Grade 7 - Middle School Discipline Specific Core Model

Life Science

From the introduction to the Middle School Life Sciences Standards in the NGSS:

> Students in middle grades develop understanding of key concepts to help them make sense of the life sciences. These ideas build upon students' science understanding from earlier grades and from the disciplinary core ideas, science and engineering practices, and crosscutting concepts of other experiences with physical and earth sciences. There are five life science topics in middle grades: 1) Structure, Function, and Information Processing, 2) Growth, Development, and Reproduction of Organisms, 3) Matter and Energy in Organisms and Ecosystems, 4) Interdependent Relationships in Ecosystems, and 5) Natural Selection and Adaptations. The performance expectations in middle grades blend core ideas with scientific and engineering practices and crosscutting concepts to support students in developing useable knowledge across the science disciplines. While the performance expectations in middle grades life science couple particular practices with specific disciplinary core ideas, instructional decisions should include use of many science and engineering practices integrated in the performance expectations. The concepts and practices in the performance expectations are based on the grade-band endpoints described in A Framework for K-12 Science Education. (NGSS Lead States 2013c)

Introduction

This section is a guide for educators on how to approach the teaching of life science in middle grades and is not meant to be an exhaustive list of what can be taught or how it should be taught. A primary goal of this section is to provide an example of how to bundle the PEs into related groups that can form the basis for instruction instructional segments. While there are four instructional segments in this course, no prescription of the relative amount of time to be spent on each instructional segment is made in this section.

The organizing instructional segments for the topics in grade seven are:

Instructional segment 1. Interdependent Ecosystems

Instructional segment 2. Photosynthesis and Respiration

Instructional segment 3. Cells and Body systems

Instructional segment 4. Evidence of Evolution

Instructional segment 5. Inheritance and Genetics

Instructional segment 6. Natural Selection

Instructional segment 7. Revisiting ecosystems

Throughout the instructional segments in grade seven, students engage in the disciplinary core ideas using a variety of science and engineering practices. However, teachers should mostly develop conceptual and qualitative understanding of those core ideas as seventh grade students may have not yet developed the capacity to use more advanced core ideas associated to physical science, for example, to fully understand the processes at the molecular ***scale***. For example, in grade seven students develop understanding of the functioning of cells for respiration processes. However, their understanding of processes such photosynthesis or movement of ***matter and energy*** in and out of cells will only be developed qualitatively in grade seven as the chemical reactions occurring within cells to explain these processes will not be introduced until eight grade.

Example Course Mapping for a Life Science Course

Grade 7

Instructional segment 1: Interdependent Ecosystems	Performance Expectations addressed		
	MS-LS2-2, MS-LS2-3		
	Highlighted SEP	Highlighted DCI	Highlighted CCC
	• Developing and using models	LS2.A: Interdependent Relationships in Ecosystems	• Systems and system models
	Summary of DCI		

	Organisms and populations of organisms are dependent on their environmental interactions both with other living things and with nonliving factors. Students develop models of ecosystems, tracking the flow of energy and matter within these systems.

<table>
<tr><td rowspan="6">Instructional segment 2:
Photosynthesis and Respiration</td><td colspan="3">Performance Expectations addressed</td></tr>
<tr><td colspan="3">MS-LS1-6, MS-LS1-7</td></tr>
<tr><td>Highlighted SEP</td><td>Highlighted DCI</td><td>Highlighted CCC</td></tr>
<tr><td>• Asking Questions and Defining Problems
• Analyzing and Interpreting Data</td><td>LS1.C: Organization for Matter and Energy Flow in Organisms

Other Necessary DCIs:
PS1.A: Structure and Properties of Matter</td><td>• Energy and Matter
• Systems and System Models
• Scale, Proportion, and Quantity</td></tr>
<tr><td colspan="3">Summary of DCI</td></tr>
<tr><td colspan="3">Two key processes within organisms facilitate the exchange of matter and energy within ecosystems, photosynthesis by plants and respiration by all organisms. Students develop a model that relates these two chemical processes that explains why organisms consume food in order to live, move, and grow (accumulate biomass).</td></tr>
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Instructional segment 3: Cells and body systems	Performance Expectations addressed		
	MS-LS1-1, MS-LS1-2, MS-LS1-3, MS-LS1-8		
	Highlighted SEP	Highlighted DCI	Highlighted CCC
	• *Developing and Using Models* • *Engaging in Argument from Evidence* *Obtaining, Evaluating, and Communicating Information*	LS1.A: Structure and Function LS1.B: Growth and Development of Organisms	• *Systems and System Models* • *Structure and Function*
	Summary of DCI		
	Living organisms are made of cells that include special structures responsible for specific functions. These structures interact within the system of a cell and cells in turn can build larger systems in multi-cellular organisms. Students develop models for these interactions within their own bodies when they are functioning properly and use these models to predict different problems when different components of the system fail.		

l segment 4: Evidence of	Performance Expectations addressed		
	MS-LS4-1, MS-LS4-2, MS-LS4-3, MS-LS4-4		
	Highlighted SEP	Highlighted DCI	Highlighted CCC

	• *Asking Questions and Defining Problems* • *Analyzing and Interpreting Data* • *Constructing Explanations and Designing Solutions*	LS4.A: Evidence of Common Ancestry and Diversity LS4.C: Adaptation Other Necessary DCIs: ESS1.C: The History of Planet Earth	• *Patterns* • *Structure and Function* • *Scale, Proportion, and Quantity*
	Summary of DCI		
	Fossils record the structure of organisms, and the fossil record shows how these structures have changed over time. Common elements in the structures of organisms identified in the fossil record, embryos, and modern organisms are one piece of evidence that these organisms share common ancestry. Students examine similarities between organisms and patterns of change over time to explain the diversity of species seen today.		

Instructional segment 5: Inheritance and Genetics	Performance Expectations addressed		
	MS-LS3-1, MS-LS3-2, MS-LS4-5, MS-ETS1-1		
	Highlighted SEP	Highlighted DCI	Highlighted CCC
	• *Asking Questions and Defining Problems* • *Developing and Using Models* • *Obtaining, Evaluating, and Communicating Information*	LS1.B: Growth and Development of Organisms LS3.A: Inheritance of Traits LS3.B: Variation of Traits LS4.B: Natural Selection	• *Cause and Effect*
	Summary of DCI		

	Organisms pass on their genetic code when they reproduce either sexually or asexually. This genetic code can change from generation to generation due to the different contributions from each parent during sexual reproduction and through mutations in all organisms. Students explore the variation in traits in their own school population as well as examples from other organisms.

Instructional segment 6: Natural Selection

Performance Expectations addressed		
MS-LS1-4, MS-LS2-1, MS-LS4-4, MS-LS4-6, MS-ETS1-1, MS-ETS1-2, MS-ETS1-4		
Highlighted SEP	Highlighted DCI	Highlighted CCC
• *Analyzing and Interpreting Data* • *Using Mathematics and Computational Thinking*	LS1.B: Growth and Development of Organisms LS3.A: Inheritance of Traits LS3.B: Variation of Traits LS4.C: Adaptation	• *Cause and Effect* • *Structure and Function* • *Stability and Change*
Summary of DCI		
Organisms with traits that allow them to efficiently acquire or use resources are more likely to survive and create offspring that share those traits. Students analyze data and use simulations to explore the interaction between scarce resources and the diversity of organisms within a population.		

Instructional segment 7: Ecosystem Interactions, Revisited

Performance Expectations addressed		
MS-LS2-4, MS-LS2-5		
Highlighted SEP	Highlighted DCI	Highlighted CCC
• *Asking Questions and Defining Problems* • *Constructing Explanations and Designing Solutions* • *Engaging in Argument from Evidence* • *Obtaining, Evaluating, and Communicating Information*	LS4.C: Adaptation	• *Systems and System Models* • *Influence of Science, Engineering, and Technology on Society and the Natural World*
Summary of DCI		

	Ecosystems undergo natural changes over time. Many of the physical changes induce evolutionary changes via natural selection due to adaptations. Humans can have a large impact on these changes. Students engage in a culminating activity examining changes in marine mammals over millions of years.

Grade 7 Instructional segment 1: Interdependent Ecosystems

Instructional segment 1: Interdependent Ecosystems
Guiding Questions: • How do parts of an ecosystem interact?
Highlighted Scientific and Engineering Practices: • *Develop and Use Models*
Highlighted Cross-cutting concepts: • *Energy and Matter* • *Systems and system models*
Students who demonstrate understanding can: **MS-LS2-2. Construct an explanation that predicts patterns of interactions among organisms across multiple ecosystems.** [Clarification Statement: Emphasis is on predicting consistent patterns of interactions in different ecosystems in terms of the relationships among and between organisms and abiotic components of ecosystems. Examples of types of interactions could include competitive, predatory, and mutually beneficial.] **MS-LS2-3. Develop a model to describe the cycling of matter and flow of energy among living and nonliving parts of an ecosystem.** [Clarification Statement: Emphasis is on describing the conservation of matter and flow of energy into and out of various ecosystems, and on defining the boundaries of the system.] [Assessment Boundary: Assessment does not include the use of chemical reactions to describe the processes.]
Significant Connections to California's Environmental Principles and Concepts: Principle II. The long-term functioning and health of terrestrial, freshwater, coastal and marine ecosystems are influenced by their relationships with human societies. 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.

Background and instructional Suggestions

Life science is about what living things are made up of, how they work, and how they depend on one another. Seen through the crosscutting concept of ***systems and system models***, living organisms are systems with components that interact. As described in NGSS, "Systems may interact with other systems; they may have subsystems and be a part of larger more complex systems." In this way, life science is the study of "systems within systems within systems." Cells are tiny systems of interacting individual organelles. In multicellular organisms, tissues and organs are systems of interacting cells. Body systems require interaction between different types of tissues and organs. A whole organism is a concert of interacting body systems. Finally, ecosystems (which one should note have the very word 'system' within them) are interactions between different organisms and non-living components. In this course, students **develop models** of these living systems at this full range of ***scales***.

