryosphere)
- Biosphere: all life
- Geosphere: inorganic rocks and minerals
- Anthrosphere: humanity and all of its creations (This sphere is not specifically mentioned in the *NRC Framework* [2012] because it is primarily part of the biosphere. Separating this sphere out emphasizes the significant influences humans have on the rest of Earth's systems and is consistent with the EP&Cs that are part of the CA NGSS).

This course centers on the biosphere and examines how it interacts with each of the other Earth systems. Teachers can introduce the biosphere by taking students to local ecosystems (either physically or virtually) to observe populations of plants and animals, to identify specific threats to biodiversity, and to consider alternative proposals to lessen those impacts. This local context can be a thread throughout the course.

Systems [CCC-4] are characterized by the **flow of energy and cycling of matter [CCC-5]** between their components. At the middle grade level, students constructed models of these flows (*MS-LS2-3*) analyzed data about resource availability within a

system (*MS-LS2-1*) and explained patterns in the way organisms interact (*MS-LS2-2*). This IS builds on that understanding by using more detailed **mathematical models [SEP-2]** of ecosystems, including the size of different populations. Biologists use a specific definition of population: a group of individuals from the same species living together in the same geographical area at the same time.

Using mathematical **mathematics and computational thinking [SEP 4] and modeling [SEP-2],** students can predict the effect certain interdependent factors have on the size of a population over time. The number of individuals within a population depends on birth rates, death rates, immigration, and emigration. Population growth rate is defined as the change in numbers of individuals (ΔN) divided by time (Δt). While some populations grow very quickly, populations cannot continue to grow exponentially forever. At some point they reach a maximum load that the environment they live in can handle called the 'carrying capacity.' Students can use computer simulations[1] to **conduct investigations [SEP-3]** that test how different parameters **change [CCC-7]** population sizes, and then **analyze their findings [SEP-4]** (HS-LS2-1). Graphing their results, they can describe the population changes **mathematically [SEP-5]** (HS-LS2-2). Initially growth will be exponential, but students should be able to recognize the point on the graph where competition for resources begins to dramatically impact the population size.

Students can use simulations to recognize two general types of factors that limit population growth: Density dependent factors and density independent factors. Many factors are 'density dependent' such as food resources, space, nesting sites, and water, meaning that the amount of these resources required depends on the population size. 'Density independent factors' alter the number of individuals in a population regardless of how many individuals already exist. IS1 focuses on density dependent factors while IS6 introduces density independent factors that often relate to interactions with other parts of the Earth system, such as weather pattern changes or catastrophic events like hurricanes, floods, landslides, volcanoes, etc. Nonetheless, introducing these two

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[1] There are many simulation/games available online that allow students to manipulate certain parameters that affect populations, example might be food resources or overcrowding.

categories together can help students understand **proportion and quantity [CCC-3]** in density dependent cases and how that is eliminated in density independent cases. Both density dependent and independent factors affect the **flow of energy and matter [CCC-5]** within and into a system, which is ultimately the way in which they **affect [CCC-2]** the size of populations.

Many times, humans alter the availability of resources and change the landscape. For example, if a new freeway gets built dividing a population's territory in half and limiting its migration, how will this cause both density dependent and density independent changes to the ecosystem? Human induced changes to climate also cause changes. The Education and the Environment Initiative (EEI) Curriculum Ecosystem Change in California, which focuses on changes in a grassland ecosystem in the state provides guidance teaching EP&Cs II and IV as students obtain information about both the positive and negative ways humans influence ecosystem resources.

One of the resources organisms compete for is the food from which they obtain their energy. Organisms store potential energy within the chemical bonds of the matter in their bodies. As individual organisms grow and when populations become more plentiful, more total energy is stored. Biomass is the dry weight of all of the living organisms in an ecosystem and is related to the amount of energy available for these organisms. As a general rule, when an animal eats, it is only able to store about 10 percent of the energy from its food to build up its own energy stores. The rest of the energy is lost due to inefficient digestive processes or utilized in respiration to keep the animal alive long enough to eat again. As a result, each higher trophic level ends up with available energy that is just 10 percent the size of the level below it, creating a pyramid-like structure in population sizes with the lowest trophic levels at the base of the pyramid.

Using the **conceptual model [SEP-2]** of this energy pyramid, students find that very large populations of producers are required to support much smaller populations of tertiary consumers for the ecosystem to remain *stable [CCC-7].* Mathematical **models [SEP-2]** utilize this principle to predict the size of a predator populations given known populations of prey at other trophic levels. Students can explore many computer

simulations and hands-on demonstrations that so that they can support claims about the relative amounts of energy in different trophic levels (HS-LS2-4).

Energy flows from abiotic (non-living forms) to biotic (living) forms, starting with sunlight or other light sources and inorganic compounds in producers and moving through consumers and decomposers. Nutrients (matter) cycle in the same manner. They can exist in forms that are largely abiotic such as carbon dioxide (CO_2) and nitrogen (N_2) and move into living organisms (biotic) in a different form such as glucose ($C_6H_{12}O_6$) or starch (many joined glucoses) and nitrates (NO_3^-). The movement from abiotic to biotic molecular forms involves living processes. For carbon (figure 7.2), these processes are photosynthesis and cellular respiration (discussed in IS2). For nitrogen, 'nitrogen-fixing' bacteria change nitrogen gas into nitrates while bacterial decomposers change ammonia and nitrates back into nitrogen. In some cases, abiotic processes can do a similar job. When a lightning bolt travels through the atmosphere, its energy can break apart molecules of nitrogen in the air; free nitrogen atoms bond with oxygen to create nitrate that gets carried to the soil by raindrops. Other nutrients are involved in similar cycles (such as the phosphorous cycle as it relates to DNA or how climate change alters the calcium cycle by affecting hard-shelled marine organisms). Students can develop **models [SEP-2]** on paper, with technology, using their body moving around the room to represent the flow through different processes, or as a chemical model using organic chemistry molecule kits. The models show how simple inorganic molecules are made into larger organic molecules and then how they cycle back to the simple inorganic molecules.

Figure 7.1. The Carbon Cycle includes Biotic and Abiotic Processes
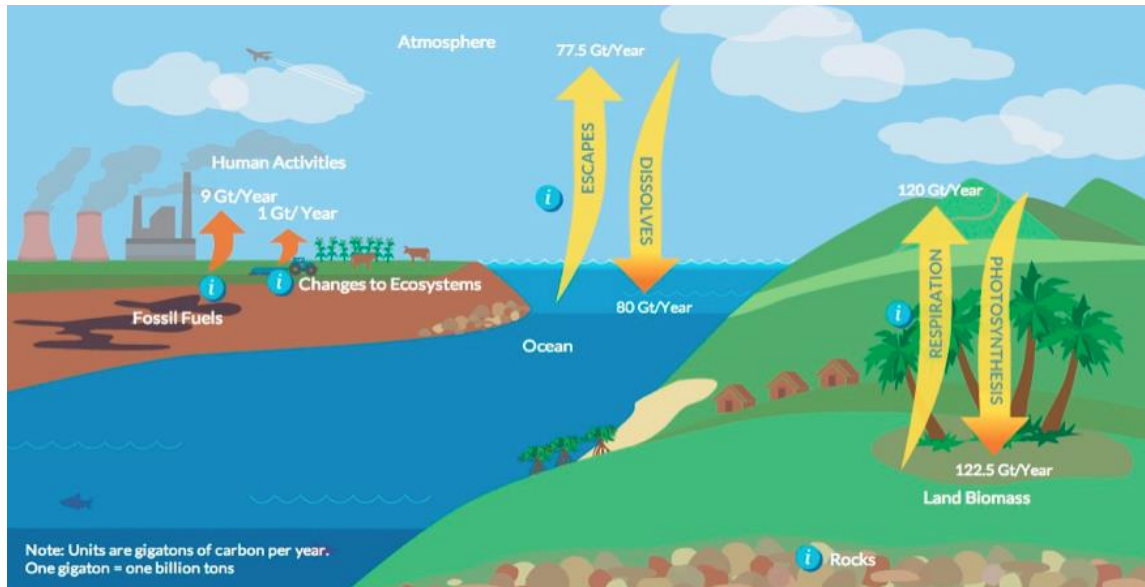
Source: WGBH n.d.

While carbon and nitrogen are essential nutrients, toxic material also cycles through the ecosystem. Humans are major sources of disruptions to nutrient cycles, including adding toxins. Students can **obtain information [SEP-8]** about how mercury accumulates in certain fish species and learn about the impacts this can have on human health. Human activities such as coal power plants have added significant amounts of mercury to the environment (CA EP&Cs III & IV).

Up to this point, this IS has considered how **flow of energy and matter [CCC-5]** between populations in an ecosystem and how that flow helps determine the size of a given population. Now, students zoom in and see how each population itself acts like a **system [CCC-4]** whose members can interact. Students will look closely at the behaviors of populations that help those populations survive (HS-LS2-8). For a population to succeed and not become a genetic dead end, the gene pool (the set of all the different genes) of the population must be passed on to the next generation. Producing a new generation of healthy offspring capable of successful reproduction is important for a population's survival.

High School Living Earth Snapshot 7.1. Does Living as a Group or Individual Help You Survive?

Anchoring phenomenon: Prairie dogs squeak and communicate to one another as they work together to fight off a snake that intrudes into their colony.

Mr. T starts class showing a short video clip on prairie dogs and how they sound alarms to protect their family units against snakes (for example, NatGeoWild, Prairie Dog Snake Alarm: https://www.youtube.com/watch?v=icaGIeOY9gc). He then asks the students to do a quickwrite on what behavior the prairie dogs use to protect themselves and how did that behavior help their family?

Students will play a game that is actually a physical **model [SEP-2]** of individual and group behavior. Students use their bodies to represent components in a **system [CCC-4]** that have a predator-prey relationship. Since Mr. T has 30 students he designates two students who will act as predators. He needs an even number of students as prey, so the 28 students that are left are now prey. Mr. T now randomly hands each prey a white index card that has a color code on it. Each color represents a different genotype. Mr. T set the cards up ahead of time so that there are four cards for each color (i.e., four blue cards, four yellow cards, four green cards, four red cards, etc.).

For the first round (prey living as *Individuals)* the predators and prey will NOT have knowledge about the individual's genetics (in other words they will not know who is genetically related to whom). Mr. T instructs the 28 prey to randomly wander around the open area and after one minute he signals the predators to "attack". The predators then tag a prey. That individual steps out of the group and the rest of the students continue wandering and again Mr. T signals for "attack" and again each predator selects an individual who then steps out of the group. After seven attacks, half the prey (14 individuals) have been tagged. Now a recorder tallies all the colors left on a shared class spreadsheet showing how many of each genotype survived (for example, 0 blue, one yellow, …).

Now Mr. T assigns two different students as predators and tells them to go sit in the corner and hide their eyes while he re-distributes the index cards to the remaining 28

students who are again the prey. This time he tells the prey students to quietly (so the predators don't know) find the other students who share their color. These four students have the same genotypes and represent a grouping of kin. The second round (*altruistic prey in groups*) now begins. Since Mr. T has a big open area he will blindfold the predators. This is so they cannot "learn" about genotypes and relatives within the prey groups. The group units now randomly wander in the space and again Mr. T signals the predators to "attack". The groups can surround an individual so that when they are tagged the individual prey is "saved" and that prey does not get eliminated. Each genotype/color group gets only one save in this round and after that save if anyone in the group is tagged again, they will be eliminated. This rule is designed to simulate the cost: benefit ratio of altruism. Saving a member of your group incurs an individual cost because it means your group will not be able to save you during the next attack. The benefit is that the group to which you belong is more likely to survive as a whole. The game continues for a total of seven "attacks." This time there may be less than 14 individuals that were eliminated due to the individuals who were saved by the "herding" effect of their group. Now a recorder can tally all the colors and numbers of individuals for each color left in the group on the shared class spreadsheet.

Mr. T reassigns the roles of each of the students (picking new predators and shuffling the genotype cards) to prevent "learning" by predators. The class enacts each scenario one more time.

After the class completes the four rounds of the game, Mr. T has the students look at the whole class data that has been recorded. He defines the terms 'individual fitness' (your ability to pass on your genes) and 'inclusive fitness' (your individual fitness plus indirect fitness due to belonging to a group that herds to save individuals). Mr. T then asks the students to use these terms to describe the similarities and differences they saw between the two scenarios and **explain [SEP-6]** how inclusive behavior (group behavior) can be advantageous for some populations (HS-LS2-8). Mr. T wants the students to specifically address what the "save" meant in altruistic group scenario. Students should use examples of animals that they know that use *inclusive fitness behaviors.* The students may talk about the prairie dogs (as in the video), dolphin pods,

rabbit warrens, bird flocks, monkey troops, or any other social, family or group behavior. Mr. T ends class showing a video clip where water buffalo work as a group to counter attack lions that have surrounded an individual water buffalo (for example, NatGeoWild, Buffalo Herd Counter Attack: http://channel.nationalgeographic.com/wild/caught-in-the-act/videos/buffalo-herd-counter-attack/). What was the individual fitness of the animal being attacked? How does its fitness change because of the behavior of the group?

The rest of this course zooms-in to explain many of the mechanisms that drive the processes described in this IS. At the end of the course (IS6), students will return to ecosystems and human impacts to revisit their models and address more complex ecosystem interactions. As preparation, IS1 can introduce the idea that urbanization, building of dams, and dissemination of invasive species are active parts of the **flow of energy and cycling of matter [CCC-5]** within almost all ecosystems, even those that appear relatively 'undisturbed' (CA EP&Cs II & IV).

Living Earth – Instructional Segment 2: History of Earth's Atmosphere: Photosynthesis and Respiration

In the middle grades, students explained the role photosynthesis plays in cycling of matter by the production of sugars (food) using light energy and carbon dioxide (MS-LS1-6), and developed a model of how food molecules can be rearranged to extract usable energy (MS-LS1-7). They also are already familiar with cycles of matter within a system from their investigation of the water cycle (5-LS2-1, MS-ESS2-4). In this IS, students explore the **cycling of matter [CCC-5]** between the biosphere and the rest of Earth's **systems [CCC-4].**

Living Earth – Instructional Segment 2: Earth's Atmosphere: Photosynthesis and Respiration
Guiding Questions: • How do living things acquire energy and matter for life? • How do organisms store energy? • How are photosynthesis and cellular respiration connected? • How do organisms use the raw materials they ingest from the environment? • How has the cycling of energy and matter changed over Earth's history?
Performance Expectations
Students who demonstrate understanding can: **HS-LS1-5. Use a model to illustrate how photosynthesis transforms light energy into stored chemical energy.** [Clarification Statement: Emphasis is on illustrating inputs and outputs of matter and the transfer and transformation of energy in photosynthesis by plants and other photosynthesizing organisms. Examples of models could include diagrams, chemical equations, and conceptual models.] [*Assessment Boundary: Assessment does not include specific biochemical steps.*] **HS-LS1-6. Construct and revise an explanation based on evidence for how carbon, hydrogen, and oxygen from sugar molecules may combine with other elements to form amino acids and/or other large carbon-based molecules.** [Clarification Statement: Emphasis is on using evidence from models and simulations to support explanations.] [*Assessment Boundary: Assessment does not include the details of the specific chemical reactions or identification of macromolecules.*] **HS-LS1-7. Use a model to illustrate that cellular respiration is a chemical**

process whereby the bonds of food molecules and oxygen molecules are broken and the bonds in new compounds are formed resulting in a net transfer of energy.[Clarification Statement: Emphasis is on the conceptual understanding of the inputs and outputs of the process of cellular respiration.] [*Assessment Boundary: Assessment should not include identification of the steps or specific processes involved in cellular respiration.*]

HS-LS2-3. Construct and revise an explanation based on evidence for the cycling of matter and flow of energy in aerobic and anaerobic conditions. [Clarification Statement: Emphasis is on conceptual understanding of the role of aerobic and anaerobic respiration in different environments.] [*Assessment Boundary: Assessment does not include the specific chemical processes of either aerobic or anaerobic respiration.*]

HS-LS2-5. Develop a model to illustrate the role of photosynthesis and cellular respiration in the cycling of carbon among the biosphere, atmosphere, hydrosphere, and geosphere. [Clarification Statement: Examples of models could include simulations and mathematical models.] [*Assessment Boundary: Assessment does not include the specific chemical steps of photosynthesis and respiration.*]

HS-ESS1-6. Apply scientific reasoning and evidence from ancient Earth materials, meteorites, and other planetary surfaces to construct an account of Earth's formation and early history. [Clarification Statement: Emphasis is on using available evidence within the solar system to reconstruct the early history of Earth, which formed along with the rest of the solar system 4.6 billion years ago. Examples of evidence include the absolute ages of ancient materials (obtained by radiometric dating of meteorites, moon rocks, and Earth's oldest minerals), the sizes and compositions of solar system objects, and

the impact cratering record of planetary surfaces.]

HS-ESS2-6. Develop a quantitative model to describe the cycling of carbon among the hydrosphere, atmosphere, geosphere, and biosphere. [Clarification Statement: Emphasis is on modeling biogeochemical cycles that include the cycling of carbon through the ocean, atmosphere, soil, and biosphere (including humans), providing the foundation for living organisms.]

HS-ESS2-7. Construct an argument based on evidence about the simultaneous coevolution of Earth's systems and life on Earth. [Clarification Statement: Emphasis is on the dynamic causes, effects, and feedbacks between the biosphere and Earth's other systems, whereby geoscience factors control the evolution of life, which in turn continuously alters Earth's surface. Examples of include how photosynthetic life altered the atmosphere through the production of oxygen, which in turn increased weathering rates and allowed for the evolution of animal life; how microbial life on land increased the formation of soil, which in turn allowed for the evolution of land plants; or how the evolution of corals created reefs that altered patterns of erosion and deposition along coastlines and provided habitats for the evolution of new life forms.] *[*Assessment Boundary: Assessment does not include a comprehensive understanding of the mechanisms of how the biosphere interacts with all of Earth's other systems.]

HS-ESS3-6. Use a computational representation to illustrate the relationships among Earth systems and how those relationships are being modified due to human activity.* [Clarification Statement: Examples of Earth systems to be considered are the hydrosphere, atmosphere, cryosphere, geosphere, and/or biosphere. An example of the far-reaching impacts from a human activity is how an increase in atmospheric carbon dioxide results in an increase in

photosynthetic biomass on land and an increase in ocean acidification, with resulting impacts on sea organism health and marine populations.] [Assessment Boundary: Assessment does not include running computational representations but is limited to using the published results of scientific computational models.] (Introduced but not fully assessed until IS6)

*The performance expectations marked with an asterisk integrate traditional science content with engineering through a practice or disciplinary core idea.