Every one of these systems and subsystems exhibit five key features of ***systems*** that will be revisited in different instructional segments in this course: systems have 1) boundaries, 2) inputs/outputs of ***energy and matter*** across these boundaries 3) components, 4) interactions between components, and 5) one or more properties that the entire system exhibits as a whole.

While the life science DCI's are organized with the smallest ***scales*** first, a *CA NGSS* course sequence based on developmentally sequenced learning objectives might begin the study of living systems with the most tangible, macroscopic system: ecosystems. In ecosystems, the mechanisms of ***energy and matter*** exchange are familiar to students (predator eats prey, for example).

A ***system model*** is a way of thinking about and simplifying the real world. In order to develop a useful model of a system, students need to decide which objects are components of the system and which objects do not need to be included (i.e., define the system boundaries). Students begin this process by considering pictures of simple ecosystems

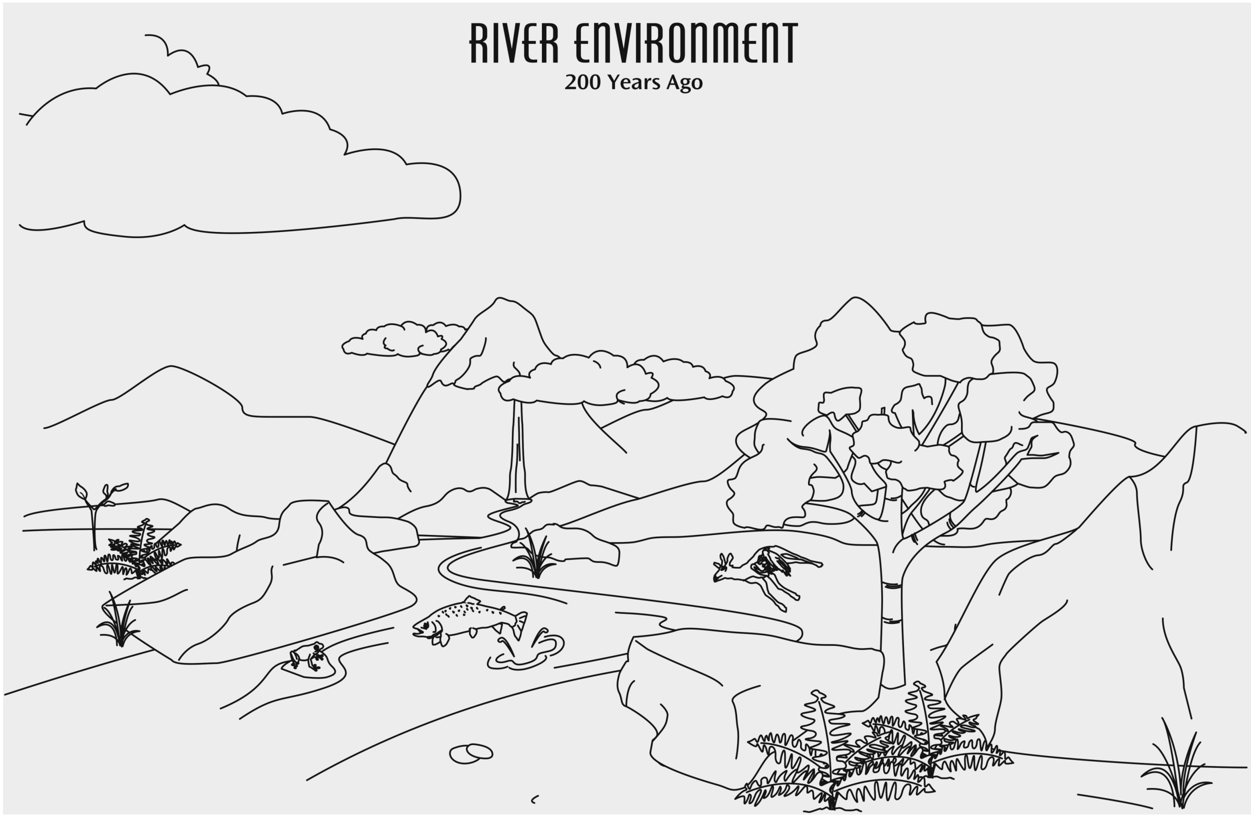

Figure 17. A river environment. Image credit: Illustration used by permission of WestEd Making Sense of Science project.

As students identify the different objects involved, they might recognize that the objects fall into different categories such as living and non-living objects. Many students struggle to decide if non-living objects should be included in the ***system model*** of an ecosystem. To answer this question, students must return to the definition of systems and ecosystems. Students might decide that a river is an essential component of an ecosystem because other components interact with it in so many essential ways. Beyond the water's obvious role of being available for organisms to drink, it also provides living space for aquatic life, cools the surrounding air by evaporative cooling, and breaks down rocks into smaller particles important for the development of soil.

There are many ways that students can illustrate these interactions through different styles of diagrams. Instructional segment 2 from the Integrated 7th grade model shows one example, along with a discussion of its relative merits. Another alternative is to have students make concept maps of the ecosystem using index cards, string, and paper cutouts of arrows. Each component of the ecosystem is written on an index card and taped to the wall or table and then students connect the components with string, being sure to write short phrases on the paper arrows that describe how the two objects interact. Many pairs of objects might require two or more arrows pointing different directions. For example, a tree provides food and shelter to a bird while the bird aids the tree by eating its fruit and dropping the seeds. Where technology is available, these concept maps can be constructed collaboratively online. Students then classify these relationships, noting that some of them involve the exchange of ***matter***, some the exchange of ***energy***, and often both energy and matter. (*MS-LS2-3*). Students should be able to build on their model for the exchange of matter in ecosystems that they developed in 5th grade (*5-LS2-1*). Now, they will begin to make distinctions between ***matter and energy***.

Many ecosystem interactions involve the exchange of 'biomass,' the accumulated material that organisms have rearranged and integrated into their own body structures from the food they have eaten. The organic molecules of biomass are complex, and other organisms can use them as building blocks to manufacture, replace and repair their internal structures. The biomass molecules also have significant stored chemical potential energy that organisms can use in their biological activities and processes. When one organism eats another, it takes in the other organism's biomass accomplishing a transfer of both ***matter and energy***.

Middle School Vignette

Human-Caused Changes to Ecosystems Influence the Cycling of Matter, and Flow of Energy

The vignette presents an example of how teaching and learning may look in a 7th-Grade classroom when the *CA NGSS* are implemented. The purpose is to illustrate how a teacher engages students in three-dimensional learning by providing them with experiences and opportunities to develop and use the Science and Engineering Practices and the Crosscutting Concepts to understand the Disciplinary Core Ideas associated with the topic in the instructional segment.

It is important to note that the vignette focuses on only a limited number of performance expectations. It should not be viewed as showing all instruction necessary to prepare students to fully achieve these performance expectations or complete the instructional segment. Neither does it indicate that the performance expectations should be taught one at a time.

The vignette uses specific classroom contexts and themes, but it is not meant to imply that this is the only way or the best way in which students are able to achieve the indicated performance expectations. Rather, the vignette highlights examples of teaching strategies, organization of the lesson structure, and possible students' responses. Also, science instruction should take into account that student understanding builds over time and that some topics or ideas require activating prior knowledge and extend that knowledge by revisiting it throughout the course of a year.

Introduction

Mr. R designed a series of lessons where students **modeled** flows of energy and matter into and within ecosystems. They applied these models to make predictions about patterns at larger ***scales,*** including the interactions among organisms in multiple ecosystems. Mr. R planned to use components from two California EEI units, *Energy: Pass It On!* and *The Flow of Energy Through Ecosystems*, as the foundation for these lessons.

Day 1 – Energy Flow in California's Ecosystems.

Mr. R told students that they were going to examine the writings of a fictional explorer who visits several natural regions in California in search of different organisms.

Mr. R instructed the students that they were going to read and identify evidence of interactions between the different components in one of three California ecosystems. As they read their assigned journal entry they should take notes, listing any organisms which they encountered in the reading, including plants, animals, fungi, or bacteria. Their notes should include descriptions of any interactions between organisms, as well as the conditions where the organism was found. Mr. R distributed one of the pages from the *Explorer's Journal* (High Desert, North Coastal Forests, Oak Woodland) and a blank sheet of writing paper to each student. After the students finished the reading, he formed groups of three students who all read different about different ecosystems. The first person in the group identifies an organism from their notes that appears in their ecosystem and describes it. The second and third members have to find an organism in his or her ecosystems that shares something in common with that organism. Students record each trio of organisms and what they share in common. Mr. R offered the example of Joshua tree from the desert, oak tree from the oak woodland, and redwood tree from the coastal forest as organisms that provide shade to other organisms. Mr. R let the students work for a few minutes after he noticed one group came up with the connection, "turkey vulture-turkey vulture-blue jay." He called on that group to share their trio and asks them, "What do those organisms share in common?" The group answers in unison that "they are all birds." Mr. R realized that he didn't make his instructions clear enough to meet the learning objective he wanted and he shares this fact with his students. He clarifies that the "something in common" should relate to the way in which they interact with other organisms or the role they play in the ecosystem. He asked the group if the articles provide any evidence that these two types of birds eat the same thing, are eaten by the same thing, or change their environment the same way ("No, vultures eat dead things while blue jays eat seeds and stuff."). He then asked if they could find an organism that eats similar things to the turkey vulture from the coastal forest ecosystem. A group member glanced down at his notes and identified the fly because it also eats dead things. Mr. let the groups return to finding more trios, and they created combinations such as badger-earthworm-ant ("they all dig the ground"), jackrabbit-deer-deer ("they all eat grass"), coyote-mountain lion-bear ("big animals that eat furry animals").

Mr. R projected the visual aid *Organisms and Their Functions* to introduce some common interactions that exist in ecosystems that describe how energy flows from component to component (producers, consumers, decomposers, etc.). He then asked students to try to label each of their organism trios with one of these terms. Mr. R explained that more than one term can apply to some of the organisms. Some trios may not have any of these labels because these labels primarily describe the flow of energy through an ecosystem, but there are other ways that components in an ecosystem can interact. Mr. R then projected the visual aid *Roles in an Ecosystem*. He asked students to quickly identify examples of organisms from each ecosystem that fit each of the categories of producers, consumers, and decomposers. Are there any ecosystems that are missing one of these categories? Mr. R facilitated a class discussion that led students to the conclusion that all ecosystems have organisms that serve each of the functions in energy flow; that is, all ecosystems have producers, consumers (herbivores, carnivores, omnivores, scavengers), and decomposers. To make sure students understand this, he asked them to respond to the prompt, "Why do you think all ecosystems have all of these categories of organisms? What happens if one of these categories is missing?" (*MS-LS2-2*). They will revise this **explanation** as they learn more over the next few days.

Day 2 – Energy Flow Among Producers, Consumers, and Decomposers.

Mr. R projected an image of a food web for the students to examine, for example "*Marine Ecosystem Food Web"* (from the EEI *The Flow of Energy Through Ecosystems* instructional segment). Mr. R asked the students to think back to what they learned in fifth grade about the movement of matter among plants, animals, decomposers, and the environment. He reminded students about the term "food chain" and called on several students to identify food chains from the marine ecosystem drawing. Following up on their earlier discussion of producers and consumers, and decomposers, he explained that he wanted each of their food chains to start with the energy input to the ecosystem, the Sun, and end with one of the higher-level consumers like the Humboldt squid.

Once students had identified several food chains in the marine ecosystem, Mr. R asked them, "Why are there so many arrows on the drawing?" Students pointed out that "the arrows between indicated that different organisms in an ecosystem can be involved in more than one food chain, and that these organisms from different food chains get energy from each other." Mr. R introduced the term "food web" and explained that a food web is a **model** of the many different exchanges of ***energy and matter*** that can be found in any ecosystem.

Building further on their ability to develop models that describe phenomena, in this case food webs, the teacher organized students into three teams based on the ecosystems they had investigated. He instructed each team to create a food web, a model of cycling of matter and the transfer of energy through an ecosystem, based on the text and drawing that represents their ecosystem. Mr. R explained that team drawings should each start with the Sun, include at least two or more producers, two or more consumers, and a decomposer. He reiterated that since they were creating food webs, their drawings should show interconnections among the different food chains. He called their attention back to the marine ecosystem food web as an example and pointed out that the plant plankton are eaten by several different organisms, and those organisms are eaten by several other organisms. Once the teams had completed their drawings, they reported out to the class showing their drawings and presenting their findings about the food webs in their ecosystems. As they made their reports, Mr. R had the students cite specific textual evidence to support their analysis of the cycling of matter and the transfer of energy between organisms in their ecosystem. Mr. R emphasized that each of these drawings represents a ***system***, and that systems can have energy and matter flowing in and out. He asked students to add features to their drawing that identify how energy and matter might enter or leave their ecosystem.

Day 3 – Tracking Energy Flow in Natural Systems.

Mr. R displayed all the student food webs on the wall and began class the next day asking his students why none of their drawings included humans. He posed the question, "Are humans a part of ecosystems?" His objective for the day was to ensure that students could develop models that explain California's Environmental Principle IV:

"The exchange of matter between natural systems and human societies affects the long-term functioning of both;" Concept c: "The capacity of natural systems to adjust to human-caused alterations depends on the nature of the system as well as the scope, scale, and duration of the activity and the nature of its byproducts."

Students read the informational text, *Where Are the Wolverines?* He instructed them to read the first part of the story and identify the food and energy sources that are important to a wolverine's survival. He also had them look for information about the habitat where they live and get their food, preparing them for the second half of the text where they would be looking at how damage to that habitat affects the cycling of matter and transferring of energy in that ecosystem.

When they had finished reading, Mr. R organized the students into teams and distributed sets of *Food Web Cards*, a piece of chart paper, and colored markers to each team. He told students to place the *Food Web Cards* on the chart paper, and draw arrows between the cards with markers to indicate which organism eats which other organism(s). As the teams started to build their food webs, one of them mentioned that they did not have Food Web Cards for all of the organisms so their webs would only be partially complete. Mr. R told them that they could add additional organisms to their food webs if they recalled them from the text.

When the students had completed their food webs, Mr. R had teams rotate around the room so that they could evaluate another team's food web, adding sticky notes about possible ways the web could be improved. As the students returned to review their own food webs, he reminded them that not all connections in the web are equally important. Wolverines get the bulk of their diet from deer and elk, though they also require other food to survive. He asked them a series of questions to help them recognize how changes to one organism in the food web may or may not affect other organisms. For example, he asked: "What would happen if you removed deer from the wolverine food web?" (The survival rate of wolverines and mountain lions would probably drop, since these species rely on deer as an important source of food. The survival rate of shrubs might increase, since deer would no longer eat them.) "What would happen if you removed wolverines from the food web?" (The number of deer and elk would increase, because wolverines would not eat them. However, the number of wolverines in any given area is so small that removing them would probably have little effect on other populations.) “What would happen if one species of small mammal, such as a squirrel, were removed from the wolverine food web?” (This might have little effect on bears, wolverines, and lions, since small mammals provide only a small portion of their diet. Removing just one species might not have a big effect on consumers. It might affect seed dispersal, depending on what other species also eat and spread seeds that squirrels use.) and “What would happen if shrubs were removed from the wolverine food web?” (This might have a large effect on the ecosystem. Deer would no longer have an appropriate food source. If the number of deer drops, wolverine, and mountain lion numbers would probably drop as well.)

One of the excited students pointed out that removing these different plants and animals from the food webs is disrupting the transfer of matter and the flow of energy through the wolverine’s ecosystem. Mr. R mentioned that what happened to California’s wolverines is an example of a major environmental principle which identifies that human-caused alterations to natural systems can significantly affect how matter and energy move in natural systems. He mentioned that they will be learning more from the wolverine the following day.

Day 4 – Matter and Energy in the Wolverine Habitat.

Mr. R asked students to think back to the wolverine story and identify how human activities may have affected the survival of wolverines in California. As students called out their ideas he made notes about what caused the changes for wolverines. They identified everything from mining and logging, to farming and recreation.

When they finished their discussion, Mr. R distributed a copy of the *Human Practices and the Wolverine Food Web* form to each student. He divided the students into teams of four and gave each team a set of eight *Human Practices Cards*. Mr. R instructed the students to divide the cards among the team members, with each student taking a turn presenting the information on their card and leading a brief team discussion about how their described human activity might affect relationships in the food web. Mr. R saw this exercise as an opportunity to call students' attention to the Crosscutting Concept "Cause and Effect" so he instructed them to look for causes and effects as they read the cards.

After they discussed the different human activities, students placed all of the cards in the center of the table so that each of them can access the cards. Mr. R told the students that they were going to individually complete the *Human Practices and the Wolverine Food Web*. He explained that as they completed the "prediction" column, they were to include two major components: cause and effect statements about the influence of each human practice on the Wolverine's food web; and predictions, based on clear reasons and relevant evidence, regarding how each human practice could affect the cycling of matter and flow of energy in the wolverine's habitat. Mr. R asks students to return to their answer to the question, "Why do you think all ecosystems have all different categories of organisms (producers, consumers, decomposers, etc…)? What happens if one of these categories is missing?" He asks them to draw a line beneath their response from Day 1 and add any new reasoning that they have learned.

Day 5 –Effects on the Cycling of Matter and Flow of Energy.

As their final assessment for this instructional segment Mr. R told the students that they were each going to develop a model that describes the cycling of matter and flow of energy in an ecosystem, based on an animal other than the wolverine, which lives in a different ecosystem. He explained that they would need to make the case for the design of their model based on an argument supported by empirical evidence drawn from information from multiple print or digital sources. The final component of this activity would be the students using their models to make predictions about how human-caused changes to the physical or biological components of an ecosystem would affect the cycling of matter and flow of energy among the organisms in the ecosystem they selected. (Students who did not have all of the skills necessary to do this original research were allowed to base their model on the wolverine.) Mr. R explained that the students could present their models through either an oral presentation, a multimedia presentation, or another visual display.

Performance Expectations		
MS-LS2-3. Ecosystems: Interactions, Energy, and Dynamics *Develop a model to describe the cycling of matter and flow of energy among living and nonliving parts of an ecosystem.*		
Science and engineering practices	**Disciplinary core ideas**	**Crusscutting concepts**
Developing and Using Models *Develop a model to describe phenomena.*	**LS2.B Cycle of Matter and Energy Transfer in Ecosystems** *Food webs are models that demonstrate how matter and energy is transferred between producers, consumers, and decomposers as the three groups interact within an ecosystem. Transfers of matter into and out of the physical environment occur at every level. Decomposers recycle nutrients from dead plant or animal matter back to the soil in terrestrial environments or to the water in aquatic environments. The atoms that make up the organisms in an ecosystem are cycled repeatedly between the living and nonliving parts of the ecosystem.*	**Cause and Effect** *Cause and effect relationships may be used to predict phenomena in natural or designed systems.* **Energy and Matter** *The transfer of energy can be tracked as energy flows through a natural system.*

California's Environmental Principles and Concepts
Principle II: *The long-term functioning and health of terrestrial, freshwater, coastal and marine ecosystems are influenced by their relationships with human societies.* **Concept b:** *The methods used to extract, harvest, transport and consume natural resources influence the geographic extent, composition, biological diversity, and viability of natural systems.* **Principle IV:** The exchange of matter between natural systems and human societies affects the long-term functioning of both. **Concept c:** *The capacity of natural systems to adjust to human-caused alterations depends on the nature of the system as well as the scope, scale, and duration of the activity and the nature of its byproducts.*

Vignette Debrief

The *CA NGSS* require that students engage in science and engineering practices to develop deeper understanding of the disciplinary core ideas and crosscutting concepts. These lessons give students multiple opportunities to engage with the core ideas in life sciences related to the cycling of matter and flow of energy among living and nonliving parts of an ecosystem. In this vignette, the teacher selected one performance expectations but in the lessons prepared students to move into studies of larger-scale patterns involving not just the flow of matter and energy, but the much wider array of interactions among organisms, such as predator-prey relations, competition for resources, and symbiotic relationships.