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	LS4.A: Evidence of Common Ancestry and Diversity	[CCC-1] Patterns
[SEP-3] Planning and Carrying Out Investigations	LS4.B: Natural Selection	[CCC-2] Cause and Effect
[SEP-6] Constructing Explanations (for science) and Designing Solutions (for engineering)	LS4.C: Adaptation	[CCC-4] System and System Models
	ESS1.C: The History of	[CCC-5] Energy and Matter: Flows, Cycles,

[SEP-7] Engaging in Argument from Evidence [SEP-8] Obtaining, Evaluating, and Communicating Information	Planet Earth ESS2.C: The Roles of Water in Earth's Surface Processes	and Conservation [CCC-7] Stability and Change

Highlighted California Environmental Principles & Concepts:

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.

CA CCSS Math Connections: N-Q.1-3; F.IF.5; S-ID.6.a-c; MP.2, MP.4

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

CA CCSS ELA/Literacy Connections: SL.11-12.5; RST.11-12.1,

WHST.9-12.2a-e, 5,8,9

Students can consider the phenomenon of a sealed glass sphere that supports the survival and growth of both algae and brine shrimp (figure 7.3 left). How do they survive without air flowing in? On a more advanced level, they can observe how the global atmospheric CO_2 concentrations on Earth follow a distinctive **pattern [CCC-1]** each year (figure 7.3, right; caused by the fact that there is more land in the northern

hemisphere and therefore more respiration during the growing season of the northern hemisphere summer). They should be able to explain and model each of these processes by the end of this IS.

Figure 7.2. Phenomena Illustrating Relationship Between Photosynthesis and Respiration
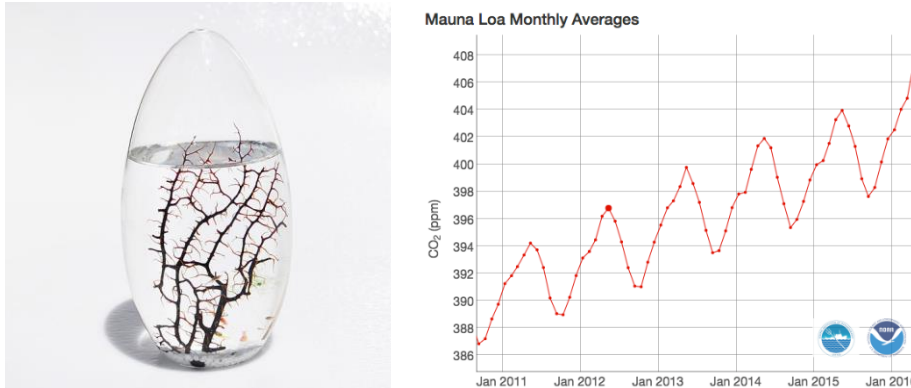
A sealed sphere that supports survival of both brine shrimp and algae (left). CO_2 levels are highest in June each year and cycle annually (right). Source: Source: Ecosphere Associates Inc. 2013 and National Oceanic and Atmospheric Administration (NOAA) 2016b.

All living organisms need energy, and students traced the flow of energy in ecosystems back to plants and the Sun in elementary school. Photosynthesis by producers involves two interdependent cellular processes: capturing sunlight/light energy by chloroplasts and using that energy to fix atmospheric carbon dioxide into a glucose molecule. Plants either use the glucose directly or store energy by connecting glucose molecules together to form starch (which is easier to store).

Opportunities for ELA/ELD Connection

Working with a partner, students select a law of thermodynamics to research and construct an explanation to answer, "How is energy transferred and conserved?" and "How can energy be harnessed to perform useful tasks?" Each pair must research multiple print and digital sources, synthesize and summarize the key points, and present their findings using a visual display (e.g., poster, slides, handouts). The presentation should include a general description/definition of the law plus an example demonstrating the application of the principle.

CA CCSS ELA/Literacy Standards: RST.9–12.1, 2, 7, 9; WHST.9–12. 7, 8

CA ELD Standards: ELD.PI.9–12.6, 9

Heterotrophs (consumers or animals) ingest producers as food that they use for energy and building blocks for growth. Consumers often store energy in stacked glucose molecules in the form of glycogen (in higher animals, glycogen is stored in liver and muscle tissues). Both plants and animals use cellular respiration as the process by which organic molecules are broken down to release energy and form molecules of adenosine triphosphate (ATP). The process of cellular respiration uses up oxygen and releases carbon dioxide. The ATP formed in cellular respiration has high levels of potential energy that allow cells to do work; and therefore, if there is no ATP then there is no life. The energy from ATP is released when it is converted back into adenine diphosphate (ADP). Students do not need to know the individual biochemical steps of these two processes but rather need to understand the connections between them. Students will need to understand that these processes happen in order for organisms to make ATP, the molecular source or "currency" of energy for the cell.

The products of photosynthesis are used as the reactants for cellular respiration and vice versa. Students can create **models [SEP-2]** of these processes using chemical equations or pictorial models that emphasize the **energy and matter [CCC-5]** inputs and outputs from each process (HS-LS1-5, HS-LS1-7; figure 7.4). Sometimes both

processes occur in the same organism, and sometimes the respiration occurs in a consumer after it has eaten the producer. With each cycle of organisms eating or being eaten, there is less **usable** energy available to the organism (a consequence of the second Law of Thermodynamics, HS-PS3-4). In this way, ecosystems are constantly losing usable energy and therefore rely on the Sun to provide a constant influx of energy.

Figure 7.3. Models of Photosynthesis and Respiration
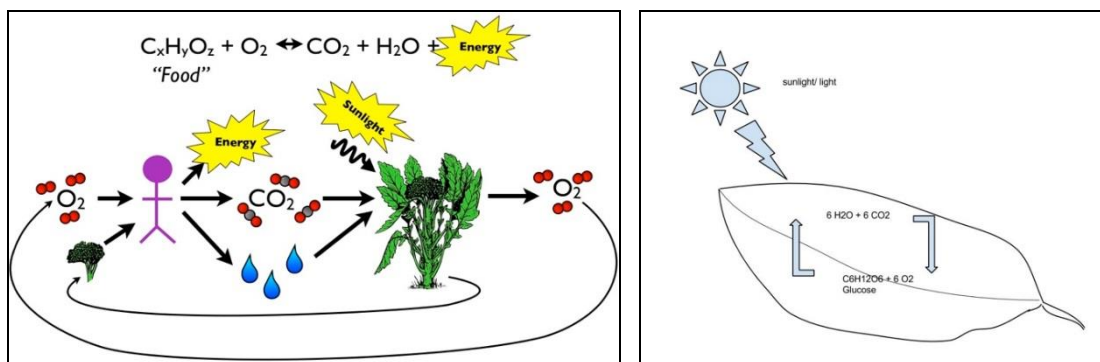
Examples of models showing how photosynthesis and respiration are mirrors of one another, involving the same basic ingredients. Matter cycles within the Earth system between the two processes, but energy must constantly flow in as sunlight to replace the energy put to work by organisms to grow and survive. Diagrams by M. d'Alessio and V. Vandergon

Engineering
Connection
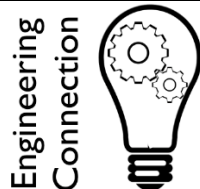
Engineering Connection: Wastewater Treatment Facilities

When raw sewage flows into waterways, it can impact the health of both humans and ecosystems (EP&Cs II, IV), which is why wastewater treatment facilities are an important part of all California cities. Engineers have learned to put biological processes to work to process human waste in wastewater treatment facilities. Students can **obtain information [SEP-8]** about the different stages of sewage treatment, some of which involve bacteria that rapidly decompose organic waste. Students can make physical **models [SEP-2]** of this process by using sugars to represent the organic waste, yeast to represent the waste-processing bacteria, and glucose test strips to measure the concentration of simulated waste in the water. Performing investigations using these models, students can develop techniques for speeding up the wastewater treatment process. Is there an optimal amount of yeast to add? Does the treatment process speed up or slow down when students add air or seal the container? What techniques can they develop for efficiently adding air? Students can **construct an explanation [SEP-6]** about how the change in oxygen in the bacteria's environment affects their respiration rate (HS-LS2-3).

A detailed model of photosynthesis and respiration can include the unique chemical properties of carbon. Carbon is structurally important to building all biological molecules, including the glucose molecule. What is so special about carbon? Due to its electron structure and configuration, carbon can covalently bond to four other atoms and forms single and double bonds with other atoms. The same raw materials can be recombined in different configurations with different chemical potential energy, allowing carbon-based molecules to store or release energy during these changes. Students should be

able to use computer simulations of this process to help them **construct explanations [SEP-6]** about how organisms build a wide range of organic molecules such as amino acids (HS-LS1-6).

Students can build a physical **model [SEP-2]** of a glucose molecule and show how to split it up (with an emphasis on the components needed to build the glucose and the components left after the breakdown of the glucose). They should start with the atoms of carbon, hydrogen and oxygen and make the simple molecules of CO_2, H_2O, and O_2 and then trace the movement of these molecules, much like they did in MS-LS1-7 but with added detail about what happens at each stage in the process. For example, the carbon dioxide and water are raw ingredients to photosynthesis and then are released as waste again in cellular respiration. Because of CO_2's role in both processes, photosynthesis and respiration are crucial parts of the global carbon cycle.

When did the cycling of **energy and matter [CCC-5]** start on Earth and how is cycling maintained? When asked what the Earth might have looked like 4.6 billion years ago when it first formed, students' image might be informed by prior knowledge that may include non-scientific sources and may not be consistent with the scientific understanding that Earth was lifeless. Teachers may need to explicitly discuss existing ideas and their sources before beginning instruction. When Earth first formed, its interior was still very hot and its interior rapidly convected (ties to HS-ESS2-3). Hot magma rising up is part of convection, so rapid convection caused volcanic activity in Earth's early history. When these volcanoes erupted, they released large amounts of gas that built up our early atmosphere with CO_2. Around 3.4 billion years ago, organisms evolved that could perform photosynthesis, which disassembles CO_2. This marked the beginning of life's interaction with the global carbon cycle, an example of Earth's interacting **system [CCC-4]** of systems (biosphere interacts with atmosphere). In the *CA NGSS*, students must use evidence like the graph in figure 7.5 and their model of photosynthesis (HS-LS1-5) to **construct an argument [SEP-7]** that life has been an important influence on other components of the Earth system (HS-ESS2-7; HS-LS2-5). Early on, ocean water and chemical reactions with rock material absorbed much of the oxygen that plants produced. By examining records from rock layers, students can

reconstruct aspects of Earth's early history (HS-ESS1-6). They can see evidence of biosphere-geosphere interactions in deep red colored rock layers that accumulated at the bottom of the ancient ocean called 'banded iron' (because they are rich in iron oxides). The oldest banded iron formations provide evidence of when plants first evolved, and thick deposits of banded iron about 2.4-1.9 billion years ago reveal another major **change [CCC-7]** – the expansion of multicellular cyanobacteria and a boom in photosynthesis.

Figure 7.4. CO_2 and O_2 in the Atmosphere
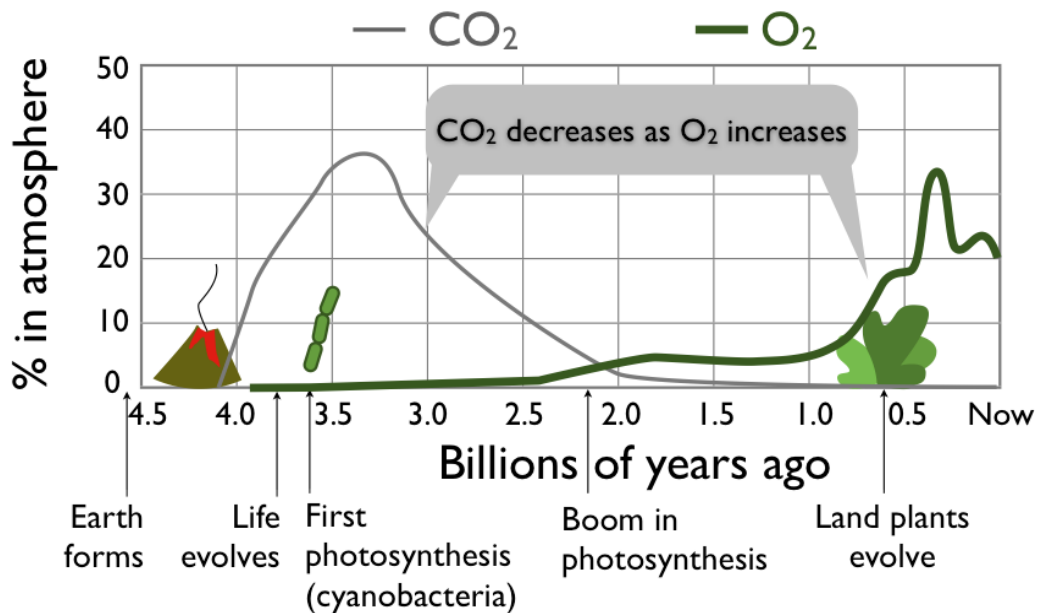
Concentration of CO_2 and O_2 in Earth's atmosphere over its history. Dramatic changes happened as plants used CO_2 to grow their biomass and released O_2 during photosynthesis. Diagram by M. d'Alessio, based on data from Holland 2006.

Examining the carbon cycle will help students understand how Earth **systems [CCC-4]** maintain life. The exchange of carbon between the atmosphere and the biosphere is just one of many important interactions between Earth's systems that involve the movement of carbon. In fact, one of the few additions that California made in

adopting the CA NGSS was to add this sentence to the Clarification Statement for Performance Expectation *HS-ESS2-6*: "The carbon cycle is a property of the Earth system that arises from interactions among the hydrosphere, atmosphere, geosphere, and biosphere." Scientists track the movement of carbon atoms through the carbon cycle much like they track the movement of water molecules through the water cycle. In both cases, scientists think about the **cycle of matter [CCC-5]** within a closed **system [CCC-4]** because at this point in Earth's history, very little water or carbon leaves the planet or arrives from space. We simply need to track the movement of the matter that is already here. A biological model of the carbon cycle is shown in IS1.

In the CA NGSS, students must develop a quantitative **model [SEP-2]** of the carbon cycle (*HS-ESS2-6*), which needs to include:

1. Places where carbon accumulates within the Earth system (called 'reservoirs', reminiscent of the storage of water in the water cycle);
2. Processes by which carbon can be exchanged within and between reservoirs (called 'flows');
3. The relative importance of these processes and reservoirs, based on the amount of carbon they hold or transfer.

Various representations exist for the carbon cycle, including simple pictures like Figure 7.1. Interactive animations (such as WGBH "Carbon Dioxide and the Carbon Cycle" at http://ca.pbslearningmedia.org/resource/pcep14.sci.ess.co2cycle/carbon-dioxide-carbon-cycle/), hands-on experiments (see OMSI "Experiment: Burning Issues" at http://www.omsi.edu/sites/all/FTP/files/chemistry/U4BurningIssues_OpGuide.pdf, and kinesthetic activities build on the static illustrations to help students develop conceptual **models [SEP-2]** of the reservoirs and processes by which carbon is exchanged between these reservoirs. For example, students can develop a simple physical **model [SEP-2]** of the atmosphere-ocean **system [CCC-4]** by adding pH indicator to water in a closed container (see IS1 of the chemistry course). Students can use this model to **investigate [SEP-3]** what happens as a plant grows, a candle burns, or a person exhales through a straw into the water. They notice that pH changes as CO_2 from these

sources interacts with the water to form carbonic acid. This same chemical reaction happens at the global scale with interactions between the atmosphere and the hydrosphere (PS1.B; IS6 of the chemistry course), making Earth's oceans one of the biggest reservoirs of carbon on the planet (see Table 7.2 for the relative sizes of different reservoirs). Students will **explain [SEP-6]** how the concentration of CO_2 in the atmosphere affects the rate of a chemical reaction in HS-PS1-5 and the final concentration of acid in the ocean is an example of a system in equilibrium as explored in HS-PS1-6. Because the system is near equilibrium, massive amounts of carbon (~80 gigatons) are absorbed into the ocean while massive amounts are also released back to the atmosphere. These opposite flows are similar in magnitude but do not balance out – the ocean absorbs about 2.5 gigatons per year more of carbon from the atmosphere than it releases back, causing the ocean to become more acidic. An acidic ocean can **cause [CCC-2]** major damage to plankton (that form the base of the ocean food chain, LS2.A, LS2.B) and coral reefs (which host a large portion of the ocean's biodiversity), both of which **affect [CCC-2]** sea life (LS3.C) (IS6 addresses human impacts). Scientists use complex computer models to calculate the expected changes in ocean chemistry based on different human activities, and the CA NGSS pushes students to use simple computer representations of **models [SEP-2]** to illustrate the relationships between different Earth **systems [CCC-4]** and **quantify [CCC-3]** how human activities change these systems (HS-ESS3-6; see IS6).

Table 7.2. Carbon Reservoirs and Atmospheric Flows

CARBON RESERVOIRS AND ATMOSPHERE FLOWS			
RESERVOIR	FORM OF CARBON	AMOUNT IN RESERVOIR	FLOW RATE WITH ATMOSPHERE
Atmosphere	Mainly carbon dioxide (gas)	840 Gt	Greenhouse gases are increasing due to human activities.
Biomass (*biosphere*)	Sugar, protein, etc. (solid, liquid)	2,500 Gt (mostly in plants and soil)	About 120 Gt per year into and out of air. Currently absorbing about 2.5 Gt per year
Ocean (hydrosphere)	Mostly dissolved bicarbonate salts	41,000 Gt	About 80 Gt per year into and out of air. Currently absorbing about 2.5 Gt per year
Sedimentary rocks (*geosphere*)	Carbonate minerals (solid)	60,000,000 Gt	Negligible annually but important over very long time scales.
Fossil Fuels (*geosphere/* anthrosphere)	Methane (gas) Petroleum (liquid) Coal (solid)	10,000 Gt	About 9 Gt/year into atmosphere, mostly from burning as fuels for energy.
Units are Gigatons (Gt) of carbon. 1 Gt = 1 billion tons			

Table by Dr. Art Sussman, courtesy of WestEd

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? When 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*) (mentioned above in why carbon is a good atom for living organisms). Living organisms are therefore a large reservoir of carbon. When those organisms die, the carbon stored in their bodies can accumulate in layers that get 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 presented written or orally (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 considered 'non-renewable' because we consume them faster 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.

Living Earth – Instructional Segment 3: Evidence of Evolution

Evolutionary scientist Theodor Dobzhansky made the now famous quote "Nothing in biology makes sense except in the light of evolution." One option is for evolution to therefore 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 IS.