A model of a system is different than a simple 'representation' because a model can be used to predict the behavior of the system. Food webs are a perfect example of a model, and students **developed models** of energy and matter flow in ecosystems used them to predict various impacts during this vignette. To assess their learning, Mr. R asks students to **write explanations**. Throughout the activity, students rely on textual sources to **obtain information** about ecosystems.

Food webs model ***the flow of energy and matter*** between different living components of a ***system*** (potentially identifying inputs and outputs of energy as well, such as the input of solar energy at the beginning of every food chain). They also allow students to identify *cause and effect* relationships, in particular how changes to one or more organisms in a food web would affect other organisms in the same food web.

Making the connection between the human-caused alterations to the wolverine's habitat and how those changes influenced the cycling of matter and flow of energy in that ecosystem, gave students an opportunity to begin developing their understanding California Environmental Principle IV, Concept c, "*the capacity of natural systems to adjust to human-caused alterations depends on the nature of the system as well as the scope, scale, and duration of the activity and the nature of its byproducts.*"

CCSS Connections to English Language Arts

Students used the text in *"Where Are the Wolverines?"* to answer questions about connections between the survival rate of wolverines in California and the ecosystem disruptions caused by human activities in forest habitats. This connects to the *CA CCSS for ELA/Literacy* Reading Informational Text standards (RI.5). In addition, they developed oral or multimedia presentations to present their models about the cycling of matter and flow of energy in ecosystems. During their presentations they provided evidence from literary or informational texts about how human-caused changes to ecosystems can affect the survival of their organisms, which corresponds to Writing Standards 1 and 9 (WHST.6-8.1 and WHST.6-8.9).

Connections to CA ELD Standards

RI.5. *Draw on information from multiple print or digital sources, demonstrating the ability to locate an answer to a question quickly or to solve a problem efficiently.*

RST.6-8.1 *Cite specific textual evidence to support analysis of science and technical texts.*

WHST.6-8.1 *Write arguments to support claims with clear reasons and relevant evidence.*

WHST.6-8.9 *Draw evidence from literary or informational texts to support analysis, reflection, and research.*

Resources for the Vignette

- California Education and the Environment Initiative. 2010). *Energy: Pass It On!* Sacramento: Office of Education and the Environment.
- California Education and the Environment Initiative. 2010. *The Flow of Energy Through Ecosystems.* Sacramento: Office of Education and the Environment.

Other interactions represent transfers of matter that are not biomass, and that cannot provide calories to organisms. Examples are water, carbon dioxide, and the simple minerals that decomposers such as microorganisms release to the soil. Other interactions involve the transfer of pure ***energy*** without the transfer of mass. Almost all ecosystems have a large input of pure energy from the Sun (which is usually considered outside the system because it is so far from Earth). Most 'energy' is exchanged through biomass (which involves the exchange of matter), so the only other way that pure energy exchanged between components in ecosystems is through the flow of thermal energy. In particular, most organisms give off 'waste heat'. For warm blooded organisms like ourselves, we can easily conceptualize how we heat up the air around us, but chemical reactions in all organisms generate some thermal energy that is dissipated to the environment. This energy is effectively lost from the ecosystem because it is no longer contained in the biomass of the organism. One important result of this dissipation is the "energy pyramid," a common graphic representation that the amount of biomass decreases markedly at each step going from producers to primary consumers to higher level consumers and to decomposers. Students will **investigate** this relationship **mathematically** in high school (*HS-LS2-4*).

Some of these relationships are very complex. One example of a very intricate relationship comes from northern California's salmon spawning. Salmon spend most of their adult life in the ocean, accumulating biomass from the organisms it eats there. As they return to the river in which they were born, they bring biomass built from ocean material into the river. Since most species of salmon die after they spawn, the biomass from their decaying carcasses fertilizes the area surrounding the streams. Scientists can actually quantify the size of this ***effect*** because nitrogen from the ocean has a different isotopic signature than nitrogen in the river system (lighter isotopes of nitrogen evaporate more easily, so rainwater filling rivers has slightly more abundant N-12 while ocean water has slightly more N-14). In Alaska, the scientists have tracked the ocean biomass large distances away from rivers themselves, a fact that they attributed to the fact that bears sometimes physically carry their salmon catch away from the river to eat it, and that they are messy eaters. In California, where human activities have reduced the bear population, this biomass no longer occurs. Human activities have therefore disrupted the movement of biomass (*EP&Cs II, III, IV*).

After considering one example ecosystem as a whole class, smaller groups of students **investigate** different ecosystems. During reports, students look for common ***patterns*** that exist in the interactions between components. They might notice the living organisms interacting as predator-prey, competitors for the same resource such as space or food, or symbiotic relationships (like the bird and tree). By explaining these common types of relationships, students can view new ecosystems through the lens of these categories (*MS-LS2-2*). For example, students could be given a list of organisms from an environment they are unlikely to have encountered before (such as creatures that live around the hydrothermal vents at deep-sea mid-ocean ridges) and they would have to **ask questions** about the different organisms to determine how the organisms might interact. They might look to clues about relative size, where each organism lives, or the shape of its body parts to make these inferences. To enhance their **model** of ***energy and matter flow***, students should be able to explain how these relationships relate to the flow of energy and matter within ecosystems (*MS-LS2-3*).

Grade 7 Instructional segment 2: Photosynthesis & Respiration

Instructional segment 2: Photosynthesis & Respiration

Guiding Questions:

- How do plants and animals get their energy?
- What processes allow energy and matter to be exchanged in ecosystems?

Highlighted Scientific and Engineering Practices:

- *Developing and Using Models*
- *Using Mathematics and Computational Thinking*

Highlighted Cross-cutting concepts:

- *Energy and Matter*
- *Systems and System Models*
- *Scale, Proportion, and Quantity*

Students who demonstrate understanding can:

MS-LS1-6. **Construct a scientific explanation based on evidence for the role of photosynthesis in the cycling of matter and flow of energy into and out of organisms.** [Clarification Statement: Emphasis is on tracing movement of matter and flow of energy.] [Assessment Boundary: Assessment does not include the biochemical mechanisms of photosynthesis.]

MS-LS1-7. **Develop a model to describe how food is rearranged through chemical reactions forming new molecules that support growth and/or release energy as this matter moves through an organism.** [Clarification Statement: Emphasis is on describing that molecules are broken apart and put back together and that in this process, energy is released.] [Assessment Boundary: Assessment does not include details of the chemical reactions for photosynthesis or respiration.]

Other necessary PEs that will be developed further in Grade 8:

MS-PS1-1. **Develop models to describe the atomic composition of simple molecules and extended structures.** [Clarification Statement: Emphasis is on developing models of molecules that vary in complexity. Examples of simple molecules could include ammonia and methanol. Examples of extended structures could include sodium chloride or diamonds. Examples of molecular-level models could include drawings, 3D ball and stick structures, or computer representations showing different molecules with different types of atoms.] [Assessment

Boundary: Assessment does not include valence electrons and bonding energy, discussing the ionic nature of subunits of complex structures, or a complete description of all individual atoms in a complex molecule or extended structure is not required.]

MS-PS1-5. Develop and use a model to describe how the total number of atoms does not change in a chemical reaction and thus mass is conserved. [Clarification Statement: Emphasis is on law of conservation of matter and on physical models or drawings, including digital forms that represent atoms.] [Assessment Boundary: Assessment does not include the use of atomic masses, balancing symbolic equations, or intermolecular forces.]

Significant Connections to California's Environmental Principles and Concepts:

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

Background and instructional Suggestions

In this unit, students develop a **model** of the two key chemical processes used to ***cycle energy and matter*** in ecosystems, photosynthesis and respiration. They are treated together as a pair because they essentially involve the same basic chemical transformation represented by the same chemical equation, just read from different directions regarding which is the starting point and which shows the resulting products. The assessment boundaries for the PEnd *MS-LS1-6* and *MS-LS1-7* both emphasize that the details of the chemical reactions will not be assessed. However, the wording of the PEvolrequires at least some discussion of chemistry and chemical reactions. The assessment boundary statements steer teachers away from having students bogged down in the details of the chemical reactions, especially the multi-step chemical cycles that might be addressed in more advanced biology courses. Even though students will not be required to reproduce any chemical equations on assessments, this instructional segment introduces the life science application of basic concepts in chemistry such as the ***energy*** in chemical reactions and conservation of matter in chemical equations. These chemical processes are at the core of ***energy and matter flow*** within ecosystems (*EP&C Principle III*).

The discipline specific middle school course sequence presents some challenges for teaching these PE staIn the *CA NGSS*, students **developed a model** that matter is made up of particles that are too small to see during 5th grade (*5-PS-1-1*), but they have not yet been introduced to the terms or concepts of atoms, chemical bonding, or molecules (they address these issues in *MS-PS1-1*, *MS-PS1-2*, and *MS-PS1-5* in 8th grade in the Discipline Specific middle school sequence). It is very difficult to fully address performance expectations that **model** how molecules are rearranged without introduction to these essential concepts. The vignette below is one example of how the essential physical science concepts can be integrated alongside the teaching of the life science.