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 fossils across the world from each other but living organisms that are very different from each other?   • What evidence shows that different species are related?   • How did modern day humans evolve?
Performance Expectations
Students who demonstrate understanding can: **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. 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.

*The performance expectations marked with an asterisk integrate traditional science content with engineering through a practice or disciplinary core idea.

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	LS1.A: Structure and Function	[CCC-1] Patterns
[SEP-3] Planning and Carrying Out Investigations	LS1.B: Growth and Development of Organisms	[CCC-3] Scale, Proportion, and Quantity
[SEP-4] Analyzing and Interpreting Data		[CCC-6] Structure and Function
[SEP-5] Using Mathematics and Computational Thinking		[CCC-7] Stability and Change
[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		

Highlighted California Environmental Principles & 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 ELD Connections: ELD.PI.11-12.1,5,6a-b,9,10,11a

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

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 absence of fossils of modern species in very old sediments. The 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 IS 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 needed to be tested, 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 PEs of the CA NGSS, including having students **ask their own 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 placed down and accumulate over time.

Each layer that gets deposited preserves a record of what the physical environment was like at the time. Even after the climate of this region has changed and millions of years have passed, we can get a glimpse of what the ecosystem was like at this spot because the ancient river channel in Time 1 of figure 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 7.5. Tuolumne Table Mountain Near Jamestown
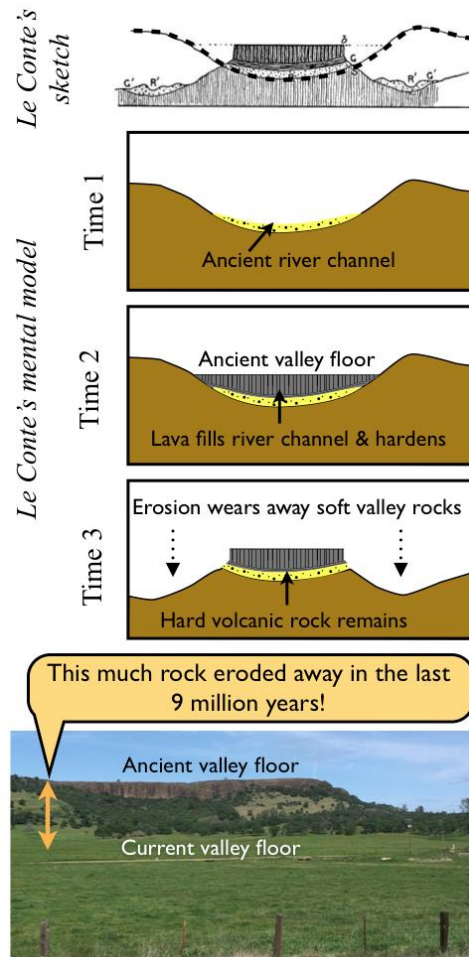
Tuolumne Table Mountain near Jamestown, CA reveals how much soil and rock has eroded. Joseph LeConte sketched the drawing on the top for a textbook he wrote in 1882. LeConte was one of the first faculty at the University of California and a charter member of the Sierra Club. There are several schools 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 7.6 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.amnh.org/exhibitions/past-exhibitions/fighting-dinos) or mother dinosaurs sitting on their nests of eggs are only possible because some depositional event covered them quickly. Even in places like the middle of the open ocean where there are no dramatic events like landslides, there are seasonal, decadal, and longer term variations producing changes in deposition rates that get recorded by the layers of rock. Processes that appear to occur at a **stable**

[CCC-7], constant rate may actually be periodically **changing [CCC-7]** when viewed at the right **timescale [CCC-3].**

Figure 7.6. Coastal Bluff Changes Over Time
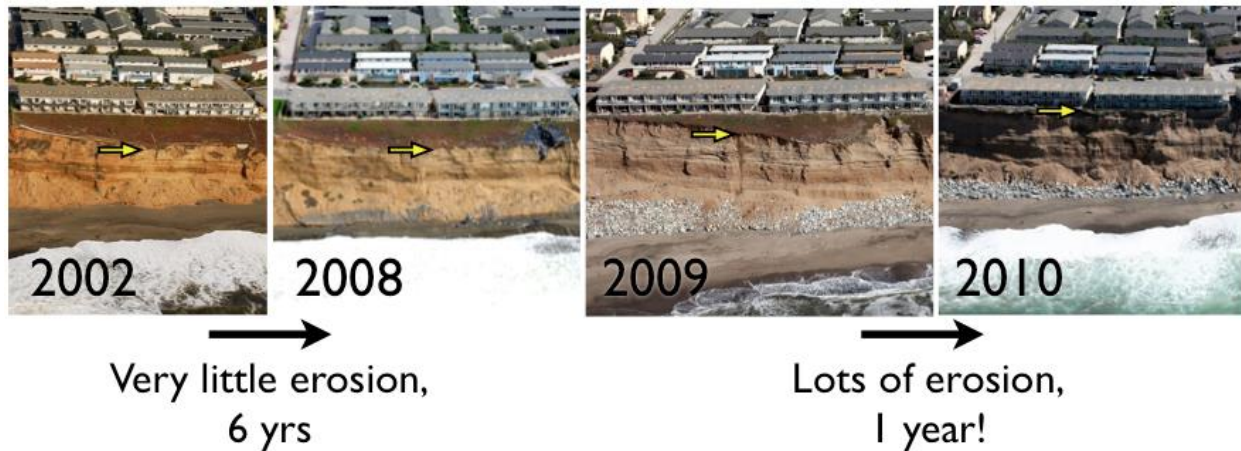
Changes over time in coastal bluffs in Pacifica California. They go for many years without much erosion and then erode more than a dozen feet in a single year. The yellow arrow shows the migration of the cliff top from year to year at a single position. By 2010, the cliff is located directly beside the apartment building. Source: California Coastal Records Project 2013.
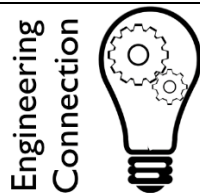
Engineering Connection: Coastline Erosion

When this natural process 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 down. Sequences of layers reveal a sequence of time like pages in a book (as students explained in middle school with *MS-ESS1-4*). In this way, scientists can examine fossils and look at how organisms change over time.

Evidence for Evolution

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 make the evidence more in depth. 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 as 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 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 fore limbs 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 (making them also analogous). 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 analogous structures caused by genetic similarity and common ancestry? In high school, students develop a nuanced understanding of **cause and effect [CCC-2]** where 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 in the water. 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 fly trap and pitcher plant demonstrates a homologous trait used to help the plant catch insects (all these plants share a common ancestor). Thorns and spines, however, are a common analogous trait that protects plants from herbivores that evolved in a wide range of plants through convergent evolution. As students develop arguments 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 of these organs/structures no longer have a use in the modern day organism, but there is evidence that the structure was once functional in the ancestor; these traits are now called vestigial organs/structures. Some classic examples of vestigial organs/structures are the remnants of hip bones in snakes and whales and the remainder of the tip of a tail bone (the coccyx) in humans.

Evolution itself is not a linear process, but rather a branching process in which a historical species had members of populations change and branch off 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 day species

we see on earth today. The tips of the tree represent these modern day 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 7.7. Tree of Life
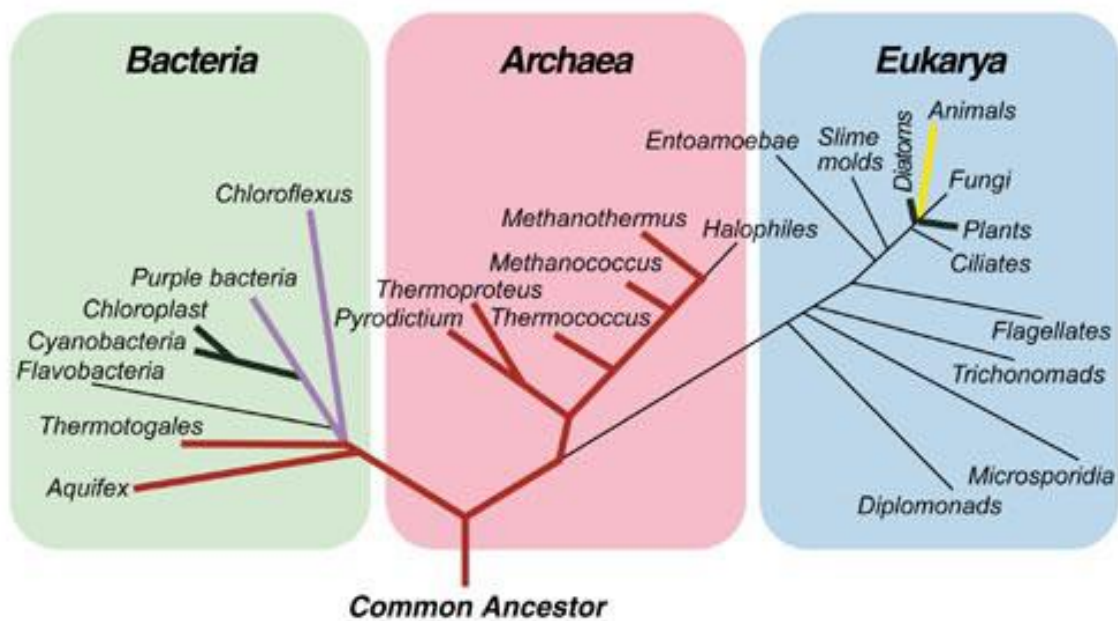
A tree diagram showing the relationship of all living species on Earth. All branches relate to the common ancestor at the base, which diverged into three main braches: bacteria, microbes known as archaea, and a group of multicellular organisms called eukarya that includes humans. Longer branches indicate a more significant change in DNA from its common ancestor. Source: Farmer 2000.

High School 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 asks students if they have 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 asks them if they remember how long they took the medicine. He passes around an empty antibiotic bottle and projects a picture of the label on the screen so that everyone can see how long the instructions say to take the drug. Can they just stop taking the antibiotic when they start feeling better?

Investigative phenomenon: Bacteria can become resistant to antibacterial drugs.

Evolution appears '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 will simulate the effects of antibiotics on bacteria populations using colored index cards or foam packing 'peanuts' (https://www.nsta.org/middleschool/connections/201312WelbornWorksheetAnswers.pdf). Each index card represents an individual bacteria organism; most cards are white, but two red cards represent individuals of the same species that are somehow resistant to the antibiotic. During each round, an antibiotic is applied that kills three out of four of the white cards, but none of the resistant red cards. After each round, the bacteria reproduce (students collect another card of the same color). Students graph the number of bacteria and identify the **trend [CCC-1]** that the population has evolved to become resistant to antibiotics.

Mr. K asks students to formulate the 'rules' of the index card game as a **computational algorithm [SEP-5]**. Students then write their own computer code and us it to predict what happens to the population of bacteria when a person with an infection stops taking antibiotics before the end of the prescription. They culminate by constructing an **explanation [SEP-6]** about how the use of antibacterial agents can

cause bacteria to evolve into 'superbugs' (HS-LS4-4). They watch a video to **obtain information [SEP-8]** about how resistant bacteria are impacting behaviors and health at local hospitals. Mr. K then pretends to be one student's father who wants to throw out his antibiotic when his symptoms go away but before the prescription ends. He asks 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 100s of eggs) than will survive. He noticed that despite the potential for large numbers in a population most populations remain fairly constant in numbers over generations. Darwin concluded that there had to be competition for resources and that is part of what helped keep population numbers stable over time. He also noticed that while fossils and modern living organisms differed from place to place, the fossils and modern living organisms in the same area were very similar to one another. For example, Darwin saw that several bird species in the Galápagos Islands looked very similar to one species found on the continent of nearby South America. He also knew that offspring looked like their parents but there was slight variation. He understood how animal breeders manipulate the traits in the population of their livestock or dogs by selectively breeding to reinforce or eliminate certain traits. It was all these observations that helped him frame the Theory of Natural Selection which states that there is competition over resources and the individuals in a population that can get the resources they need are able to reproduce and pass on their traits to their offspring and therefore are the more fit individuals of the population. If no individuals reproduce, 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 tap root.
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.
The individuals that leave living offspring are the individuals that have certain traits that help them survive and reproduce, thus they are the individuals that are selected naturally by the environment.	Birds that can break open nuts that have grown harder in a drought year can acquire enough food and survive the environmental change (drought) so they then go 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 and 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?

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[2] HHMI-Howard Hughes Medical Institute http://www.hhmi.org (accessed June 27, 2016). This website is free, kept up to date, and has excellent resources for evolution as well as other science topics designed by experts in the field for use by teachers and students.

High School 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.scientificamerican.com/magazine/sa/2014/09-01/) 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 assigns different students to read different articles in a classic jigsaw. Then she organizes the students so that each group discusses a common article. Each student group creates a collaborative presentation about their article that summarizes the argument made in the paper. Students must identify the claim, describe the evidence, and tie it all together with reasoning. The students should pay particular attention to fossil evidence (ESS1.C), which is described more in some articles than others. Then, students join together in different groups formed with one expert on each article. Each expert presents the collaborative presentation about their article to his or her small group. Then, the group lays out a large sheet of butcher paper and must create a comprehensive concept map illustrating the possible explanations of how humans evolved and then tie those explanations to other key course ideas. For example, students know that the pace of present-day climate change is much faster than a climate shift 160,000 years ago that one article mentions 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 emphasizes 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 adds, "And the person that 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. At the middle grade level, students explained how spatial patterns in the fossil record provide evidence that plates are moving (*MS-ESS2-3*). They can now revisit this understanding in light of evolution and populations and better understand why the fossil evidence for plate tectonics is so compelling. Take, for example, fossils of a specific species of fossil fern, *Glossopteris* that grew in narrow geographic regions on South America, Africa, India, and Australia. It is virtually impossible that the same species would evolve independently in different places at the same time. If it had been transferred to all these separate continents by some hypothetical wind current, then these new populations would have existed in isolation and would have been free to change and evolve providing a foundation for many speciation events (*HS-LS4-5*). While it did develop and change over the 40 million years or so that it dominated the vegetation of the southern continents, the changes in one part tracked to the changes in others. This could only happen if they were part of a single, interconnected population. And that could only happen if the continents were once together and have since moved. Students learn about the mechanisms that drive plate motion in 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 PE in the Chemistry in the Earth System course). None of them existed as the same species on two different continents after the age data shows that the continents broke apart. In fact, many of them went extinct around the same time at the end of the Permian period, which is an interesting mass-extinction story in and of itself that could be discussed in IS6.

Living Earth – Instructional Segment 4: Inheritance of Traits

Middle grade students are introduced to genes and the connection to genes and proteins, including what happens if there are mutations in gene sequences (*MS-LS3-1*) and the variation within individuals that are the result of the inheritance of genetic traits (*MS-LS3-2*). This IS defines the mechanisms for inheritance that were introduced in IS3 and provides a motivation for understanding IS5 where students learn how organisms use DNA to code for amino acids, the building blocks of proteins. While this IS provides the big picture view of inheritance by DNA, IS5 goes into more detail about cell division and explains the mechanism of inheritance at the scale of the cell itself.

Living Earth – Instructional Segment 4: Inheritance of Traits
Guiding Questions: • How are characteristics of one generation passed to the next? • What allows traits to be transmitted from parents to offspring? • How does variation affect a population under selective pressures?
Performance Expectations
Students who demonstrate understanding can: **HS-LS3-1**. **Ask questions to clarify relationships about the role of DNA and chromosomes in coding the instructions for characteristic traits passed from parents to offspring.** [Assessment Boundary: Assessment does not include the phases of meiosis or the biochemical mechanism of specific steps in the process.] **HS-LS3-2. Make and defend a claim based on evidence that inheritable genetic variations may result from: (1) new genetic combinations through meiosis, (2) viable errors occurring during replication, and/or (3) mutations caused by environmental factors.** [Clarification Statement: Emphasis is on

using data to support arguments for the way variation occurs.] [Assessment Boundary: Assessment does not include the phases of meiosis or the biochemical mechanism of specific steps in the process.]

HS-LS3-3. Apply concepts of statistics and probability to explain the variation and distribution of expressed traits in a population. [Clarification Statement: Emphasis is on the use of mathematics to describe the probability of traits as it relates to genetic and environmental factors in the expression of traits.] [Assessment Boundary: Assessment does not include Hardy-Weinberg calculations.]

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-LS4-3. Apply concepts of statistics and probability to support explanations that organisms with an advantageous heritable trait tend to increase in proportion to organisms lacking this

trait. [Clarification Statement: Emphasis is on analyzing shifts in numerical distribution of traits and using these shifts as evidence to support explanations.] [Assessment Boundary: Assessment is limited to basic statistical and graphical analysis. Assessment does not include allele frequency calculations.]

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-1] Asking Questions and Defining Problems [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	LS1.B: Growth and Development of Organisms LS3.A: Inheritance of Traits LS3.B: Variation of Traits LS4.B: Natural Selection	[CCC-3] Scale, Proportion, and Quantity

(for engineering) [SEP-7] Engaging in Argument from Evidence [SEP-8] Obtaining, Evaluating, and Communicating Information]		

Highlighted California Environmental Principles & 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.
CA CCSS Math Connections: MP.2;MP.4
CA ELD Connections: ELD.PI.11-12.1,5,6a-b,9,10,11a
CA CCSS ELA/Literacy Connections: RST.11-12.1,9, WHST.9-12.1.a-e, 2.a-e, 7,9

One way to help students meet HS-LS3-1 and better appreciate the nature of science is through a historical approach. Students obtain information about the study of DNA, learning about what scientists knew, what questions they asked, and how they

designed investigations to answer those questions. Discussing the scientists themselves shows that science is a human endeavor. The historical approach also illustrates how ideas have unfolded over time, showing that scientific knowledge is open to revision in light of new evidence. See the chapter on instructional strategies for specific advice about teaching science through historical case studies.

At the turn of the 20th century, Mendel's conclusions about inheritance were accepted, and it was understood that chromosomes were passed from generation to generation in all living organisms. It was also known that chromosomes were composed of DNA and proteins. What was not clear for scientists in the early 1900s was how these chromosomes could provide the codes for all the phenotypes present in an organism, was it the proteins or DNA that was important. As scientists grappled with this, they began to ask more focused questions on what exactly was directing the translation of proteins. One such scientist was Frederick Griffith, who was trying to find a cure for pneumonia and was using mouse models to address specific questions about how mice contracted pneumonia. He found that he could inject strains of bacteria into mice and transform strains of non-pathogen bacteria into pathogen-causing bacteria. The full experiment might be demonstrated by a presentation that has a slide with the first part of Griffith's experiment and students predict outcomes and then "see" what comes next switching to the next slide and building on that knowledge continuing with the next set of experiments along with predictions. Students can deduce the control and variables Griffith used in his original work. The conclusion of his work was that some agent "transformed" the non-pathogen-causing strains into pathogen-causing strains of bacteria and the mice developed pneumonia.

MacLeod, and McCarty attempted to answer that question. They discovered that DNA was the transforming agent, which they concluded after testing the individual components of the bacteria cell in a cell culture system. Scientists were not entirely convinced, therefore, Alfred Hershey and Martha Chase radioactively labeled parts of viruses and provided even more evidence that it was the DNA that was being transported into hosts' cells and transforming those host cells into virus-making machines. It was also around this time that Erwin Chargaff and his students who, while

working on separating out nucleotides in different organisms, noticed that adenine and thymine were always in equal amount to each other as were guanine and cytosine. They also noticed that the total amount of adenine and thymine was NOT equal to the total amount of guanine and cytosine. A final piece of the puzzle was the X-ray photograph of DNA that Rosalind Franklin generated that showed the regular pattern and the helix formation of the molecule. These experiments, along with other evidence gathered during this time, led to the building of the **model [SEP-2]** of DNA by Watson and Crick. (There is an excellent educational resource regarding the history of this scientific discovery through the UC Berkeley Museum of Paleontology, The structure of DNA: Cooperation and competition at http://undsci.berkeley.edu/article/0_0_0/dna_01.)

Building physical **models [SEP-2]** can help explain data and observations (for Watson and Crick, it helped them merge together all that they had learned from others) and also that models can help predict new possibilities (for Watson and Crick, it helped others think about how DNA replicates) but models also have limitations. For example, Watson and Crick's model could not show how the code determined amino acid order. Having students build this model can help them make the connections that Watson and Crick made with the data produced from theirs and others' experiments. Students can also begin to see what happens if a component of the model changes. What happens if you switch a thymine with an adenine? Students should see that having an A nucleotide across from an A nucleotide alters the structure, which can help them make predictions about the effect of mutations. Students can improve their ability to **obtain information [SEP-8]** from scientific journals by reading an annotated version of Watson and Crick's original paper. Even though it is only two pages long, it has profoundly influenced the direction of the science of genetics and molecular biology

Much of the work done in the first half of the 20th century looked at the effect mutations had on phenotypes. If a genetic disease resulted, it gave the geneticists evidence of the function of that gene, though they could not "see" the genotype (see IS1). In the latter half of the 20th century and into the 21st century, techniques and tools have improved so that scientists can actually test how specific changes in a gene sequence alter phenotypes. Technology has also enabled scientists to map out entire

genomes of a large variety of organisms, and large online databases exist that students can browse freely (see National Center for Biotechnology Information, http://www.ncbi.nlm.nih.gov/).

Once scientists started mapping out entire genomes, they realized that the simple relationships between DNA sequences and phenotypes are more complicated than originally thought. Genomes contain far fewer gene sequences than scientists originally thought and many phenotypes are the results of more than one gene. Students can look at phenotype studies and **ask questions [SEP-1]** regarding what changes in DNA result in changes in phenotypes of humans (or other living organisms) and the effect of DNA changes on individuals. Students can go to National Center for Biotechnology Information and link to case studies done in humans by looking at the Online Mendelian Inheritance in Man (OMIM) link or they can expand the exercise and look at other animals or plants.

Students can investigate of organ and tissue donation by **obtaining information [SEP-8]** about how doctors use genotypes to find successful matches for people who need new organs or tissue. The success of these transplants is much higher when the doctors can find a genotype match for certain traits (for additional information see http://www.organdonor.gov/about/data.html). Which genes are most important for identifying the right match? What other traits are influenced by those genes?

This IS can now meld classic Mendelian genetics with the molecular genetics just discussed. Variation is the result of mutation and recombination events that happen at the genetic level. Students can apply a physical **model [SEP-2]** of chromosomes (such as clay or pipe cleaners) to visualize and provide **evidence [SEP-7]** for how variation happens. With this model, students can demonstrate how pairs of chromosomes physically exchange parts to create new combinations of sequences (one method of variation) and can show that the random line up of the chromosome pairs during meiosis results in different arrangements of chromosomes during sexual reproduction (another method of variation). Students can also use Punnett squares as a model that illustrates how variation can arise from the mating of two biological parents. **Analyzing [SEP-4]** the **quantity and proportion [CCC-3]** of possible outcomes helps explain the

variation we see in individuals even between siblings who have the same biological parents.

Mutations in DNA can result in a change in genotype. Some mutations result in viable cells and can produce new genes that are then inherited by the next generation, others result in cell death, and still others in uncontrolled replication that leads to cancerous tumors. Sometimes, the traits caused by mutations result in a viable cell that somehow lacks certain functionality, and we refer to these mutations as genetic diseases. A single nucleotide change in the gene sequence for hemoglobin results in sickle cell anemia. A similar mutation in the gene that is used to form proteins that form a channel for movement of particles into and out of cells produces the condition known as cystic fibrosis (though it should be noted that there can be several single changes that result in the cystic fibrosis phenotype). Errors in copying or division of the X chromosome can lead to a disease resulting in Turner syndrome. Students should be able to use evidence from these genetic diseases to construct an argument that variations are caused by genetic code that is inherited or altered either during DNA replication or by environmental factors (HS-LS3-2). Students should also be able to relate this argument not only to genetic disease but also to any variation in traits.

Other mutations can actually make it harder for diseases to affect humans. Students could **obtain information [SEP-8]** about how a mutation in the gene that creates the protein CCR5 can delay or prevent acquired immune deficiency syndrome (AIDS) symptoms in people infected with the human immunodeficiency virus (HIV) virus. They **develop a model [SEP-2]** of how viruses enter cells by matching protein receptors. Viruses like AIDS, bubonic plague, and smallpox cannot enter the cell in people that lack the CCR5 protein receptor. Does this mutation provide clues to create an AIDS treatment or vaccine? Students can also **analyze data [SEP-4]** from maps showing how common this mutation is in different parts of the world and **ask questions [SEP-1]** about why this mutation became so prevalent in northern European countries.

Once students understand how variation can occur, they can predict what combinations are possible in offspring. Punnett squares are a simple and common model used to predict traits, but they are cumbersome to use for predicting multiple

traits. For example, predicting the outcome of a tri-hybrid cross requires a cumbersome eight by eight Punnett square. Instead, students can use statistical tools that include the product and sum rules of probabilities (CCSSM Geometry-S.CP.7.8). Pedigrees are another model used to look at patterns of inheritance across generations. Students can evaluate possible genetic combinations and predict the chance of traits appearing in individual offspring. Students can use interactive computer simulations to create phenotypes of an organism by looking at combinations of genotypes and again predict what combinations are plausible. Students should be able to use information from genetics and their ability to calculate probabilities of different traits to explain the distribution of particular traits within a population (HS-LS3-3).

While genetics dictates many aspects of variation, environment also affects phenotype expression. Some environmental components can affect the phenotype without a change in genotype. In humans, nutrition is an environmental component that affects height or muscle formation. Just because an individual possesses the genotype to be tall or strong does not mean he or she will reach full genetic potential. Failure to meet genetic potential does not affect how genes are inherited, so malnourished parents can give birth to offspring that end up being much taller than their parents. Using statistics (**mathematical thinking [SEP-5]**), students can **analyze [SEP-4]** the frequency or distribution of traits observed in a population and compare it the probability of certain traits occurring based on genetics alone (CA CCSSM S-CP.4). If students identify a mismatch, they should be able to construct an **argument [SEP-7]** that environmental factors have affected phenotypes.

Linking IS3 with this IS will help students draw connections between how variation exists and how selection can act on the population. Natural selection acts on the phenotype of an individual, for example the size of a shell or beak. The selective pressure that favors one size over another will translate into a change in proportion of individuals with the favored size in the next generation–if the change is a result of inheritance. In other words, the individuals that have the favorable phenotype reproduce and pass on the favorable genetic code that generated that phenotype. The frequencies of "favored" traits are ultimately what change from generation to generation. Students

can **model [SEP-2]** these changes using computer simulations of populations (see Howard Hughes Medical Institute "Color Variation Over Time in Rock Pocket Mouse Populations" at http://www.hhmi.org/biointeractive/color-variation-over-time-rock-pocket-mouse-populations) and use **probabilities [SEP-5]** to determine whether or not there is evidence of changes in populations over time (see Howard Hughes Medical Institute "Stickleback Evolution Virtual Lab" at http://www.hhmi.org/biointeractive/stickleback-evolution-virtual-lab) (HS-LS4-3). Using these simulations as examples, students should be able to tie together their knowledge in the course to construct an explanation of how organisms evolve (HS-LS4-2). Their explanation should note how 1) organisms can reproduce to grow in numbers; 2) offspring of organisms are slightly different from their parents due to the processes of mutations and sexual reproduction; 3) organisms compete for limited resources; and 4) organisms with traits that enable them to survive and obtain resources are most likely to reproduce and pass on their traits such that the population increases in the proportion of these successful traits.

Living Earth – Instructional Segment 5: Structure, Function and Growth (From Cells to Organisms)

Understanding the characteristics of life is a unifying theme of biology. IS5 investigates the birth and operation of individual cells, something common to all life. After exploring life from the macroscopic level, students finally zoom down to the microscopic mechanisms with a focus on DNA's role in cellular operations.

Living Earth – Instructional Segment 5: **Structure, Function, and Growth (From Cells to Organisms)**
Guiding Questions: • What happens if a cell in our body dies? • How does the structure of DNA affect how cells look and behave? • How do systems work in a multi-celled organism (emergent properties) and what happens if there is a change in the system? • How do organisms survive even when there are changes in their environment?
Performance Expectations
Students who demonstrate understanding can: **HS-LS1-1. Construct an explanation based on evidence for how the structure of DNA determines the structure of proteins which carry out the essential functions of life through systems of specialized cells.** [Assessment Boundary: Assessment does not include identification of specific cell or tissue types, whole body systems, specific protein structures and functions, or the biochemistry of protein synthesis.] **HS-LS1-2. Develop and use a model to illustrate the hierarchical organization of interacting systems that provide specific functions within multicellular organisms.** [Clarification Statement: Emphasis is on functions at the organism system level such as

nutrient uptake, water delivery, and organism movement in response to neural stimuli. An example of an interacting system could be an artery depending on the proper function of elastic tissue and smooth muscle to regulate and deliver the proper amount of blood within the circulatory system.] [Assessment Boundary: Assessment does not include interactions and functions at the molecular or chemical reaction level.]

HS-LS1-3. Plan and conduct an investigation to provide evidence that feedback mechanisms maintain homeostasis. [Clarification Statement: Examples of investigations could include heart rate response to exercise, stomate response to moisture and temperature, and root development in response to water levels.] [Assessment Boundary: Assessment does not include the cellular processes involved in the feedback mechanism.]

HS-LS1-4. Use a model to illustrate the role of cellular division (mitosis) and differentiation in producing and maintaining complex organisms. [Assessment Boundary: Assessment does not include specific gene control mechanisms or rote memorization of the steps of mitosis.]

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	LS1.C: Organization for Matter and Energy	[CCC-1] Patterns

[SEP-3] Planning and Carrying Out Investigations [SEP-4] Analyzing and Interpreting Data [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	Flow in Organisms LS2.B: Cycles of Matter and Energy Transfer in Ecosystems ESS1.C: The History of Planet Earth ESS2.D: Weather and Climate ESS2.E: Biogeology	[CCC-2] Cause and Effect [CCC-3] Scale, Proportion, and Quantity [CCC-4] System and System Models [CCC-6] Structure and Function [CCC-7] Stability and Change
CA CCSS Math Connections: F-IF.7.a-e; F-BF.1a-c; MP.2; MP.4		
CA ELD Connections: ELD.PI.11-12.1,5,6a-b,9,10,11a		
CA CCSS ELA/Literacy Connections: RST.11-12.1,8, WHST.9-12.2.a-e, 7,9		

Before starting IS5, teachers should assess what students know about the characteristics of life. For example, working in small groups, students can sort pictures of living and non-living things into two categories and **support an argument [SEP-7]** for

where they put each item. Objects can include plants, insects, mammals, electronics, plastic toys, as well as unusual examples and outliers such as a sponge, rock, lichen, tunicates, snake skin, molds, and/or a skeleton. Students come to a consensus as to what goes in each category and why. After presenting their thinking to the entire class and listening to the thinking of their classmates, students re-sort the items. Groups discuss the similarities and differences between the living organisms. IS5 also builds on other key ideas in life science that students engaged in during middle school, including: models of cells and how they interact in multicellular organisms (*MS-LS1-1, MS-LS1-2 and MS-LS1-3*). Formative assessments at the beginning of the course will help teachers determine what level of detail they will need to revisit in order to help students succeed.

Human skin cells have a lifespan of only a few weeks before they die off, but we do not really notice because the new ones look identical to the old ones. We see evidence for this skin loss as we scrape off 'dead skin.' How do cells do this? Students can watch cells divide by a video and observe that the two cells at the end look identical. What is the mechanism for making such exact copies?

In the middle grades, students developed a model of how genes stored information about how to make proteins (MS-LS3-2), but that model did not include DNA or how DNA is encoded in genes. Their model did include the fact that genes record information about traits or phenotypes. Now, students must **explain [SEP-6]** the mechanism by which the structure of DNA determines the structure of proteins and how this process determines the overall structure and function of the cell or organism.

As George Beadle (a biologist in the early twentieth century) said, "one ought to be able to discover what genes do by making them defective." Students can start with the idea that DNA holds the information necessary for all phenotypes of the organism. Cells do not need all of this information at all times or in all cells (analogous to a library that holds lots of books arranged by subject, but only some of those books are checked out at certain times). But which parts of the DNA sequence contain the information for which phenotypes? Often, genes are mapped to phenotypes by looking at mutations. If a

mutation alters the phenotype, then the section of DNA that mutated must be responsible for that phenotype.

Once students recognize a **cause and effect [CCC-2]** sequence between mutated genetic code in DNA and changes in phenotype, they are ready to examine the precise mechanism: How does a DNA sequence blueprint get translated into a phenotype? Students can use a codon table along with colored beads as a **physical model [SEP-2]** for protein synthesis. The line-up of the nucleotides on the DNA strand is the template for the order of the amino acids, which then determines which specific protein gets made based on its **structure [CCC-6].** Students do not need to understand the details of the translation process, memorize a codon table, or map out metabolic pathways.

Historically, most of these connections were made by looking at mutants, and now students can observe this by looking at loss of function in strains of bacteria[3] or mutant strains of quick growing plants[4]. Mutation gene maps for model organisms are available and students can refer to these as they look at mutated phenotypes. Students can then gather **evidence [SEP-7]** to construct an **explanation [SEP-6]** for how a specific DNA sequence causes a specific loss of function, and can use this specific case to support the claim that there is a connection between, DNA, the proteins cells produce, and the physical features of an organism (HS-LS1-1). Relating back to the discussion of mutations in IS4, students can **plan and carry out investigations [SEP-3]** to determine if mutants can grow in varying environments. Because students will need to refer back to their data to look at variations within populations and effects of environment on individuals within populations, teachers will need to introduce an organizational structure such as science notebooking or a 21st century version of students-created web pages describing investigations with data stored in collaborative web-based spreadsheets.

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[3] It is possible to buy safe bacteria strains from many biological supply companies that are resistant to antibiotics and compare to ones that are not or ones that grow in the presence of lactose and ones that cannot breakdown lactose and therefore change color.

[4] A search on the web should provide links to companies that maintain normal and mutant seed stocks.

Mutations are technically tiny changes at the micro scale to DNA sequences, but how do these modifications affect the overall function of body systems at the **scale [CCC-3]** of an entire organism? While students constructed arguments that the body works as a set of interacting **systems [CCC-4]** in the middle grades (MS-LS1-3), now they are ready to understand some specific examples of interactions and the reason that these interactions are so important. Students can develop and use **models [SEP-2]** that show how a system works then "mutate" part of it and observe the effects. A model that demonstrates how the movement of the diaphragm affects the pressure in the chest cavity allowing for our lungs to push out or take in air could either be pictorial (a labeled diagram showing interacting components of the respiratory system) or a physical model with tubes and plastic bags taped to a piece of cardboard to represent the lungs and diaphragm. If one "lung" is non-functional, what happens? Students should develop and use a model that explains not only how individual systems interact, but also how they interact to enable the functions of the entire organism (HS-LS1-2). While examples can come from any organism, this is a key opportunity within the CA NGSS to explore specific mechanisms within the human body.

One of the ways that cells work together in tissues, organs, and finally organ systems is to maintain **stability [CCC-7]** through homeostasis. Maintaining homeostasis means that despite changes in the environment an organism has the ability to maintain certain internal chemical and physical states. Students can measure their internal body temperature on a cold morning, a hot day, or after vigorous exercise. Even as the temperature outside spans as much as 40°C, a person's internal temperature only varies by a few degrees. How does this happen and why does the body work so hard to maintain a constant temperature? The significance is in the functioning of proteins, especially when looking at enzymes which must have stable environments in order to function correctly. Enzymes usually have a fairly narrow range within their environment in which they can work. For multicellular organisms, the first line of regulation is through their skin or outer layers (epithelium) which respond to stimuli in the environment. The brain then processes these stimuli and activates balancing feedback mechanisms to counteract the environmental change. When it is hot, mammals like humans sweat or pant, and when it is cold they shiver. Students can

plan and conduct investigations [SEP-3] where they change conditions for plants or animals and watch how they respond (HS-LS1-3). They can measure their own heart rate returning to normal after vigorous exercise, observe plants growing taller in the dark to reach new light sources, or observe the behavioral response of planaria flatworms as the amount of light changes. Students do not need to explain the specific mechanisms that accomplish these changes (i.e., photosensitivity, hormone distribution, avoidance, etc.), but they should gather evidence that organisms respond to changes and use that evidence to construct a conceptual **model [SEP-2]** that can to predict outcomes of future experiments that vary parameters from their initial trials.

One of the characteristics of life is the ability to grow (whether as a single cell or as a multi-cellular organism). In the 1860s, Rudolf Virchow proposed that new cells arose from pre-existing cells. As microscope technology advanced in the late 1800s, scientists were able to gather direct evidence supporting Virchow's claim. In order to go from a single cell (fertilized egg) to a multicellular organism, cells need to produce more cells. As unicellular organisms reproduce, they also make more cells. In both cases, information gets copied from the parent to the daughter cells. From IS4, students know that DNA records this information, but how do cells duplicate DNA?