Middle School Vignette

Mass and Energy in Photosynthesis

Day 1: The mass in photosynthesis

Mr. G displays a simple food web on the board and asks students to trace out how material flows from one organism to the next, applying their **model** from 5th grade (*5-LS2-1*) and instructional segment 1. He writes two questions on the board and tells students that they will form the basis of the next several lessons: "If the mouse eats only blades of grass, how come it doesn't just look like a bunch of chewed up grass all stuck together?" and "From where does the blade of grass get its mass?". Mr. G tells students that they will begin with the first question and asks students to discuss the following questions in groups: 'Which contributes the most to the mass of a plant: Soil, air, water, or sunshine? What makes you think this? **Plan an investigation** to figure out if you are correct." There is no overall consensus between the teams and all the teams demonstrate some sort of misconception – Soledad reports that the mass comes from sunshine since she knows plants grow in the desert where there is no water. Robert claims that the mass must come from the soil because it is the heaviest thing that plants need in order to grow. Most teams agree that it cannot be the air since air "doesn't weigh anything." Most of the teams have proposed worthwhile experiments where they vary just a single parameter and make measurements of the inputs and outputs. For example, Soledad's team wants to grow plants with different amounts of sunlight and compare the mass of the final plant. Robert's team argues that such an experiment could still prove his team correct; maybe the plant that grew more got all its mass from the soil. "You have to measure the soil," complains Robert's teammate. Mr. G then begins to describe a famous investigation published in 1648 by Jan Baptist von Helmont (Hershey 2003). He had this same question and decided to plant a small tree in a pot and water it with the same amount of water every day for five years. At the end of this long period, von Helmont measured the mass of the tree and the mass of the soil. The tree had gained 164 pounds while the soil had an almost identical mass to the start of the experiment. Von Helmont correctly concluded that the mass of the tree could not have come from the soil, but he jumped to the conclusion that the water must have been the source of the mass too hastily – he hadn't measured the mass of the water. Mr. G then provides students data from a more modern experiment in a controlled environment. They calculate the amount of water added and find it is less than the mass increase by the tree (*CA CCSSM 7.EE.4*). That leaves students debating between only the air and the sunlight. Mr. G intervenes and asks Soledad's teammates if sunlight carries any mass and her teammates uniformly agree that sunlight isn't heavy or light, with Soledad herself mentioning, "you can feel air pushing against you like when it's windy, but you can't feel light pushing on you in a room. I don't think light has any mass, but air does." Students agree, but remain skeptical. How can air turn into a tree?

Day 2: Modeling Chemical Reactions

The next day, students return and Mr. G reminds them of the two **questions** they wrote on the board the day before. For their warm-up, he has them write a brief scientific **explanation** about where the mass of a tree comes from, prompting them to include **evidence** along with their reasoning. Most of the students are able to reproduce the **argument** from the day before, but they don't necessarily believe it. Mr. G writes balanced equation for photosynthesis on the board using both element symbols and common names for each compound. He tells students that this equation is how scientists represent the chemical ***change*** going on inside the tree. He uses the term 'chemical change' without defining it in a technical sense. The distinction between physical and chemical changes or chemical reactions is not essential for this discussion. He described how the letters are abbreviations of different types of atoms, and that each combination of atoms is called a molecule. He also spent a few minutes describing how the left side of the equation represented the starting ingredients and the right side represented the material after it had been rearranged to make a tree. He explained the meaning of the numbers for the subscripts (explaining them as analogous to the numbers in front of variables in mathematical equations). Mr. G then challenged the students to **model** that reaction using a common children' toy of interconnecting plastic bricks. Each group of students had a variety of colored toy bricks that they could assemble in their work areas.

Marco, the reporter for one student group, **communicates** how they used a different type of toy brick for each molecule. Mr. G had noticed that almost all of the other student groups had used a similar type of modeling. Marco explained how their **model** represented carbon dioxide with the small black brick ("just like coal"), water with the small blue brick ("just like the ocean"), glucose with the big white brik ("just like a sugar cube"), and oxygen with the small red brick ("just like fire"). Kelly, another member of the same student group, proudly added that they had used six of each color of brick except for only one white brick so their model was just as correct as the equation that Mr. G had put on the board.

Mr. G then had everybody gather around the group that included Juanita and Alex. Alex explained that they had tried to use models where each color of toy brick represented a different kind of atom in the chemical equation. "Each letter in the chemical names is a different color," described Alex, "so we only used three colors." Juanita interjected that, "but we couldn't agree about how to put together the glucose molecule."

Mr. G had everybody return to their working group areas, and he projected illustrations of **models** that scientists use to represent the bonding within and the shapes of common molecules (carbon dioxide, water, glucose and oxygen). He challenged the groups to discuss what kind of materials that they might use to represent those molecules and the equation. Walking around the room, he helped steer the conversations toward a consensus on using different colored sticky notes to represent the three different types of atoms involved. Mr. G told them they could use a smaller size sticky notes to represent hydrogen since it is the smallest atom.

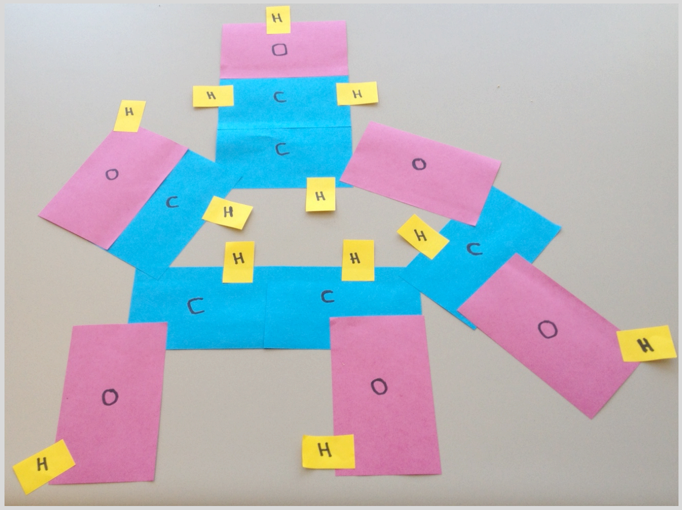

Figure 18. Model of glucose from one of the student groups.

The next day, each of the student groups gathered their supplies of sticky notes and began to assemble them to model photosynthesis (a preview of *MS-PS1-1* that students will master in grade 8). As shown in Figure 18, most of the student groups successfully created a model of a glucose molecule. They had also used the correct numbers of all the molecules. They were able to use **evidence** to **explain** that in the reaction none of the atoms had disappeared, and that there were also no new atoms in the products (a preview of *MS-PS1-5*). The products side of their **model** had exactly the same numbers and kinds of atoms as the reactants side of their model. Mr. G reinforced their use of the term "***conservation of matter***" to describe this feature of the chemical ***change***. The tree is made up of a combination of water and carbon dioxide. With this model of rearranging atoms, students were finally able to accept the idea that air played an important role in making up the mass of the tree.

Day 3: Energy and the chemical reaction of respiration

In the next lesson, Mr. G. wrote up an equation representing cellular respiration. He asked students what happens to the atoms of a tree leaf or a blade of grass when an animal eats them. He encourages them to use their understanding of conservation of mass to reason out that the atoms must be rearranged again inside the organism.

Following that introduction, Mr. G challenged the students to use the sticky notes to **model** the reaction of respiration. There was some grumbling about having to make the sugar molecule again, but Mr. G reminded them that not only did plants always make sugar without any whining, the plants also did not complain about being eaten. As always, Mr. G interacted with the different student groups and helped guide the actions and conversations in educationally productive directions.

When it was time to share in groups, the students seemed comfortable with the concept that photosynthesis and respiration were examples of atoms being rearranged and that the amount of mass remained constant. Mr. G felt the students now had the foundation to understand the relationship between ***matter and energy*** in biomass. He returned to a food web and asked where the mouse got its energy for staying alive. Students easily answered that the energy came from the grass, but did not yet make the link between respiration and energy. Mr G gave a brief lecture about how the linkages between different atoms are called chemical bonds, and that breaking apart chemical bonds and creating new ones involves transfers of energy. It takes quite a bit of energy to build up the complex glucose molecule during photosynthesis, and that energy comes from the Sun. Breaking apart glucose molecules and forming carbon dioxide and water molecules releases energy that organisms can harness for their daily lives. The more glucose they 'burn,' the more energy they can access.

Day 4: Photosynthesis and Respiration in Ecosystems

Mr. G transitioned the class to considering the ***cycles of matter and the flows of energy*** from the point of view of whole organisms. He first elicited from the students what they knew about ***systems and system models*** in terms of drawing the boundary of a system, identifying the parts of the system, and identifying the system’s inputs and outputs. As a whole class, they agreed on the conventions they would use in drawing the system.

Returning to the river environment diagram, Mr. G asked the students to work in pairs and use a system model to illustrate the ***flows of matter and energy*** into and out of the deer and also into and out of the grass. The students generally had no or few problems identifying flows of matter and energy into and out of these organisms. By sharing their diagrams with each other, they were able to fill in missing items or correct mistakes without needing Mr. G to point it out for them. A whole class sharing and discussion cleared up any remaining inconsistencies relating to the diagrams.

Mr. G then challenged the students to create a diagram of a ***system*** consisting of the deer and grass, and to show in their **model** the ***flows of matter and energy*** focusing on the processes of photosynthesis and respiration. **Figure 19** shows the consensus diagram that emerged after students worked on their individual team diagrams, critiqued each other's diagrams, iteratively improved them, and then finalized the diagram after whole class discussion. Mr. G guided the class to keep simplifying the diagram so that it highlighted the ***cycling of matter*** within the ***system*** and the ***flows of energy*** into and out of the system.