Cells, just like organisms, have a life cycle referred to as the cell cycle (figure 7.9). The cell cycle is a conceptual model that describes the essential events in a cell's life. The assessment boundaries for HS-LS1-4 and HS-LS3-1 are clear that rote memorization of different stages of the cell cycle or mitosis is not the goal of the CA NGSS. One of the common consequences of differentiating between these stages is that students think of them as separate and independent events rather than a continuous evolution. Students should be able to describe the events and sequence of the cell cycle model. They should be able to describe the stages that contribute to the overall goal of the process. In particular, students should ensure that their model includes the idea that organisms that reproduce sexually contain two sets of genetic material, one variation from each parent. Students should begin to ask questions about how these duplicate copies of DNA determine which traits offspring inherit from their parents (HS-LS3-1). Students must be able to use their model of the cell cycle to explain how organisms grow, how multi-cellular organisms copy the same genetic code

but differentiate into different cell types, and how organisms replace dead cells with new ones (HS-LS1-4). Students can also apply their model to predict what happens when there are mistakes in this process. For example, what would happen if the stages of mitotic cell division do not occur in order (i.e., if cytokinesis occurs before mitosis)? Students can also use the model to explain cancer[5] and the effects of unchecked, out-of-control cell division on normal cell function.

Figure 7.8. Two Pictorial Models of the Stages of the Cell Cycle
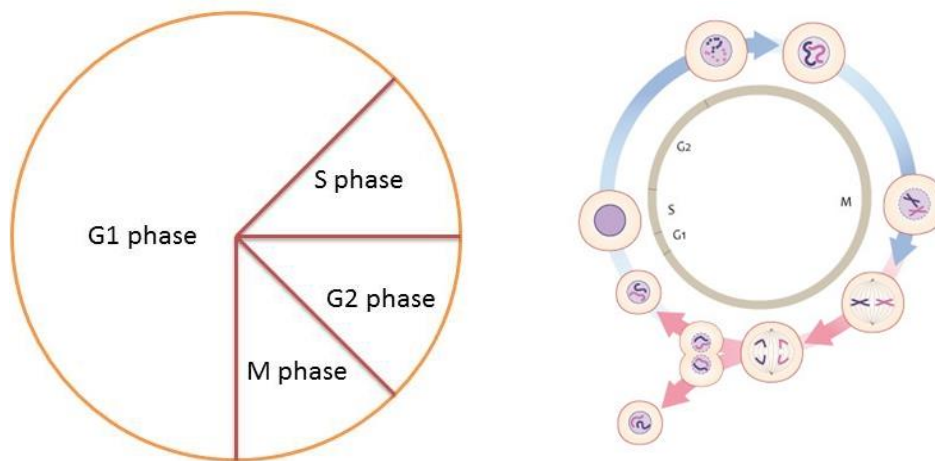
Stages of the cell cycle. On the left, the size of the pie is proportional to the time spent in each phase. On the right, the icons visually depict what happens at each stage. Source: V. Vandergon; Genomics Education Programme 2014.

Cell division is the first part in the growth of an organism and as new cells are formed in multicellular organisms, they differentiate into specific cell types. These specific cell types then participate in the formation of a tissue which then forms organs which are often parts of a physiological system in multicellular organisms (this links

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[5] Resources are available to look at cancer rates and types including http://www.cancerresearch.org/ (accessed June 27, 2016) which has short YouTube videos as well as the latest on cancer research. Make sure to use reputable government supported research sites.

back to IS1). Many multicellular organisms stop growing once they reach adulthood, but mitosis does not stop. Some cells die off as they reach the end of their life cycle and these dead cells need to be replaced. This replacement of dead cells occurs through mitosis of the remaining living cells. Extensions of this IS might include discussions of stem cells that have not yet differentiated and have the ability to become a variety of types of cells, leading to new tissue and organ formation. Stem cell use in organ transplant is one way that scientists are helping decrease rejection of transplanted organs by the recipient of the donated organ. Stem cells can be used to generate signals for the recipient's body so that their immune system thinks that the organ belongs there.

This IS culminates with students researching and **constructing an explanation [SEP-6]** about how different diseases cause a cascade effect in the interdependent **systems [CCC-4]** of the human body (HS-LS1-2). Amyotrophic Lateral Sclerosis (ALS, also known as Lou Gehrig's disease) is a good example of a disease that results in multiple effects on the body systems but there are many such diseases in humans (i.e. cystic fibrosis, muscular dystrophy, etc.) The cause of ALS disease is still uncertain and only about 5-10 percent of cases can be traced to genetic inheritance of a mutated gene. Most of the time there is a random event that causes a neurodegenerative progression of the nerve cells in the brain and the spinal cord so that the muscles in the human body do not receive messages and therefore begin to atrophy due to disuse. As the muscles atrophy, other systems in the body are affected. For example, muscles in the respiratory system stop working and the individual with ALS has trouble breathing. Students should also obtain information about treatments and solutions that modern medicine has found for these diseases. In diseases where organs fail, teachers can highlight the importance of organ transplants and how donations of working organs and tissues from others can save lives.

Engineering Connection: Organ Donation

Students can learn about the role of engineering to meet critical medical needs to solve another problem in organ donation: matching suitable donors with patients. In addition to striking examples of engineering like magnetic resonance imaging (MRI) imaging and robotic surgery, some engineers also develop important processes such as matching donors and patients by breaking down the problem into smaller, more manageable problems. Students can consider the different aspects of the problem of donor matching (awareness about the process by potential donors, rapid and reliable genetic testing, etc.) and brainstorm and evaluate possible solutions to them.

High School Living Earth Snapshot 7.4: How Did We Eradicate Diseases in the US?

Anchoring phenomenon: Tuberculosis used to kill millions of people but it is no longer common.

Mr H. introduces a historical case study about the different factors that go into eradicating diseases. Even though they may not remember it, every child admitted to school in California must receive a "TB Test." Despite this universality, it's likely that students have never met anyone that had TB and may not even know what it stands for ('tuberculosis'). So why all the fuss with TB tests? Ms. H tells students that if she was teaching 200 years ago, the class would live in fear of this disease. During the 19th century, TB caused as many as 20 percent of the deaths some years. Today, fewer than 250 people in all of California die of the disease in an average year (California Department of Public Health 2015). How did society accomplish this change?

Ms. H divides the class into two groups that **obtain and evaluate information [SEP-8]** from different articles that introduce historical case studies of two major scientific innovations: 1) the origin of modern germ theory, including the discovery of tuberculosis bacteria by R. Koch in 1882; and 2) the application of science practices to randomized controlled drug trials, including the very first large scale trial which tested an antibiotic to combat tuberculosis. Each group answers focus questions about the nature of science and core ideas about disease transmission. What effect did each of these innovations have on tuberculosis death rates?

Investigative phenomenon: The death rate from tuberculosis dropped several times during the last 200 years.

Ms. H provides each group with a graph showing how death rates changed around the time of events described in their article. Students **analyze the graphs [SEP-4]**, identifying **trends [CCC-1]** and looking for evidence of possible **cause and effect relationships [CCC-2]** between events labeled on the graph and changes in the death

rate. Students reorganize in 'jigsaw' style where two students from the group that discussed Koch's investigation **communicate [SEP-8]** their findings to two students that discussed the antibiotic trial (and then they switch). Students must present an **argument [SEP-7]** about whether or not their group's innovation led to a significant decline in TB-related death rates (using their group's graph as evidence). Students realize that there is evidence that both sets of innovations may have helped, but also that rapid declines in death rates seem to happen even before some of the major events.

Figure 7.10: Two Graphs of the Decline of Tuberculosis
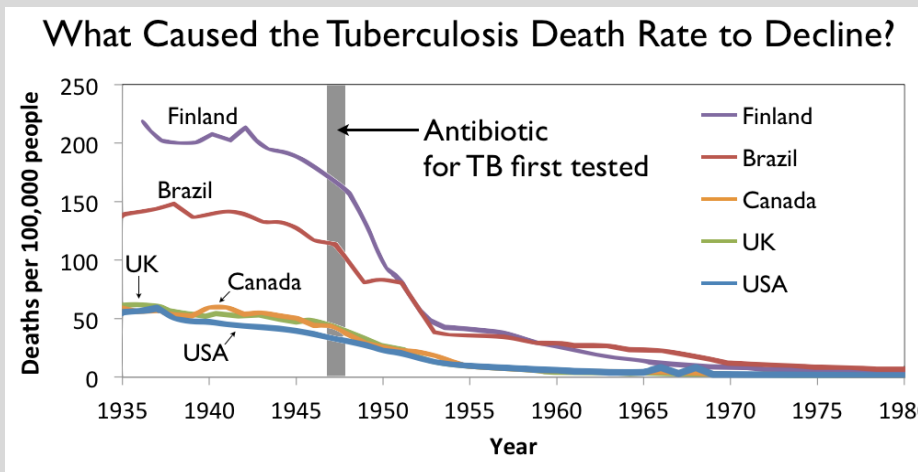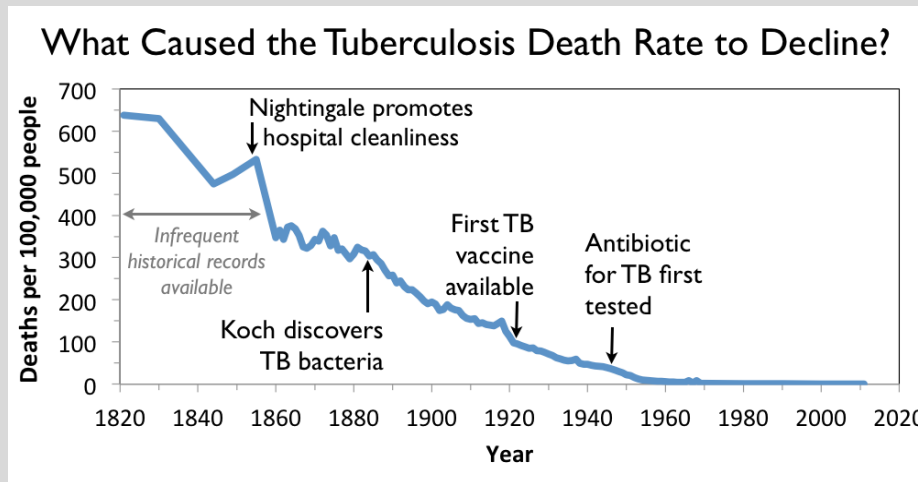
Charts by M. d'Alessio with data from Antunes and Waldman 1999; United States Census Bureau 1975; Official Statistics of Finland 2010; Public Health England n.d.;

Gallant, Ogunnaike-Cooke, and McGuire 2014; Wikipedia 2016

Ms. H wants his high school students to move beyond the simple understanding of linear **cause and effect relationships [CCC-2]** from elementary school. According to the progression of CCCs in Appendix 3 of this *CA Science Framework*, high school students should recognize that "changes in systems may have various causes that may not have equal effects." This is especially true when it comes to the 'health revolution' that eradicated so many diseases like TB (Aiello, Larson, and Sedlak 2007). Innovations in medicine (drawn directly from scientific discoveries) influenced cultural norms for sanitation (such as hand washing) and led to changes in public policy and land use. These innovations occurred within the context of new technologies such as water filtration and sewage treatment that enhanced the standard of living in the US and other western countries. Students watch a short video highlighting some of these key advances that dramatically increased life expectancy. Monitoring efforts, including the TB tests taken by every California student, are part of this process. No individual factor is the singular cause of this health revolution. Ms. H leads a whole class discussion where they generate a collaborative concept map representing society as a **system [CCC-4]** in which changes to different components result in the revolutionary overall system behavior where infectious disease no longer dominates our lives and deaths.

Living Earth – Instructional Segment 6: Ecosystem Stability & the Response to Climate Change

In this IS, students will study the effects of natural and human induced changes on ecosystems and the populations within them. At the middle grade level, students learned that any change, either physical or biological, to an ecosystem can lead to a change in populations living in that ecosystem (*MS-LS2-4*). They now build on that knowledge to explore more complicated changes, many relating to shifts in global climate.

Living Earth – Instructional Segment 6:
Ecosystem Stability & the Response to Climate Change
Guiding Questions: • What effects changes in ecosystems that ultimately effect populations?   • What are the changes that are happening in the climate and what effects are those having on life?   • How are human activities impacting Earth's systems and how does that affect life on Earth?   • What can humans do to mitigate their negative impact on the environment?
Performance Expectations
Students who demonstrate understanding can: **HS-LS2-6. Evaluate the claims, evidence, and reasoning that the complex interactions in ecosystems maintain relatively consistent numbers and types of organisms in stable conditions, but changing conditions may result in a new ecosystem.**   [Clarification Statement: Examples of changes in ecosystem conditions could include modest biological or physical changes, such as moderate hunting or a seasonal flood; and extreme changes,

such as volcanic eruption or sea level rise.]

HS-LS2-7. Design, evaluate, and refine a solution for reducing the impacts of human activities on the environment and biodiversity.* [Clarification Statement: Examples of human activities can include urbanization, building dams, and dissemination of invasive species.]

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-LS4-6. Create or revise a simulation to test a solution to mitigate adverse impacts of human activity on biodiversity.* [Clarification Statement: Emphasis is on designing solutions for a proposed problem related to threatened or endangered species, or to genetic variation of organisms for multiple species.]

HS-ESS3-5. Analyze geoscience data and the results from global climate models to make an evidence-based forecast of the current rate of global or regional climate change and associated future impacts to Earth systems. [Clarification Statement: Examples of evidence, for both data and climate model outputs, are for climate changes (such as precipitation and temperature) and their associated impacts (such as on sea level, glacial ice volumes, or atmosphere and ocean composition).] [Assessment Boundary: Assessment is limited to one example of a climate change and its

associated impacts.]

HS-ESS3-6. Use a computational representation to illustrate the relationships among Earth systems and how those relationships are being modified due to human activity. [Clarification Statement: Examples of Earth systems to be considered are the hydrosphere, atmosphere, cryosphere, geosphere, and/or biosphere. An example of the far-reaching impacts from a human activity is how an increase in atmospheric carbon dioxide results in an increase in photosynthetic biomass on land and an increase in ocean acidification, with resulting impacts on sea organism health and marine populations.] [Assessment Boundary: Assessment does not include running computational representations but is limited to using the published results of scientific computational models.]

HS-ETS1-1. Analyze a major global challenge to specify qualitative and quantitative criteria and constraints for solutions that account for societal needs and wants.

HS-ETS1-2. Design a solution to a complex real-world problem by breaking it down into smaller, more manageable problems that can be solved through engineering.

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.

HS-ETS1-4. Use a computer simulation to model the impact of proposed solutions to a complex real-world problem with numerous criteria and constraints on interactions within and between systems relevant to the problem.

*The performance expectations marked with an asterisk integrate traditional science content with engineering through a practice or disciplinary core idea.

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-1] Asking Questions and Defining Problems	**LS2.C: Ecosystem Dynamics, Functioning, and Resilience**	**[CCC-1] Patterns**
[SEP-2] Developing and Using Models	**LS4.C: Adaptation**	**[CCC-3] Scale, Proportion, and Quantity**
[SEP-4] Analyzing and Interpreting Data	**LS4.D: Biodiversity and Humans**	**[CCC-4] System and System Models**
[SEP-6] Constructing Explanations (for science) and Designing Solutions (for engineering)	**ESS3.D: Global Climate Change**	**[CCC-7] Stability and Change**
[SEP-7] Engaging in Argument from Evidence		----------------------------
[SEP-8] Obtaining, Evaluating, and		**Influence of Science, Engineering, and Technology on Society and the Natural World**

Communicating Information]		
Highlighted California Environmental Principles & 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; N-Q.1-3; S-ID.1; S-IC.1,6		
CA ELD Connections: ELD.PI.11-12.1,5,6a-b,9,10,11a		
CA CCSS ELA/Literacy Connections: RST.9-10.8; RST.11-12.1,2,7,8; WHST.9-12.2.a-e, 7,8.9		

In high school, students confront complicated chains of **cause and effect [CCC-2]** that can work within ecosystems. For example, many human-induced **changes [CCC-7]** in ecosystems have unintended consequences, meaning humans did something to an ecosystem for one reason without realizing that there would be changes to other components of the ecosystem, or they had to balance other priorities (*EP&C V*). In other cases, natural changes to the physical system can cause cascading impacts on the living populations within ecosystems. A flood might drown many of the animals that live within the floodplain area (a density independent factor), but this may in turn cause

other animals to migrate and compete for resources or territory (density dependent factors). This pressure could cause a shift in the ecosystem as a whole; if the population ends up depleting or eliminating resources then the ecosystem may not be able to recover to its original state. Students can observe these changes through data-rich case studies and through computer simulations. Once they have developed conceptual models of ecosystem changes, they should be able to **evaluate different claims [SEP-7]** about the impacts of a new, hypothetical change (HS-LS2-6).

Populations with variation in their gene pool are more often able to withstand selective pressures as long as some of the individuals' phenotypes are advantageous for the population given the environment. Often, there are many variations in a population that do not confer particular advantages at the moment, however if there is a change in the environment, these phenotypes may then have an advantage. Those individuals that survive and reproduce living offspring have the advantageous phenotype. The advantageous phenotype that survived while others disappeared is called an adaptation.

The majority of this IS centers around how populations respond to the varied stresses due to climate change. What sort of changes will occur in ecosystems? What sort of variations will be beneficial to populations?

Climate Change Background

Many of the changes facing ecosystems today are related to changes in abiotic factors due to climate change. Before understanding the effects of climate change, it is important to first examine the causes. While the details of global climate change can be very complex and technical, the underlying science is fundamentally simple and has been known for a long time. The main ideas relate to:

- the flows of energy into, within and out of the Earth system;
- Earth's cycles of matter, especially the carbon cycle; and
- the effects of human activities, especially the combustion of fossil fuels.

Students can make a conceptual model of Earth's energy budget using an analogy of the line for a ride at an amusement park. The constant stream of eager visitors arriving at the end of the line represents solar radiation. As visitors get on the ride at the front of the line, they act like energy radiating out into space. Earth's global average temperature measures the amount of heat stored internally in Earth's system and so it is like the number of people waiting in line at any given time. The line will remain the same length if people get on the ride as quickly as new people arrive at the end of the line. Earth's temperature will remain **stable [CCC-7]** as long as the energy input and output remain unchanged.

Earth's energy input comes almost entirely from the Sun. While there is a small amount of radioactive decay within Earth's interior that generates heat, the flow of solar energy to Earth's surface is about 4,000 times greater than the flow of energy from Earth's interior to its surface. Relatively small changes in the solar input can result in an Ice Age or the melting of all of Earth's ice, much like the sudden arrival of a large group at an amusement ride can cause the line to quickly grow longer. The line will stabilize at this new length (without continuing to grow) as long as the influx of people returns back to its original rate. Planets can do the same thing, maintaining their temperature at a new value after a temporary disturbance.

Most of the sunlight that reaches Earth is absorbed and is transformed to thermal energy. If there were no atmosphere to hold that energy, it would radiate right back into space as infrared radiation (like an unpopular amusement park ride where people get on as soon as they arrive because there is no line). Gases in the atmosphere, such as CO_2, absorb infrared energy heading into space and cause it to remain within the Earth's system for a longer period of time. Because these gases have the same effect as a greenhouse where heat is trapped inside the system, gases like CO_2 are referred to as 'greenhouse gases.' Calculations by scientists show that if Earth had no greenhouse gases, its surface temperature would be near 0°F (or -18°C) instead of its current value of much warmer 59°F (15°C). The energy coming into the Earth is still balanced almost exactly by what is leaving the planet but there is enough heat trapped

in the system to allow life to thrive (like the amusement park ride whose line is always the same length).

By increasing the amount of greenhouse gases in the atmosphere, human activities are increasing the greenhouse effect and warming Earth's climate. In a given year, less energy leaves Earth than arrives. It is like one of the seatbelts breaking on the amusement park ride and fewer people are able to get on the ride. All of a sudden, the line gets longer and longer as new people arrive because people are not able to leave the line as quickly at the front. At the amusement park, this might lead to impatient children. On Earth, the imbalance in energy flows leads to an overall rise in average temperature.

Amusement parks and planets are **systems [CCC-4]** with complicated inner workings. When lines for one ride at an amusement park get too long, visitors inside the park may respond by going to another ride or park operators may add additional workers or cars to help move people through more quickly. Similar changes happen in Earth's web of systems. While the greenhouse effect seems like a simple **cause and effect [CCC-2]** relationship viewed from outside the system, interactions *within* the system can often give rise to more complicated chains of cause and effect referred to as feedbacks. Climate scientists are particularly concerned about feedback effects that could increase the amount and rate of global climate change. One example is that global warming is clearly reducing the amount of ice on our planet. Glaciers around the world are shrinking in size and even disappearing. The amount of ice covering the ocean in summer and fall is also shrinking. As the ice melts, the surface beneath it is darker in color and absorbs more incoming sunlight. More absorption causes more heating, and this heating causes even more absorption of sunlight (figure 7.11). This kind of feedback loop amplifies or reinforces the change, and the distinction between 'cause' and 'effect' begins to blur as each effect causes more change. The clarification statements in the CA NGSS and many scientists use the term 'positive feedback', but this term could be replaced by a more descriptive term such as reinforcing feedbacks because it leads to confusion – many 'reinforcing feedbacks' have very negative outcomes.

Figure 7.11. A Reinforcing Feedback in Earth's Climate
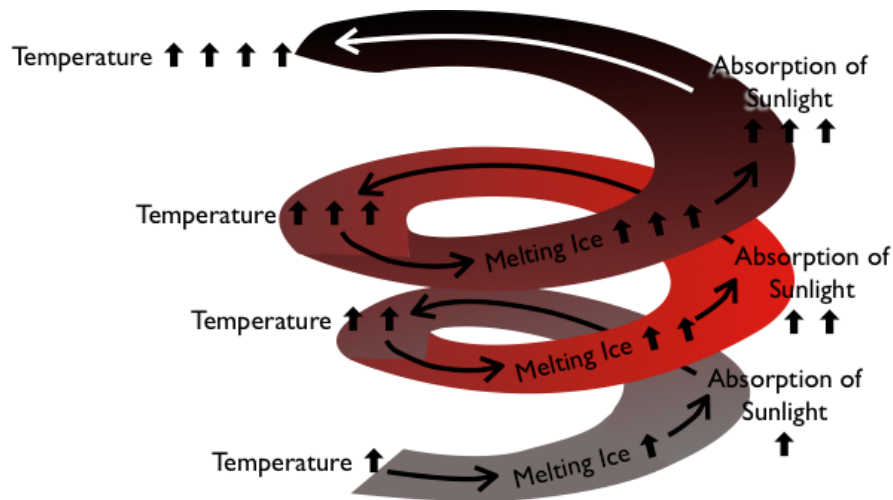
A counterbalancing feedback loop reduces the amount of change (figure 7.12). For example, warmer temperatures cause more water to evaporate which enables more clouds to form. Since clouds reflect sunlight back into space, more clouds cause more incoming solar energy to be reflected before it has a chance to be absorbed by the planet. This causes decreasing global temperatures. More warming could cause more cloud formation and reflection, which would then lead to less warming again[6]. These changes are opposite and can balance each other out. Diagram by M. d'Alessio and A. Sussman

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[6] Even though this example describes a counterbalancing feedback involving clouds, clouds are also involved in a reinforcing feedback where they trap more heat, causing more evaporation, and more clouds that trap more heat… Both of these mechanisms occur on Earth. The question researchers are currently trying to answer is, "Which feedback loop is more powerful, reinforcing or counterbalancing?" **Cause and effect [CCC-2]** gets very complicated in the Earth system!

Figure 7.12. A Counterbalancing Feedback in Earth's Climate System
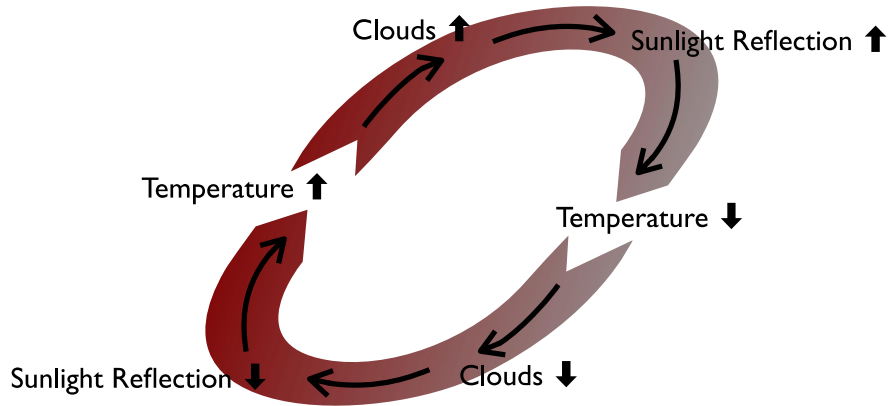
Temperature changes cause changes to the number of clouds because of evaporation. Clouds, in turn, reflect light. Diagram by M. d'Alessio and A. Sussman.

Predicting Climate Change Impacts on Ecosystems

Many of the feedbacks in climate change involve ecosystems as part of the chain of events and will cause drastic changes to the abiotic conditions. How much will ecosystems change? Global climate models allow scientists and students to see how the climate is expected to change as greenhouse gases trap more energy in the atmosphere. Because of the linkages between different components of Earth's **systems [CCC-4]**, the impacts extend to all of Earth's systems (figure 7.13 shows an example of a few of these linkages).

Figure 7.13. Human Impacts on the Earth System Related to Climate Change
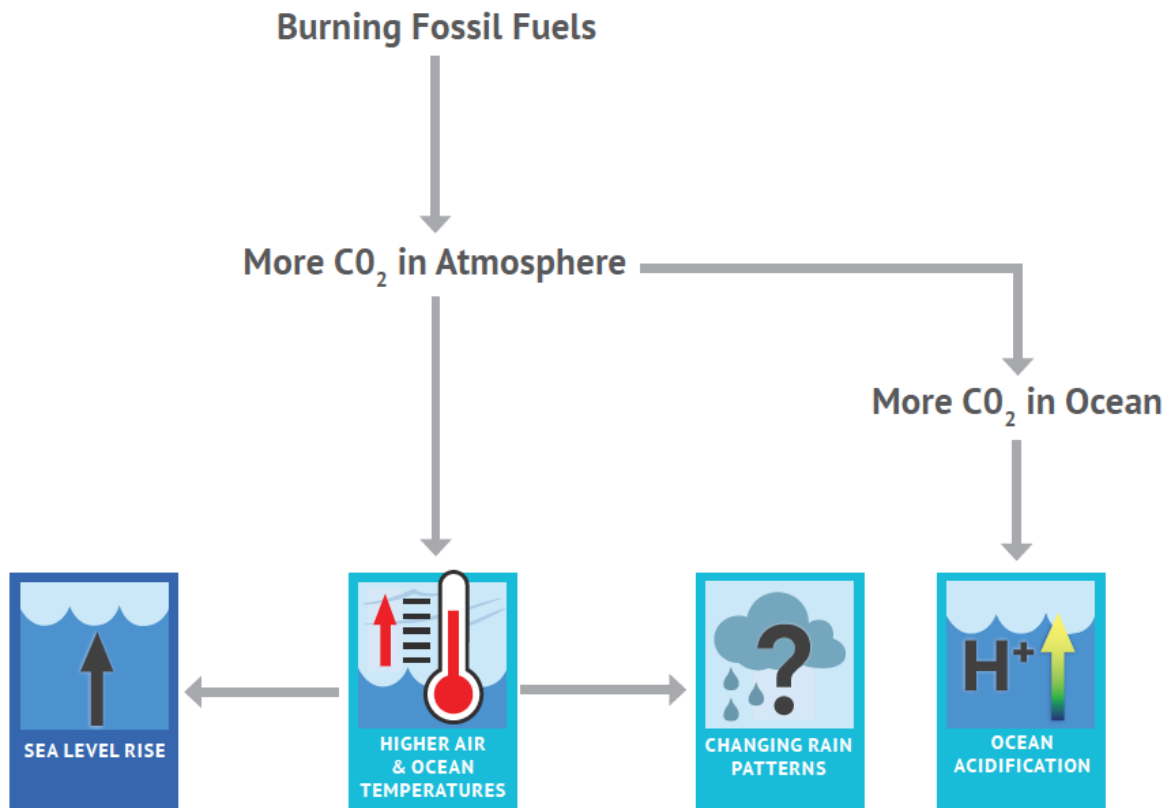
One example of how humans affect the climate, which impacts all parts of Earth's systems. Illustration by Dr. Art Sussman and Lisa Rosenthal, courtesy respectively of WestEd and WGBH.

Models can help scientists predict how a climate change can effect populations within an ecosystem, especially over time. Students can employ simple computational simulations to explore real world population impacts (*HS-ESS3-6, HS-LS2-1*). For example, sea stars in California's coastal tide pools have seen a recent spike in an illness called 'wasting disease' that causes death in a matter of a few days. The problem is dramatic and students can even report observations of afflicted organisms to a long-term monitoring project online (see UC Santa Cruz, "Sea Star Wasting Syndrome" at http://www.eeb.ucsc.edu/pacificrockyintertidal/data-products/sea-star-wasting/). The cause is currently unknown, but one hypothesis is that a species of *Vibrio*

bacteria may infect them. Bacteria thrive in warmer temperatures, so seasonal cooling is an important moderator of bacteria populations. Climate forecasts predict that winter temperatures will increase. Will this cause a *Vibrio* bacteria population explosion? Students can design a computer **model [SEP-2]** by looking up laboratory experiments on bacteria growth (freely available online) and have their model mimic bacteria growth in ocean water temperatures that match climate forecasts. Students can use the model to assess the impact on coastal tide pool populations that can be infected by the bacteria (HS-LS2-6). Other similar problems can be modeled such as the rise in malaria due to mosquitos extending their range to higher elevations or changing growing conditions suitable for rice, wheat, and other food staples (due to changes in rainfall and temperature). The High School Four Course Model - Chemistry section describes a similar simulation exploring the impact of ocean acidification on plankton species. Fully meeting the *HS-ESS3-6* requires that students not only obtain information about the problem, but also use simulations of the interaction of different Earth systems (including the biosphere) to demonstrate the specific impacts of human activities. They can also use these computer simulations to evaluate potential solutions to these problems (*HS-ETS1-4*).

High School Living Earth Snapshot 7.5: Food Diaries

Everyday phenomenon: Different people eat different foods each day.

Ms. M partners with the health teacher at her school to have students record everything they eat and drink for three days. Students enter their diet into an online tool (USDA "Supertracker" at https://www.supertracker.usda.gov/) that reports their intake of different nutrients and they examine their individual diets in the health class. In Ms. M's class, they use a different online tool to calculate the total carbon emissions from the production and transport of their food (CleanMetrics "Food Carbon Emissions Calculator" at http://www.foodemissions.com/foodemissions/Calculator.aspx). Students then enter all their data into a single online spreadsheet to compare each student's carbon footprint from food and intake of nutrients like fat, sodium, carbohydrates, and fiber (though Ms. M hides the column with student names). The class **analyzes the data [SEP-4]** and notice several **patterns [CCC-1]** such as students that eat more vegetables and less meat have lower carbon footprints. Ms. M. asks students to create an infographic illustrating the foods that are both healthy for people and healthy for the climate. They prepare a presentation **communicating [SEP-8]** their findings to the people that run the school lunch program and post their infographic in the cafeteria.

Engineering
Connection

Engineering Connection: Conservation Biology

Within ecosystem science, some aspects of conservation biology are a form of engineering that focuses developing processes that save endangered and threatened species (both animal and plant species). Conservation biologists support the use of wildlife corridors (these link large areas of land to other large areas so animals can migrate safely), develop breeding programs for protecting endangered species, identify specific hotspots of species-rich regions worthy of extra protection and determine plans that provide sufficient protection, argue for the maintenance of larger environment regions instead of habitat fragmentation, observe genetic diversity in small populations, and monitor the effects of climate change on all ecosystems.

As climate shifts, some organisms might need to migrate to new locations during part or all of the year, but their pathway could be interrupted by a freeway, fence, or other obstacle. Teachers can present students with a challenge to evaluate several possible plans for a wildlife corridor beneath a freeway and the possible expansion of a protected open space, which would allow them to use engineering design practices to **solve [SEP-6]** a real-world problem in an ecosystem using the tools and strategies of conservation biology. As they **obtain more information [SEP-8]**, including the needs of people as well as plants and other animals, they refine their solution (EP&C V; HS-LS2-7).

High School Living Earth Snapshot 7.6: Shrinking Pika Habitat

Anchoring phenomenon: Pikas live only at high elevations (and are adorable).

Mr. R starts class off by showing a slideshow of adorable creatures called pikas that live in the eastern Sierra Nevada Mountains and other mountains around the world. Pikas' bodies are so well adapted to the colder climates of higher elevation that they can overheat in certain temperatures and die in temperatures as low as 80 degrees after a few hours. While other animals can relocate higher up in the mountains, pikas already live at the highest elevations and they could not survive the migration down from one high peak to another. The pikas serve a unique role in the high altitude ecosystems in which they live: they build piles of grass that help fertilize the soil and fix nitrogen and they are also a food source for larger predators within the sparsely populated high altitude regions. Without an understanding of the interweaving of life with the Earth's systems it is hard to justify "what all the fuss is about" for a single small organism.

Investigative phenomenon: Global warming will increase the temperatures at high elevations.

Mr. R tells students that they will be making a kinesthetic **model [SEP-2]**, a model using their bodies, of the effects of climate change on pikas. Mr. R scattered wooden sticks supplies outside on the soccer field before class to represent plants that the pikas will collect for their winter food supplies. He placed orange cones out in a triangle shape with the peak of the triangle representing the peak of a mountain and the long side representing the lowest point on the mountain that pikas can survive. If they stray below the line, they will overheat and could die. Each person plays the part of a pika and must collect sticks and bring them back to their burrow, one at a time (pikas cannot carry much). By the time winter comes, they must have collected 10 sticks. Students run around and frantically collect the sticks until Mr. R announces the coming of winter. He then shrinks areas enclosed by the cones announcing that global warming has limited the area. Students find that there are insufficient sticks for all of them to survive. He

repeats the process a third time, keeping the size of the mountain constant but giving students more time to search for sticks, representing a longer summer. More of the pikas survive.

Students return to the computer lab and Mr. R shows them a computer simulation of the exact situation that they encountered in the kinesthetic activity (HS-ETS1-4). He emphasizes that both are examples of **models [SEP-2]**. Students can adjust the temperature and watch how the size of the pika habitat shrinks and grows. The simulation is sophisticated and students can adjust the temperature month by month. They can explore the **effect [CCC-2]** of longer summers and see how that affects vegetation growth (so that pikas have more food available) or warmer winters, in which pikas need less food in order to survive. Students then visit the Cal-Adapt website (http://cal-adapt.org/) run by the California Energy Commission and find specific temperature forecasts for the habitat of the pika in the Eastern Sierra (HS-ESS3-5). They see that the average temperature in August is expected to rise by 10°F between 2000 and 2100 under one scenario, but only 3° if humans emit less carbon dioxide from their use of fossil fuels (figure 7.14). Students quickly enter the temperature changes into their simulator to explore the impact of the predictions on the pika.

Figure 7.14: Temperature Forecast for Habitat of the Pika
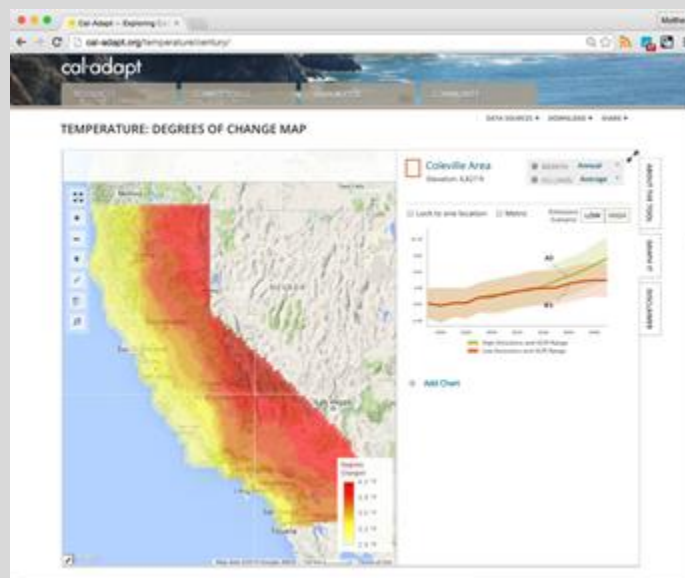
Source: California Energy Commission 2015.

Investigative problem: What can people do to protect pikas and the rest of their ecosystem?