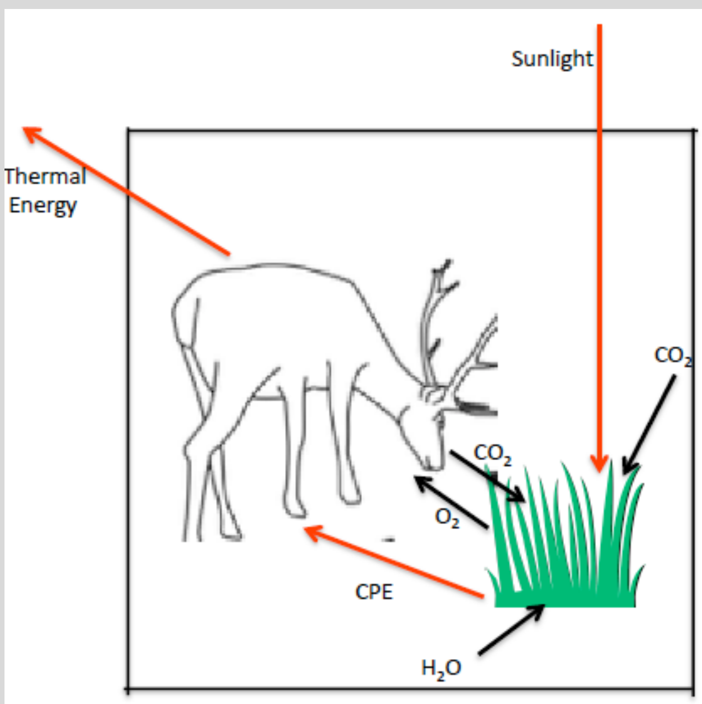

Figure 19. A deer-grass system

Performance Expectations		
MS-LS1-6. From Molecules to Organisms: Structures and Processes *Construct a scientific explanation based on evidence for the role of photosynthesis in the cycling of matter and flow of energy into and out of organisms.* **MS-LS1-7. From Molecules to Organisms: Structures and Processes** *Develop a model to describe how food is rearranged through chemical reactions forming new molecules that support growth and/or release energy as this matter moves through an organism.*		
Science and engineering practices	**Disciplinary core ideas**	**Cross cutting concepts**
Developing and Using Models *Develop a model to describe phenomena.* **Constructing Explanations and Designing Solutions** *Construct a scientific explanation based on valid and reliable evidence obtained from sources and the assumption that theories and laws that describe the natural world operate today as they did in the past and will continue to do so in the future.*	**LS1.C: Organization for Matter and Energy Flow in Organisms** *Plants, algae (including phytoplankton), and many microorganisms use the energy from light to make sugars (food) from carbon dioxide from the atmosphere and water through the process of photosynthesis, which also releases oxygen. These sugars can be used immediately or stored for growth or later use.* *Within individual organisms, food moves*	**Systems and System Models** **Energy and Matter** *Matter is conserved because atoms are conserved in physical and chemical processes.* *Within a natural system, the transfer of energy drives the motion and/or cycling of matter.*

	through a series of chemical reactions in which it is broken down and rearranged to form new molecules, to support growth, or to release energy. **PS3.D: Energy in Chemical Processes and Everyday Life** *The chemical reaction by which plants produce complex food molecules (sugars) requires an energy input (i.e., from sunlight) to occur. In this reaction, carbon dioxide and water combine to form carbon-based organic molecules and release oxygen.* *Cellular respiration in plants and animals involve chemical reactions with oxygen that release stored energy. In these processes, complex molecules containing carbon react with oxygen to produce carbon dioxide and other materials.*	
California's Environmental Principles and Concepts		
Principle III. Natural systems proceed through cycles that humans depend upon, benefit from and can alter.		

2372 **Resource for the Vignette**

2373

Hershey, D. 2003. “Misconceptions about Helmont's Willow Experiment.” Plant Science Bulletin 49 (3): 78–84. http://botany.org/PlantScienceBulletin/psb-2003-49-3.php#Misconceptions (accessed August 5, 2015).

Grade 7 Instructional segment 3: Cells and body systems

Instructional segment 3: Cells and body systems
Guiding Questions: • How do individual cells and their parts sustain life? • How do cells work together to make a complex organism?
Highlighted Scientific and Engineering Practices: • *Developing and Using Models* • *Engaging in Argument from Evidence* • *Obtaining, Evaluating, and Communicating Information*
Highlighted Cross-cutting concepts: • *Systems and System Models* • *Structure and Function*
Students who demonstrate understanding can: **MS-LS1-1. Conduct an investigation to provide evidence that living things are made of cells; either one cell or many different numbers and types of cells.** [Clarification Statement: Emphasis is on developing evidence that living things **(**including Bacteria, Archaea, and Eukarya)** are made of cells, distinguishing between living and non-living things, and understanding that living things may be made of one cell or many and varied cells. ****Viruses, while not cells, have features that are both common with, and distinct from, cellular life.]** **MS-LS1-2. Develop and use a model to describe the function of a cell as a whole and ways parts of cells contribute to the function.** [Clarification Statement: Emphasis is on the cell functioning as a whole system and the primary role of identified parts of the cell, specifically the nucleus, chloroplasts, mitochondria, cell membrane, and cell wall.] [Assessment Boundary: Assessment of organelle structure/function relationships is limited to the cell wall and cell membrane. Assessment of the function of the other organelles is limited to their relationship to the whole cell. Assessment does not include the biochemical function of cells or cell parts.] **MS-LS1-3. Use argument supported by evidence for how the body is a system of interacting subsystems composed of groups of cells.** [Clarification

	Statement: Emphasis is on the conceptual understanding that cells form tissues and tissues form organs specialized for particular body functions. Examples could include the interaction of subsystems within a system and the normal functioning of those systems.] [Assessment Boundary: Assessment does not include the mechanism of one body system independent of others. Assessment is limited to the circulatory, excretory, digestive, respiratory, muscular, and nervous systems.]
MS-LS1-8.	**Gather and synthesize information that sensory receptors respond to stimuli by sending messages to the brain for immediate behavior or storage as memories.** [Assessment Boundary: Assessment does not include mechanisms for the transmission of this information.]

Significant Connections to California's Environmental Principles and Concepts: Principle I. The continuation and health of individual human lives and of human communities and societies depend on the health of the natural systems that provide essential goods and ecosystem services. Principle II. The long-term functioning and health of terrestrial, freshwater, coastal and marine ecosystems are influenced by their relationships with human societies. Principle III. Natural systems proceed through cycles that humans depend upon, benefit from and can alter. Principle IV. The exchange of matter between natural systems and human societies affects the long term functioning of both.

Background and instructional Suggestions

Students continue investigating the crosscutting concept of ***systems*** at a smaller ***scale*** by **investigating** systems within individual organisms. Students can easily recognize that their own body is a system. **Figure 20** illustrates all five of the key elements of a ***system*** as applied to a human person. It has a clear boundary (skin) and input and outputs (food and air come in, waste goes out). Humans are also an exciting expression of how the overall system has properties that are the result of complex interactions of its part. Even though the components of each of our bodies are very similar, small differences within us can lead to large differences in our personalities and behaviors. In this instructional segment, students explore some of the interactions between components within living systems, including their own bodies. While the body makes a good starting point for understanding systems, students will be able to understand the details of its subsystems by zooming into a system at a much smaller ***scale*** within the body: the cell. They can then return to the body's sub-systems ready to understand some of the mechanisms that allow them to interact.

Features of Systems

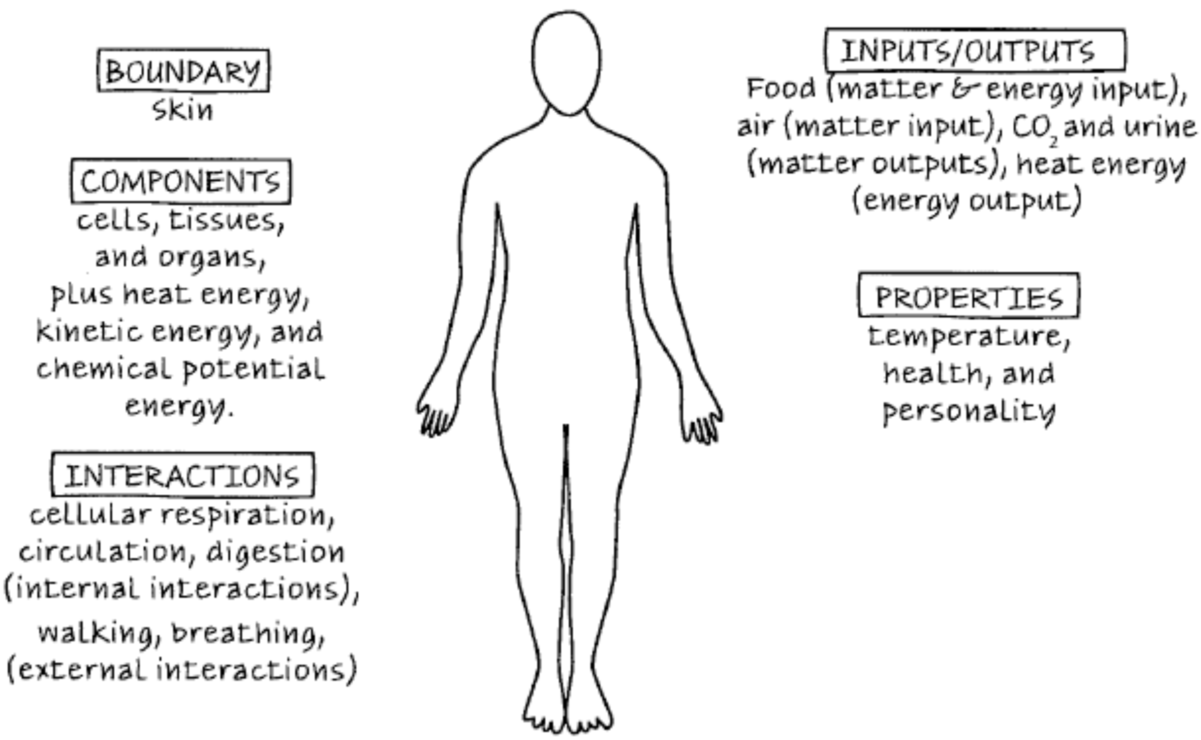

Figure 20. Features of a human person system. Image Credit: Illustration adapted from Making Sense of Science *Weather and Climate* professional development course, courtesy of WestEd.