Students recognize from the simulator that pikas do much better under the low emission scenario than the high emissions scenario (HS-ESS3-6). Students can analyze the problem and identify protection of the entire ecosystem as part of their criteria for their solution (*HS-ETS1-1*). As the environment warms what can humans do to help the pikas and their ecosystem? Students need to break the problem down into smaller, more manageable problems (*HS-ETS1-2*), identifying criteria and constraints for successful solutions, and then comparing alternative solutions against the criteria and constraints to determine which are most likely to succeed. They then modify the computer simulation they used earlier to include the effects of their solution (HS-LS4-6). How can they parameterize their solution in computer code? How much does it benefit the pikas

Source: *Inspired by Parks Climate Challenge 2009*

Many solutions to these problems may focus on addressing the causes of climate change, such as the global reliance on fossil fuels for energy generation. Both High School Four Course Model – Chemistry and Physics sections consider these questions and links should be made to those courses. In the past, comparative costs of different energy sources have been based on dollar cost to the consumer, but new studies have taken into account a wider variety of costs including degradation of natural ecosystems, health impacts, and water and air pollution. This course on the Living Earth is uniquely positioned to emphasize the importance of these measures when evaluating competing design solutions in all disciplines (HS-ETS1-3). Content from the EEI curriculum helps support many of these concepts, including the lessons on Biodiversity: *The Keystone to Life on Earth and the Greenhouse Effect on Natural Systems.*

The high school Biology course may want to culminate with a project in which students apply what they have learned about how organisms maintain life. For example, students could compare and contrast how a few different organisms maintain life (e.g.

human, redwood tree, and *E. coli*). The students should use **evidence [SEP-7]** to support their **explanations [SEP-6]** and they should effectively **communicate [SEP-8]** their **models [SEP-2]**.

High School Living Earth Vignette 7.1: Analyzing the Past, Present, and Future of Marine Mammal Evolution
Performance Expectations
Students who demonstrate understanding can: **HS-ESS2-7. Construct an argument based on evidence about the simultaneous coevolution of Earth's systems and life on Earth.** [Clarification Statement: Emphasis is on the dynamic causes, effects, and feedbacks between the biosphere and Earth's other systems, whereby geoscience factors control the evolution of life, which in turn continuously alters Earth's surface. Examples include how photosynthetic life altered the atmosphere through the production of oxygen, which in turn increased weathering rates and allowed for the evolution of animal life; how microbial life on land increased the formation of soil, which in turn allowed for the evolution of land plants; or how the evolution of corals created reefs that altered patterns of erosion and deposition along coastlines and provided habitats for the evolution of new life forms.] [*Assessment Boundary: Assessment does not include a comprehensive understanding of the mechanisms of how the biosphere interacts with all of Earth's other systems.*] **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-ESS3-6. Use a computational representation to illustrate the relationships among Earth systems and how those relationships are being modified due to human activity.* [Clarification Statement: Examples of Earth systems to be considered are the hydrosphere, atmosphere, cryosphere, geosphere, and/or biosphere. An example of the far-reaching impacts from a human activity is how an increase in atmospheric carbon dioxide results in an increase in photosynthetic biomass on land and an increase in ocean acidification, with resulting impacts on sea organism health and marine populations.] [Assessment Boundary: Assessment does not include running computational representations but is limited to using the published results of scientific computational models.]

HS-LS2-2. Use mathematical representations to support and revise explanations based on evidence about factors affecting biodiversity and populations in ecosystems of different scales. [Clarification Statement: Examples of mathematical representations include finding the average, determining trends, and using graphical comparisons of multiple sets of data.] [*Assessment Boundary: Assessment is limited to provided data.*]

HS-LS2-6. Evaluate the claims, evidence, and reasoning that the complex interactions in ecosystems maintain relatively consistent numbers and types of organisms in stable conditions, but changing conditions may result in a new ecosystem. [Clarification Statement: Examples of changes in ecosystem

conditions could include modest biological or physical changes, such as moderate hunting or a seasonal flood; and extreme changes, such as volcanic eruption or sea level rise.]

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-LS4-5. 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-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.

*The performance expectations marked with an asterisk integrate traditional science content with engineering through a practice or disciplinary core idea.

Highlighted Science and Engineering Practices	Highlighted Disciplinary Core Ideas	Highlighted Crosscutting Concepts
[SEP-1] Asking Questions and Defining Problems [SEP-2] Developing and Using Models [SEP-4] Analyzing and Interpreting Data [SEP-7] Engaging in Argument from Evidence [SEP-8] Obtaining, Evaluating, and Communicating Information	ESS2.D: Weather and Climate ESS2.E Biogeology ESS3.C: Human Impacts on Earth Systems ESS3.D: Global Climate Change LS2.C: Ecosystem Dynamics, Functioning, and Resilience LS4.A: Evidence of Common Ancestry and Diversity LS4.C: Adaptation ETS1.B: Developing Possible Solutions	[CCC-1] Patterns [CCC-2] Cause and Effect [CCC-7] Stability and Change

Highlighted California Environmental Principles & 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 V Decisions affecting resources and natural systems are complex and involve many factors.

CA CCSS Math Connections: MP.1, MP.2, MP.4, MP.7, S-ID 1, 6, 9; S-IC 6

CA CCSS ELA/Literacy Connections: W.9-10.1a-f, 6, SL.9-10.1a-d,4, RST.9-10.1,3, 7, 9, WHST.9-10.1a-e, 6, 7, 9

CA ELD Connections: ELD.9-10.P1.1, 3, 6, 10

Introduction

Climate is an environmental factor from the geosphere that has a strong impact on populations in the biosphere. In this vignette, students examine how both year-to-year fluctuations in weather conditions and longer term trends in climate have affected marine mammal populations. They analyze a variety of data sets, including fossils, amino acid sequences, population census, and temperature reconstructions over geologic time to identify patterns and correlations that are clues to cause and effect relationships. Students must integrate their knowledge of Earth systems and ecosystems as the changes introduced involve complex interactions between plate motions, climate, human activities, evolution, and population dynamics. While the data

sets provide clues, there are no easy answers in this vignette -- evidence supports many possible interpretations and no simple model is sufficient to explain all the observations. This complexity and uncertainty make the vignette an ideal culmination of the Living Earth course.

Length and position in course – This vignette describes two to three weeks of instruction that culminate many aspects of the Living Earth course.

Teacher background – Marine mammals include three different types: whales and dolphins (infraorder *Cetacea*), manatees and dugongs (order *Sirenea*), and seals and sea lions (clade *Pinnipedia*). Each 'type' occurs at a different level of taxonomy. For simplicity, this activity refers to each by their common names. Despite their many similarities, these organisms evolved independently from different land mammals around the same times and in response to the same environmental conditions.

5E Lesson Design – This sequence is based on an iterative 5E model. See the instructional strategies chapter in this framework for tips on implementing 5E lessons.

Day 1: Problems Affecting Diverse Marine Mammals	*Day 2: Fossil Evidence for Evolution*	**Day 3: DNA Evidence for Evolution**
Students are introduced to local challenges to marine mammals. They obtain and evaluate information about three different types of marine mammals. They ask	Students analyze a sequence of fossils, using patterns to trace the evolution of different marine mammals back to different land-dwelling ancestors.	Students analyze sequences of amino acids to determine relative similarity between the DNA of different marine and land-dwelling animals. DNA evidence confirms that the

questions about whether their similarities are inherited from a common ancestor.		three different marine mammal species evolved separately from one another.
Days 4-5: Animals Evolve in Response to Climate Change Students ask questions about the influence of climate changes on the evolution and biodiversity of different marine mammal species. They obtain information to support claims about complex cause and effect chains: plate motion caused changes in ocean basin shape that caused changes in ocean currents that caused changes in climate that influenced evolution.	**Days 6-7: Predicting Future Climate Impacts** Knowing that marine mammal species have been so strongly influenced by climate changes in the past, students analyze data about shorter term impacts from El Niño on sea lion populations.	**Day 8-10: Human Impacts & Human Solutions** Students obtain information about the extinct Stellar's sea cow to debate whether climate changes or human impacts caused its downfall. They evaluate different design solutions to protect modern day marine mammal populations.

Day 1 – Problems affecting Diverse Marine Mammals (Engage)

Anchoring phenomenon: In 2015, marine mammal experts rescued three times the usual number of stranded sea lion pups on Southern California beaches.

Students watch a video that introduces the anchoring phenomenon about record numbers of sea lion pups rescued on southern California beaches. The movie claims that the mystery remains unsolved, but climate change may be to blame. Students

discuss initial ideas about how climate change could have played a role. On the road to evaluating this claim during the next few days, students investigate how marine mammals responded to ancient climate shifts and then analyze recent trends.

To ensure that students have some basic background knowledge about the diversity of marine mammals, Mr. T organizes a jigsaw where each student **obtains information [SEP-8]** to become 'experts' about one of the three major types of marine mammals: seals (*Pinnapedia*), whales and dolphins (*Cetacea*), and manatees (*Sirenia*). Experts share all sorts of facts: where they live, what they eat, how they gather food, how big they are, how they sleep, how they breathe, their mating habits, and more. Groups with an expert on each type **evaluate their combined information [SEP-8]** by making a Venn diagram comparing the three types. Mr. T then has students **develop questions [SEP-1]** about the evolutionary history of marine mammals by looking at the diagram. When did each type of marine mammal evolve? What environmental factors caused them to evolve this way? How do marine mammals relate to regular land dwelling mammals? Is it possible that all these organisms evolved from a common ancestor that had the features at the center of the Venn diagram?

Day 2 – Fossil Evidence for Evolution (Explore)

Investigative phenomenon: The ancestors of ancient marine mammals have slowly changed over time (in both body shape and the shape of external structures).

Scientists trace the evolutionary history of animals using a range of tools, including fossils. On Day 2, students reconstruct the evolutionary sequence of each type of marine mammal. Mr. T provides each expert team a stack of cards. Each one shows a diagram of a complete skeleton of an ancestor to their team's marine mammal. The top card is the modern day skeleton but all the rest of the fossils are in random order; the students will have to put them in their correct evolutionary sequence. Mr. T explains that this process is quite different from the way paleontologists complete their work – each fossil comes from a layer of rock in a known sequence and often a known age. The jumbled sequence, he explains, will help students pay close attention to the gradual

progressions that exemplify many evolutionary changes. Students relate these gradual progressions back to the initial questions they developed in Day 1. Students do not need to understand much about marine mammal anatomy – their goal is to **analyze [SEP-4] patterns [CCC-1]** such as 'the tail is getting longer' or 'the teeth are shrinking.'

Mr. T has them tape their cards along the wall in sequence and add sticky notes to emphasize features that change from frame to frame. Students then return to their mixed jigsaw groups to lead 'tours' of their fossil sequence to experts from other groups. Mr. T asks the students to evaluate if all the fossil sequences start from a common ancestor. They discover that all three of these marine mammals evolve from land mammals that walked on four legs and had long tails, each one from a distinctly different looking creature. Seals evolved from something like an otter while the ancestor of the whale was the size and shape of something like a cross between a dog and a very large rat. Students end the day by reflecting on what they have discovered by writing a brief **argument [SEP-7]** refuting the statement, "Whales, manatees, and seals all evolved from a common ancestor." What evidence would they expect to find if this statement were true? Did they find that evidence? The shared traits of these different marine mammals exemplify convergent evolution.

Day 3 – DNA Evidence for Evolution (Explore)

Convergent evolution is easy to notice, but how does it happen? On Day 3, students learn how genome mapping illustrates the evolutionary history of organisms. To review what students learned earlier in the year about DNA and heritability, Mr. T wears a geeky science t-shirt that says: "98 percent Chimpanzee" on the front and "50 percent banana" on the back. He begins class by asking students to explain the shirt's joke. He then has students do a think, pair, share where they respond to the question, "What are the implications of humans being 98 percent chimpanzee? What does the information allow us to predict about humans and chimps?"

Investigative phenomenon: The amino acid sequence in the protein cytochrome C are similar for many animals, but there are notable differences.

Mr. T informs them that they will do some simple analysis of DNA sequences to see how numbers like these are constructed. He gives a short mini lecture on genome mapping and 'genetic barcoding.' Students need enough basic background to interpret data from genome mapping of marine mammals to infer how closely related two organisms are. He provides lab teams with amino acid sequences of a protein common to many organisms, cytochrome C[7]. The list contains about two dozen animals. The DNA of a grey whale is identified at the top of the list, but the rest are simply labeled "Organism A, B, C, etc." Like the previous day, they focus on the **pattern [CCC-1]** of the amino acids rather than trying to understand the details. Students try to arrange the organisms in order of how closely related they are to the grey whale. Mr. T then reveals the actual organisms (including fungus, wheat, dog, and penguin). Students discover that, at least for this one protein, the grey whale is more closely related to cows than it is to seals or manatees. While this is just one small section of DNA, it confirms the fossil evidence that the organisms evolved from different species of land animals rather than a single common marine ancestor. Mr. T has students return to their previous day's **argument [SEP-7]** and extend it with the new DNA evidence (HS-LS4-1).

Days 4-5 – Animals Evolve in Response to Climate Change (Explain)

Investigative phenomenon: Three separate species of land mammals all evolved to become entirely aquatic organisms.

Whatever the genetic mechanism, three separate species of land animals all evolved to become entirely aquatic organisms. Why? The general trend in evolution has

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[7] Evolution & the Nature of Science Institutes. 2001. "The Cytochrome-C Lab." http://www.indiana.edu/~ensiweb/lessons/mol.bio.html (accessed May 31, 2016); Students can also learn to access proteins from mapped genomes directly from the National Center for Biotechnology, "Cytochrome C Southern Elephant Seal." http://www.ncbi.nlm.nih.gov/protein/P00012.2 (accessed May 31, 2016).

been for organisms to emerge from the water, so what conditions led the three marine mammal types to return? Mr. T has students begin by writing a short 'story' that describes a possible scenario that would explain why separate land animas returned to the ocean. He invites them to be creative with their ideas, but they should be consistent with the previous concepts they learned in the class. What sort of evidence do they expect to find if their story is true? They will revisit their story at the end of this activity.

Investigative phenomenon: The diversity of marine mammals has shrunk and grown over the last 60 million years.

Students return to fossil evidence to look at when each species evolved. They plot and **analyze data [SEP-4]** showing the number of genera of each type of marine mammal alive at different points in geologic time (figure 7.15). Students analyze one marine mammal in jigsaw groups before coming together to compare them.
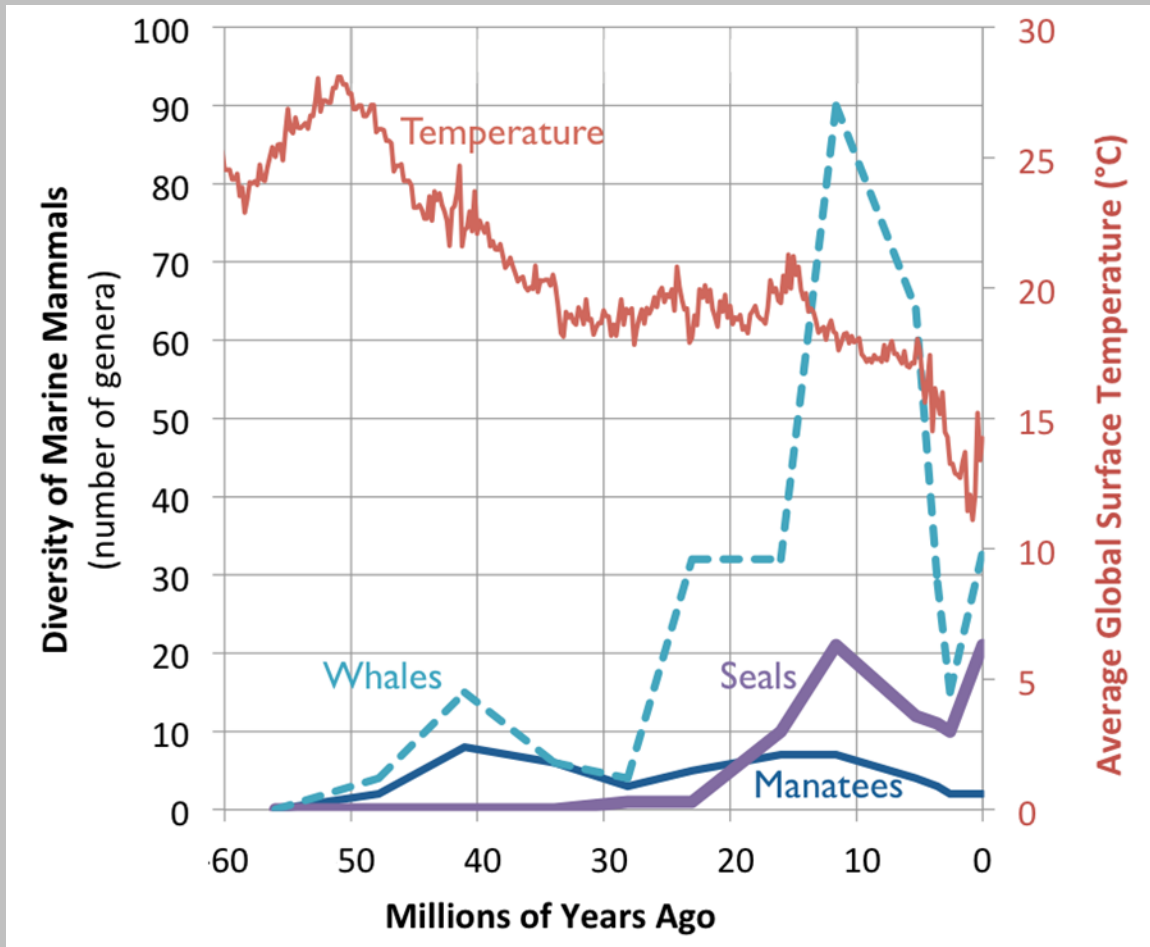
Figure 7.15. Diversity of Marine Mammals Over the Last 60 Million Years

Chart by M. d'Alessio with data from Uhen 2007 and Hansen et al. 2013.

Students find that whales and manatees evolved at nearly the exact same time ~50 million years ago, thrived for about 10 million years, and then started to die off. The diversity then explodes dramatically to a peak around 10 million years ago (around the same time that seals first evolve), only to have all three types of marine mammals collapse simultaneously a few million years later. Mr. T invites students to ask testable questions about why these creatures share such a similar history even though they evolved independently. Groups ask things like, "Did they evolve at the same time because a new food source evolved in the ocean?" and "Did they start to die out because of an asteroid?" Mr. T focuses on the group that asks, "Was there something

about the environment that changed at 50 million years ago?" He asks them what sort of physical changes could occur, and climate is one of the possibilities.

Investigative phenomenon: Some of the changes in marine mammal diversity occur at the same time as major changes in global temperature.

Mr. T provides the class with another graph showing a reconstruction of global temperatures. Students use the graphs to present possible explanations of some of the changes in biodiversity (HS-LS2-2, HS-LS4-5). Could whales and manatees have escaped into the water to avoid exceptionally high temperatures at the time? Or did the warmer temperatures simply make food sources more abundant in the ocean? Could the expansion of all marine mammals starting around 18 million years ago (Ma) be related to a slight warming known as the Mid Miocene Climatic Optimum (perhaps causing an explosion in ocean productivity)? Could the collapse shortly thereafter be related to the cooling trend a few million years later? Students read some short articles and Mr. T provides a mini lecture to help students understand the relationship between temperature and marine biological productivity and how this relates to what may have happened during the Mid Miocene Climate Optimum. Mr. T has students draw a concept map (a pictorial **model [SEP-2]**) illustrating some of the cause and effect relationships they see in the data (figure 7.16):

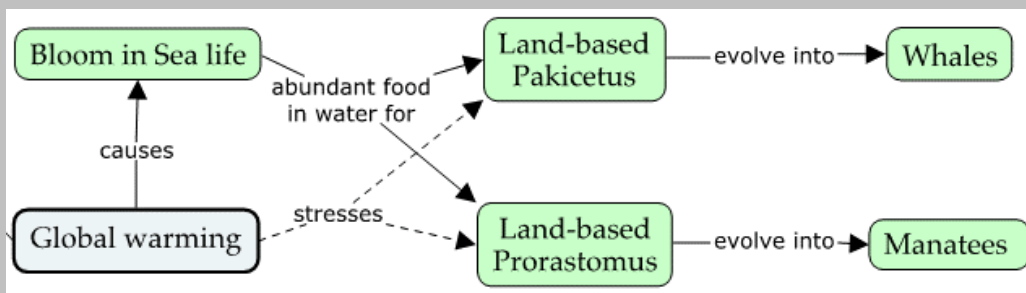**Figure 7.16. Concept Map Illustrating Cause and Effect Relationships**

Diagram by M. d'Alessio

When students see cause and effect relationships between climate change and biodiversity, they also wonder about what caused such dramatic climate fluctuations. Mr. T has students discuss an article that describes some surprising ties between the

motion of Earth's tectonic plates and climate. For example, when the Tethys Sea closed sometime between 20 and 15 Ma, it may have disrupted global wind and ocean currents so much that the planet began a dramatic cooling. That cooling affected marine mammal diversity. After the reading, Mr. T has students extend their concept map model (figure 7.17) showing the complex chain of **cause and effect [CCC-2]** (diagrams A and B below). He has them use their diagrams to **debate the claim [SEP-7]** that "Whales would not have evolved without plate tectonics." (HS-ESS2-7). Students finish the activity by returning to their stories from the beginning of Day 4. Did their story match the evidence?

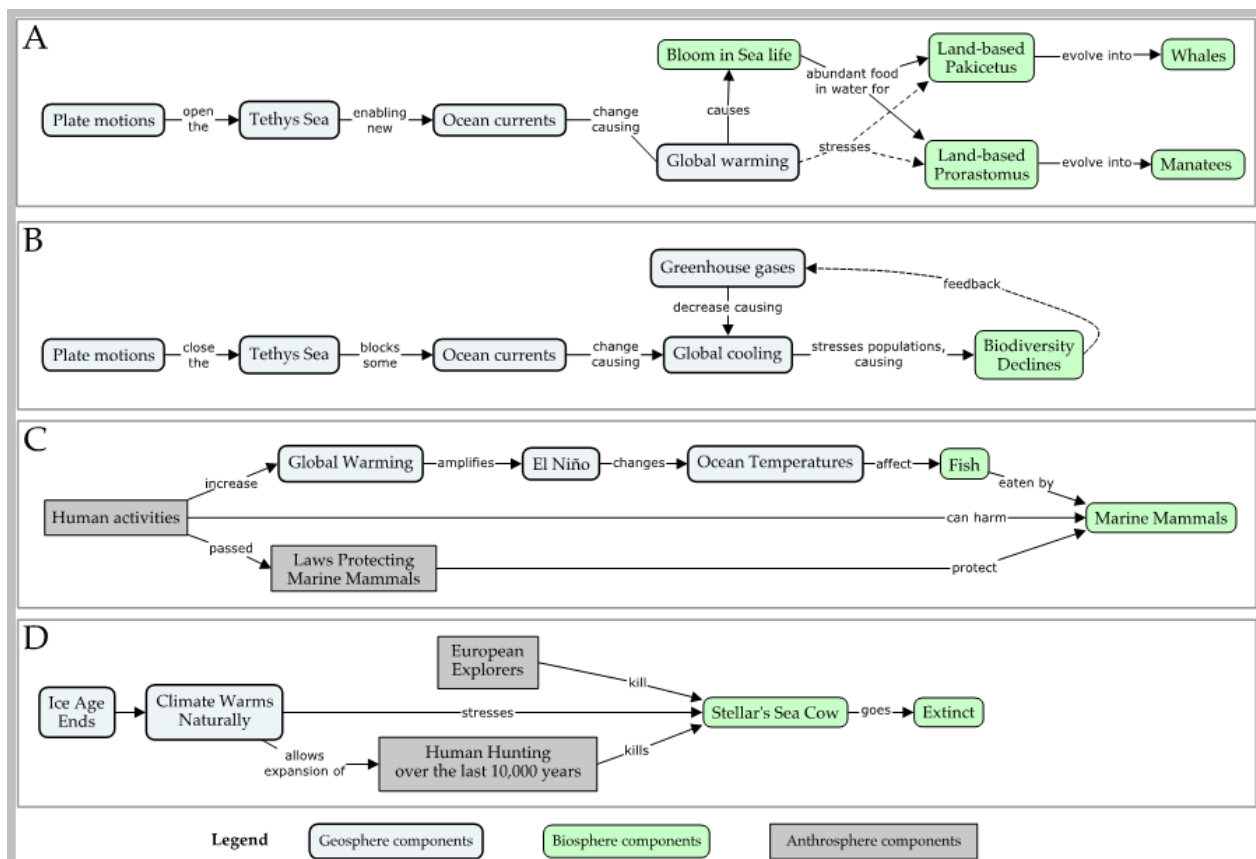**Figure 7.17. Extended Concept Map Showing Chains of Cause and Effect**

Diagram by M. d'Alessio

Day 6-7 – Predicting Future Climate Impacts (Explain)

The entire history of marine mammals in the past depends in part on changes in the climate, but how will future climate change affect today's populations? While the effects of long-term climate change are hard to model, short-term changes to global temperature are becoming increasingly common due to El Niño. Examining the effects of these short term changes provides insight into the ways ecosystems might respond to longer term changes. Students return to questions from Day 1 about sea lion populations. They use a spreadsheet to plot and **analyze [SEP-4]** sea lion population over the last 40 years (figure 7.18).

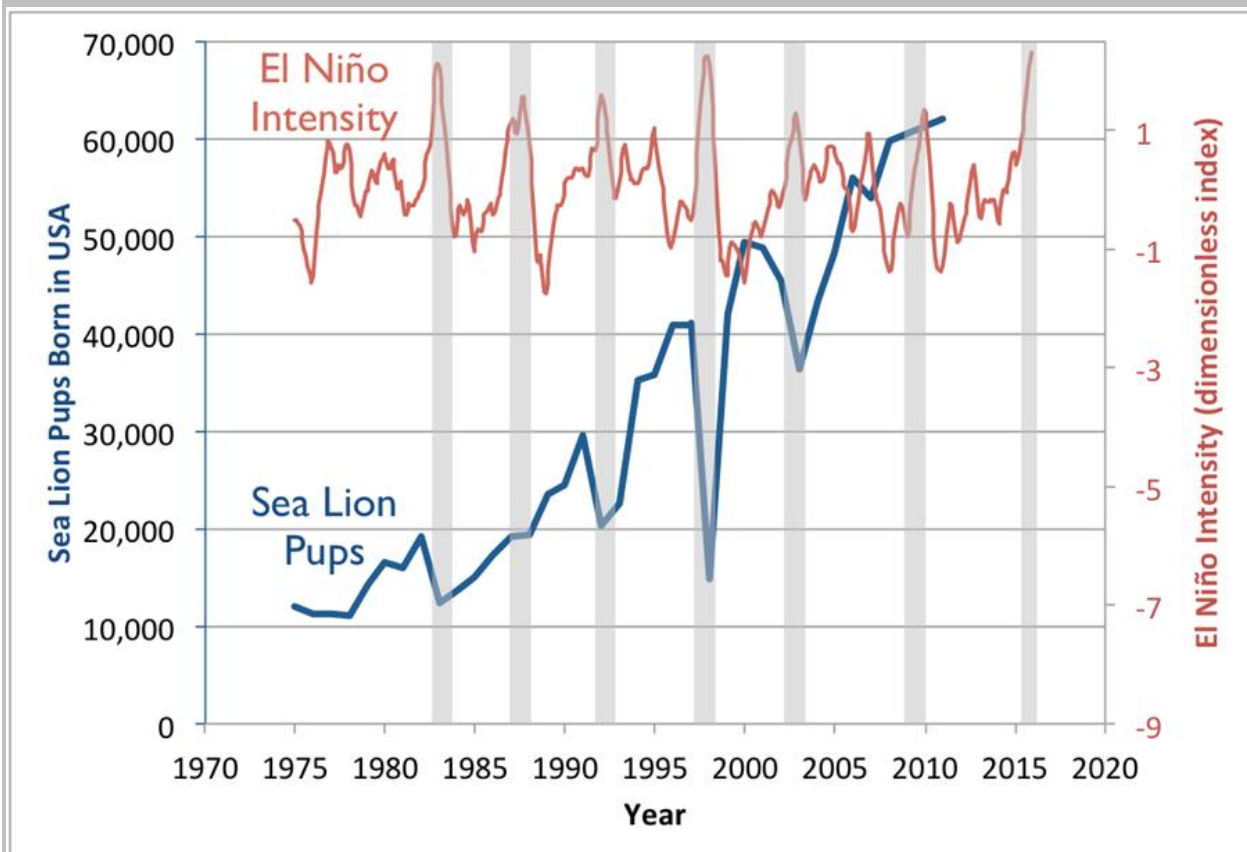**Figure 7.18. Sea Lion Pup Population and El Niño Intensity**

Chart by M. d'Alessio with data from National Oceanic and Atmospheric Administration Fisheries 2015 and Climate Prediction Center 2015.

Investigative phenomenon: Sea lion populations have increased over the last forty years, but seem to undergo population collapses every few years.

Students recognize two important features in the data: 1) Sea lion populations have generally increased since the mid 1970's; and 2) Every few years, there is a sudden reduction in the number of sea lion pups. They will consider the overall growth trend on Day 7, but right now focus on the **cause [CCC-2]** of the periodic reductions. Students discover that sea lion pups tend to die off severely in years when El Niño is extreme. They begin to create a model for the exact mechanism by which El Niño affects sea lions by graphing the availability of their favorite food sources, fish such as sardines and anchovies (see California Academy of Sciences 2015). Since the cause and effect chains have many steps, students continue to use concept maps to record their understanding, building part of diagram C in figure 7.17. They use their model to evaluate the claim that El Niño's fluctuations have caused changes in the sea lion populations (HS-LS2-6). Students plot data from the amount of fish caught by commercial fishermen, so Mr. T also leads a discussion about how these changes not only impact sea lions, but they also impact human populations (EP&C I).

Students then read articles to **obtain information [SEP-8]** about computer simulations that predict how El Niño will change as climate changes. Some models show that El Niño will probably not occur more frequently, but the intensity of El Niño and La Niña may increase, causing larger fluctuations from year to year (HS-ESS3-6; EP&C III). Will sea lions be able to adapt to these **unstable [CCC-6]** conditions? Students add their new understanding of cause and effect to their concept map models.

Day 8 - Human Impacts (Elaborate)

Students notice that the population of sea lions in the US has been growing steadily since the 1970s. Could this be related to climate change? The small but steady

temperature increases in the ocean are unlikely to be strong enough to have such a dramatic impact. What besides climate can have such a dramatic impact on animal populations? Human activities. The US passed the Marine Mammal Protection Act in 1972, which makes marine mammal conservation a priority. Mr. T tells students that this act was put in place in time to protect sea lion populations, but it was not early enough to save all of California's marine mammals. The fossil record reveals one more exciting surprise.

Investigative phenomenon: Fossils indicate that Stellar's sea cows, giant manatees, once lived off of California. These organisms were last seen alive by explorers in the 1700's near a remote island in Alaska, but have since become extinct.

Students review videos and Internet resources to **obtain information [SEP-8]** about the Steller's sea cow, finding that it is the largest manatee species known (growing up to 9 meters – nearly three times the size of Florida's well known manatees). When explorers first encountered it in 1741, it was abundant but only found in a few isolated pockets around uninhabited islands off the far west tip of the Aleutian Islands near Russia. Within 27 years after it was first discovered by Europeans, it was hunted to extinction. The Stellar's sea cow was the last branch of a genetic tree that diverged from the rest of the manatee and dugong family more than 20 million years ago. As recently as 20,000 years ago, it extended along the rim of the North Pacific as far south as Japan and the Monterey Bay in California. Since they only survived in places without human civilization, some scientists speculate that human hunting in the last 10,000 years contributed to their demise. Others note a number of other species also died out in that time period because of a major shift in climate at the end of the last ice age. Students collect evidence and engage in a **debate [SEP-7]** about whether early humans, European explorers, or natural climate change were most responsible for their extinction (EP&C II). To prepare for the debate, students construct a concept map model to represent the different possible causes of the extinction (figure 7.17D). Mr. T also prompts students to investigate the rate of **change [CCC-7]** in the last 10,000 years versus some of the other changes in the evolution of marine mammals they learned about on previous days.

Day 9-10: Human solutions (Evaluate)

Students have been posting their concept map diagrams and their data plots on the walls around the classroom throughout the week. To evaluate whether or not students can link their evidence to their model, Mr. T highlights one specific relationship on a concept map and asks a student to point to the specific feature in a specific graph or informational article that provides evidence for this link. He repeats this prompt for a variety of linkages on the concept maps and then reverses the process by holding up a graph and asking students to identify where its interpretation is represented on the concept map models.

Investigative problem: How can people reduce their impact on marine mammal populations?

Students finish this IS evaluating competing design solutions for reducing human impacts on marine mammal populations (HS-ESS3-4, HS-ETS1-3). Mr. T asks his students to decide between two possible challenges: preserving habitat for seals and sea lions in coastal California or managing overfishing in the waters of the Gulf of California where humpback whales birth their calves. He presents teams with handouts that allow them to **define the problem [SEP-1]**, including pressures from human activities and climate change. Different teams receive handouts identifying one of several different alternatives and students create a presentation **communicating [SEP-8]** the pros and cons of the plan (EP&C V). The students will continue this activity next week.

Vignette Debrief

As the culmination of the entire course, this vignette shows how the biosphere, geosphere, and anthrosphere interact.

SEPs. A major focus of the vignette is on having students **analyze [SEP-4]** different data sets and notice that they exhibit **patterns [CCC-1].** These correlations invite students to **ask questions [SEP-1]** about possible **cause and effect relationships [CCC-2].** The evolution of marine mammals presents sequences of complex chains of cause and effect relationships, so the vignette relies on concept maps as pictorial

models [SEP-2] to represent them. Students use these models to help structure **arguments [SEP-7]** such as the debate on Day 8 and the assessment on Day 9.

DCIs. Students examine evidence of common ancestry from homologous structures, fossil sequences, and DNA similarity (LS4.A) in the first 3 days of the lesson. They then seek to explain the evolutionary sequence of land mammals migrating to the ocean in terms of adapting to environmental changes (LS2.C, LS4.C). Many of these changes are related to human impacts (ESS3.C) on global climate (ESS2.D, ESS3.D), and they use computer simulations to predict future changes to marine mammal populations on days 6-7 given different climate change scenarios. While the lesson emphasizes how earth systems influence the evolution of biological systems, it also briefly touches upon the role biodiversity plays in maintaining the concentration of greenhouse gases in the atmosphere (Figure 7.17B; ESS3.E).

CCCs. While students comprehend cause and effect from a very early age, the analyses in this lesson sequence demonstrate the rich and complex understanding of **cause and effect [CCC-2]** at the high school level. Students learn to use evidence to distinguish between several possible causal mechanisms and recognize that several factors may contribute with different amounts of influence. They also can model complex chains of cause and effect (as in figures 7.16 and 7.17) that also include feedback loops (as in figure 7.17D) that can reinforce or counterbalance **change [CCC-7].** This lesson also illustrates how high school students can integrate evidence from a range of different time **scales [CCC-3],** noticing that the short-term changes in ocean temperature from El Niño from year-to-year and the slow changes in global climate over millions of years can both influence populations and survival via the same basic mechanism. Abrupt changes from year-to-year can add up to a steady evolutionary **change [CCC-7].**

EP&Cs. Humans have the capacity to affect marine mammals in so many ways. Humans can directly hunt and kill animals as they did with the Stellar's sea cow (Day 8, CA EP&C II), but they can also alter natural systems (CA EP&C III) so strongly that they influence the climate. In addition to having to adapt to the changes in their own living conditions, climate change can also disrupt food supplies such as marine fish such that

humanity suffers much like the sea lions (CA EP&C I). As students explore some of these impacts on Days 8-10, they design solutions that must meet the long-term needs of society and the ecosystem as well as being tolerable in the short term for society (CA EP&C V).

CA CCSS Connections to English Language Arts and Mathematics: Throughout the instructional sequence, students participate in pair, group and whole class discussions (SL.9-10.1a-d). They engage in reading informational texts to identify key pieces of evidence (RST.9-10.1,3, 7, 9). The students also produce several types of writing including an argument and a short story (WHST.9-10.1a-e, 6, 7, 9). In the vignette, students are also asked to analyze several data sets looking for patterns and possible causes for population changes (S-ID 1, 6, 9; S-IC 6) Students are also asked to create a formal presentation to exhibit their findings (SL-9-10.4.a).

Resources

Climate Prediction Center. 2015. Oceanic Nino Index. http://www.cpc.ncep.noaa.gov/products/analysis_monitoring/ensostuff/ensoyears.shtml (accessed August 4, 2016).

Hansen, James, Makiko Sato, Gary Russell, and Pushker Kharecha. 2013. "Climate Sensitivity, Sea Level and Atmospheric Carbon Dioxide." *Philosophical Transactions of the Royal Society A* 371 (2001).

National Oceanic and Atmospheric Administration Fisheries. 2015. "California Sea Lion (Zalophus Californianus): U.S. Stock." Silver Springs, MD: NOAA Fisheries. http://www.nmfs.noaa.gov/pr/sars/pdf/stocks/pacific/2014/po2014_ca_sea_lion-us.pdf (accessed September 9, 2016).

Uhen, Mark D. 2007. "Evolution of Marine Mammals: Back to the Sea after 300 Million Years." *The Anatomical Record: Advances in Integrative Anatomy and Evolutionary Biology* 290 (6): 514–522.