Life is the quality that distinguishes living things—composed of living cells—from nonliving objects or those that died. While a simple definition of life can be difficult to capture, all living organisms are made of cells whose specialized ***structure and function*** share some common characteristics. The statement that all living things are made of cells has a parallel structure to the scientific statement that "all matter is made up of atoms" in that both make generalizations about microscopic objects as fundamental building blocks. Unlike the idea of atoms, cells are at a ***scale*** that can be readily **investigated** and directly observed in a middle school classroom. Students **conduct an investigation** into different objects, living and non-living to see their differences at the microscopic scale (*MS-LS1-1*). **Figure 21** shows a microscopic view of an igneous rock in comparison to plant and animal skin cells. While all three are made of smaller pieces, the living cells have consistent ***patterns*** of their shape and observable parts within them that are absent from the rock sample. Which of the differences are important for sustaining life?

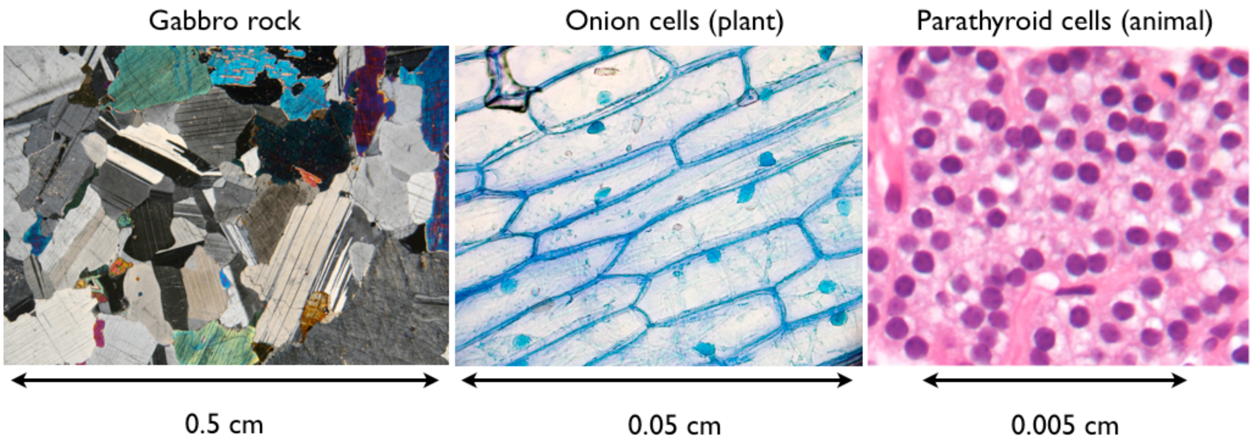

Figure 21. Views under a microscope of rocks, plant cells, and animal cells. The colors are the results of light polarization and/or stains added to the microscope slides and are not the natural colors. The actual size of each field of view also differs.

When adopting the *NGSS*, California added a clarification to *MS-LS1-1* to emphasize the difference between viruses and living organisms. This distinction is important for understanding antibiotics, which do not help cure diseases caused by viruses. The common cold, many forms of flu, and AIDS all are caused by viruses that behave differently from living bacteria, and therefore require different measures. Viruses carry their own DNA and once inside a functioning cell of another organism, they basically hijack its ***functions*** in order to reproduce themselves. During this process, short sequences of virus DNA can sometimes end up inserted into the host organism's DNA and get passed on to its descendants. Maps of the human genome show that about 10% of our DNA was probably accumulated by this process. While most of these segments of DNA serve as inert markers that allow the tracking of evolutionary relationships, some sections may actually influence our behavior. For example, some researchers have suggested that DNA sequences inserted by viruses into ancient human ancestors may lead to predispositions for schizophrenia or other mood disorders in individuals today (Feschotte 2010). These links, if they exist at all, are poorly understood. There is still much more to learn and great opportunities for jobs studying the relationships between viruses, bacteria, diseases, and cures. Specifically emphasizing similarities and differences between viruses and living cells at the middle school level has benefits to public health and lays a foundation for more advanced study.

Living organisms are made of cells that operate as complete ***systems*** with important interacting subsystems. Students **develop a model** for a cell describing the overall system function and the role of its parts (*MS-LS1-2*). In the *CA NGSS*, there are many ways to employ the practice of **developing and applying models**, including physical, mathematical, conceptual, and pictorial models. One common feature that they share is that all of these models are descriptive enough that they can be used to predict the behavior of the system. This feature makes models more than just physical representations of a system and distinguishes a 'model' in scientific terms from the everyday language use of the word. A Styrofoam 'representation' of the parts of a cell may not be usable as a 'model' because it only depicts the components of the system and does not represent their interactions. Adding arrows representing the exchange of ***energy or matter*** can transform this representation into a model so that, for example, a student examining the model can predict what would happen if the cell had a defect and did not contain any mitochondria. Students’ models should be organized around the overall system properties of a cell (i.e., what it does overall) as well as the roles and interaction between specific components such as the nucleus, chloroplasts, mitochondria, cell membrane, and cell wall.

Since an important feature of systems is the ***flow of matter*** into and out of the system, students should pay special attention to the cell membrane and cell wall and their roles in controlling what enters or leaves cells. Students' **models** of these boundaries should be detailed enough that they can explain how the physical ***structure*** of the boundaries facilitate this important ***function***, though the details of the biochemistry of this process are not required.

Students' **models** should include details that the nucleus stores genetic information in chromosomes and that the cell uses this information to synthesize specific proteins important for the overall function of the cell itself and other cells within the body system. In high school, students will develop a model of cell division by mitosis (*HS-LS1-4*). While the concept of cell division is important for developing models of other aspects of living systems, it is not specifically required for understanding the cell as a system. The overall idea that cells divide and duplicate genetic information can therefore be introduced here, or in unit 5 when inheritance is discussed.

Middle School Vignette

Structure, Function, and Information Processing

The vignette presents an example of how teaching and learning may look in a 7^{th} grade classroom when the *CA NGSS* are implemented. The purpose is to illustrate how a teacher engages students in three-dimensional learning by providing them with experiences and opportunities to develop and use the science and engineering practices and the crosscutting concepts to understand the disciplinary core ideas associated with the topic in the instructional segment.

It is important to note that the vignette focuses on only a limited number of performance expectations. It should not be viewed as showing all instruction necessary to prepare students to fully achieve these performance expectations or complete the instructional segment. Neither does it indicate that the performance expectations should be taught one at a time.

The vignette uses specific classroom contexts and themes, but it is not meant to imply that this is the only way or the best way in which students are able to achieve the indicated performance expectations. Rather, the vignette highlights examples of teaching strategies, organization of the lesson structure, and possible students' responses. Also, science instruction should take into account that student understanding builds over time and that some topics or ideas require activating prior knowledge and extend that knowledge by revisiting it throughout the course of a year.

Introduction

Day 1 – Organisms: The Sum of their Sub-Systems

Ms. K begins the second part of her instructional segment after completing her lessons about cells as tiny living systems. She tells her students that the focus of the next several lessons will be to **build models** of how these cells interact and work together to make more complicated organisms involving more complicated interacting subsystems (*MS-LS1-3*).

Ms. K asks her students to think about a pine tree. She has them visualize the pine tree as a whole organism then slowly walks them through the various parts of the tree: the trunk, the crown, the limbs, the branches and smaller twigs, and finally the needles on the twigs. They also discuss the purpose and ***function*** of the bark, needles, pinecones, and root system of the tree. Ms. K explains that the tree can be considered a ***system***, made up of several sub-systems. She then asks students to consider several questions including: "What would happen if the root system were damaged?" "What if the trunk and bark were compromised due to fire or a lightning strike?" Ms. K projects several images of the giant sequoia, *Sequoiadendron giganteum*, for the class to view, including the cross sections of the sub-systems discussed in class, trunk, roots, and bark. To further engage students in this discussion she asks them, "How many of you have ever seen a tree this big?" A few students mention family trips to some of California's national parks while others describe large trees they pass along the way to school. Ms. K then raises the rhetorical question, "How can something that large stay alive?" and prompts students to think about what it must take for this tree to live and grow. Students share some of their background knowledge about plants from elementary grades, mentioning things about plants needing water, light, nutrients, and air to function. She asks students which parts of the tree are responsible for obtaining each of these resources and sets up the problem that no single part of the tree has access to all these resources in one place. Ms. K then asks students to draw and name some the tree's sub-systems that might enable a tree this large to obtain ***energy*** and matter and move them around so that each part has everything it needs. They write about their observations of the subsystems and briefly explain how these systems interact.

Building on the base of students' knowledge, Ms. K leads a brief class discussion about the importance of each sub-system to the overall health and function of the tree as a complete system. As a follow-up, she asks students if they think that all organisms, including humans, have systems and sub-systems that affect their normal functioning.

Day 2 – Going on an Interactive Body Tour

The following day, Ms. K helps her students transition to the concept, "the body is a system of multiple interacting sub-systems" by asking them first to think of the human body as a complete organism and then prompting them to name the organ systems in the body. As they speak, she writes these down on the whiteboard, while prompting them to discuss the function of each organ. She then introduces the concept of tissues, drawing a Venn diagram on the board to emphasize similarities and differences between these scientific terms. After providing an example of muscle tissue, she asks students to name as many more tissues as they can think of. Ms. K explains that in these lessons they will make observations about the interactive relationship between sub-systems and the body as a system.

Ms. K arranges her class into small groups of 2-4 students and directs them to an online Interactive Body Tour (such as that at http://donatelifecalifornia.org/bodytour) and one other digital source they select. She assigns each group to **obtain information** about one organ and one tissue. She reminds them that as they gather relevant information from the online digital source, they should **evaluate** the credibility of each source; and take brief notes about the ***structure and function*** by quoting or paraphrasing the data and conclusions they are reading. She also asks students to keep track of at least three **questions** their team has. She emphasizes that these questions can be things that they are curious about after exploring the resources. (Other teachers take a slightly different approach: Mr. S., who does not have time for his students to research in class, assigns this research as homework. Mrs. C., whose students do not have access to computers, reviews the Interactive Body Tour in a whole group setting and gives her students additional printed materials.)

Day 3 – Exploring the Impact of a Sub-System Break Down

Following the students' group research assignments, Ms. K has each small group **communicate** their findings for the class. One student from each group writes down the key points on the class whiteboard. Ms. K guides students to focus their comments on the topic of how the ***structure*** of the organ or tissue lends itself to its ***function***. She also writes down the questions they had during their group research, and sets them aside for later in the lesson.

Following the presentations, Ms. K extends and guides the discussion by asking the students to think of organs and tissues as sub-systems, and asks students how sub-systems work together in the body to complete a task or regulate body functions, and how the sub-systems communicate with each other. She specifically covers some of the systems with which the students are most familiar: the circulatory, reproductive, excretory, digestive, respiratory, muscular-skeletal, and nervous systems. Finally, Ms. K asks her students to think of what might happen to the body if one of the sub-systems is compromised. Asking, for example, “If our lungs don’t work, how would it affect the functioning of our circulatory system?” “What other systems and sub-systems in the human body might be affected?” Ms. K follows with several more specific examples such as, “If the pancreas doesn’t work due to diabetes, how might it affect the digestive system?” “If a ligament is injured, how might it affect other parts of the muscular system?”

Ms. K asks students to consider that in many cases, the body can heal itself, as is the case with the flu or a broken bone. In other cases, medical technology or another strategy may be helpful to a person who is deaf or has diabetes. She asks them, “In a case where a particular sub-system of the human body is critical to the overall well-being and ***functionality*** of the complete ***system***, how might it affect the body as a complete system?"

To help her student understand that human health and survival depends on the many different components of the body, body systems, and the interactions among them, Ms. K. reminds students that humans have two kidneys and although it is possible to live a healthy life with one, if both kidneys fail and cannot clean the blood of toxins and excess fluids, the toxins will build up in the blood and the person will not survive. In the case of kidney failure, an individual can have their blood artificially cleansed by a dialysis machine that does the work of the kidneys. In some cases, a person can get a "new" kidney, or a kidney transplant, from a living donor or from someone who died recently, for example in an automobile accident. Ms. K explains the concept of organ transplant and explains that one person can donate their tissue—corneas, skin, bones, ligaments and tendons—and up to eight organs—kidneys, lungs, heart, liver, and intestine—upon their death. She asks the students if they know anybody who has received a transplant, is waiting for a transplant, or was an organ donor. Ms. K asks if any of the students are comfortable sharing their example and suggests that they discuss this important topic with their parents.

Day 4-5 – Synthesizing and Applying Lessons Learned

Ms. K asks the small groups to refer back to the **information** they collected about organs and tissues. First, she reviews the class **questions** from earlier in the lesson, addressing any that were not yet answered. Then she has the small groups choose one of the organs or tissues that interest them and discuss the question, "If the organ or tissue you chose partially or completely failed, which other sub-system(s) would it affect, and how might it affect the functioning of the human body as a whole?" She instructs students to gather **evidence** from additional research utilizing print and online sources if necessary, and present their results to the class, citing specific evidence for their conclusions based on their analysis of science and technical texts they found online or in the library. As an individual assessment, Ms. K requires each student to write a paper **arguing** that the body is a system of multiple interacting sub-systems (*MS-LS1-3*). The argument should focus on one organ or tissue sub-system, explain its ***structure and function***, and address how a compromised sub-system affects the human body system. The students' writing should draw on several sources and present their argument, including evidence that supports role of the sub-system's function in survival, growth and/or behavior. Ms. K tells them that they must draw evidence from informational texts to support analysis, reflection, and research; include logical reasoning, accurate data and evidence; and be presented in a formal writing style. Final manuscripts must also include responses to three questions, citing specific examples: "How might human activity negatively or positively affect the sub-system?" "When a sub-system is compromised, what are some alternatives to support survival, growth and/or behavior in the body system?" and "What are some examples of the impact of disease in our society?" Students may quote or paraphrase the data and conclusions from their research, while avoiding plagiarism and providing basic bibliographic information for sources. This activity should help students develop their understanding that the systems of the human body interact to perform all of the functions required for healthy lives, and failure of one or more of these human body systems may lead to illness or death.

Performance Expectations		
MS-LS1-3. From Molecules to Organisms: Structures and Processes Use argument supported by evidence for how the body is a system of interacting sub-systems composed of groups of cells.		
Science and engineering practices	**Disciplinary core ideas**	**Cross cutting concepts**
Engaging in Argument from Evidence *Use an oral and written argument supported by empirical evidence and*	**LS1.A: From Molecules to Organisms: Structures and Processes** *In multicellular organisms the body is a system of*	**Systems and System Models** *Systems may interact with other systems; they may have sub-systems and be a*

scientific reasoning to support or refute an explanation or a model for a phenomenon or a solution to a problem. **Obtaining, Evaluating, and Communicating Information** *Gather, read, and synthesize information from multiple appropriate sources and assess the credibility, accuracy, and possible bias of each publication and method used, and describe how they are supported or not supported by evidence.*	*multiple interacting sub-systems. These sub-systems are groups of cells that work together to form tissues and organs that are specialize for particular body functions.*	*part of larger complex systems.* **Structure and Function** *Complex and microscopic structures and systems can be visualized, modeled, and used to describe how their function depends on the relationships among its parts; therefore, complex natural and designs structures/systems can be to determine how they function.*

Vignette Debrief

The *CA NGSS* require that students engage in science and engineering practices to develop deeper understanding of the disciplinary core ideas and crosscutting concepts. The lessons give students multiple opportunities to engage with the core ideas in life sciences related to an organism as a system of interacting sub-systems, helping them to move towards mastery of the three components described in the *CA NGSS* performance expectation.

In this vignette, the teacher selected one performance expectation and in the lessons described above she engaged students only in selected portions of this PE. Full mastery of the PEs will be achieved throughout subsequent instructional segments.

Students were engaged in a number of science practices with a focus on **obtaining, evaluating and communicating information** and **engaging in argument from evidence***.* Life sciences lend themselves well to developing students' abilities to gather information from a variety of sources, consider the validity and importance of data, and **communicate** what they have learned to others; as well as developing students' abilities to make oral and written arguments supported by empirical evidence and sound scientific reasoning

With guidance from their teacher, students developed and used a model that described phenomena, in this case a system of interacting sub-systems. They used a giant sequoia as a model of interacting systems and applied it to the human body as **evidence** of the ***structure and function*** of an organisms system and sub-systems. Students performed additional research and connected what they learned from the giant sequoia model to the structure and function of the organ and tissue sub-systems in the human body. Through further discussions and research, students applied this knowledge to explain, through in-class presentations, that the systems of the human body interact to perform all of the functions required for healthy lives, and failure of one or more sub-system may lead to the organism's end.

CCSS Connections to English Language Arts

Students used the *Interactive Body Guide* from Donate Life California and one other resource to research the different structures and functions of the human body. This connects to the *CA CCSS for ELA/Literacy* Reading Informational Text standards (RI.7). In addition, they participated in a range of collaborative discussions (SL.1) and presented their claims and findings about the human body's sub-systems in front of the classroom (SL.4).

RST.6-8.1 *Cite specific textual evidence to support analysis of science and technical texts.*

WHST.6-8.1 *Write arguments focused on discipline content.*

WHST.6-8.7 *Conduct short research projects to answer a question (including a self-generated question), drawing on several sources and generating additional related, focused questions that allow for multiple avenues of exploration.*

WHST.6-8.8 *Gather relevant information from multiple print and digital sources; assess the credibility of each source; and quote or paraphrase the data and conclusions of others while avoiding plagiarism and providing basic bibliographic information for sources.*

WHST.6-8.9 *Draw evidence from informational texts to support analysis, reflection, and research.*

Resources for the Vignette

- Donate Life California. 2015. Interactive Body Tour. http://www.donatelifecalifornia.org/bodytour (accessed August 5, 2015).

While many of the body systems are essential for regulating the ***stability*** within an organism, other systems help it interact with the environment around it. An organism's ability to sense and respond to its environment enhances its chance of surviving and reproducing. Animals have external and internal sensory receptors that detect different kinds of information, and they use internal mechanisms for processing and storing it. Each receptor can respond to different inputs (electromagnetic, mechanical, chemical), some receptors respond by transmitting impulses that travel along nerve cells. In complex organisms, most such inputs travel to the brain, which is divided into several distinct regions and circuits that serve primary roles, in particular functions such as visual perception, auditory perception, interpretation of perceptual information, guidance of motor movement, and decision making. In addition, some of the brain's circuits give rise to emotions and store memories.

Despite significant advances in medical imaging of the brain, there is still a huge amount of uncertainty about how these processes work. For *Science Magazine's* 125th anniversary, they published a list of the 125 biggest unanswered questions in science and many of them related to sensory perception and memory storage[34]. For example, little is known about how memories are encoded, the purpose of dreams and how they relate to sensory perception and memory storage, or the biological basis of consciousness itself. While computing power has improved dramatically in recent decades, humans remain superior to artificial intelligence in facial recognition (including perceiving emotional state) and simple everyday perceptual tasks (such as reaching into a laundry basket and finding the corners of a towel in order to pick it up and fold it[35]). Students are fascinated by these topics and the *CA NGSS* includes a performance expectation that they can gather and synthesize information about the interaction between human sensory and nervous systems (*MS-LS1-8*). This is an excellent opportunity to encourage students to **ask questions** and **obtain, evaluate, and communicate information** about possible answers and, more importantly, about more specific questions and sub-questions that need to be answered in order to answer the big-picture questions that many students likely have.

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[34] http://www.sciencemag.org/content/309/5731/78.2.full
[35] http://alumni.berkeley.edu/california-magazine/winter-2014-gender-assumptions/how-train-your-robot-now-they-can-follow-human

Grade 7 Instructional segment 4: Evidence of Evolution

Instructional segment 4: Evidence of Evolution

Guiding Questions:

- In what ways are humans similar to dinosaurs?
- How do rocks tell us about the history of life?

Highlighted Scientific and Engineering Practices:

- *Asking Questions and Defining Problems*
- *Analyzing and Interpreting Data*
- *Constructing Explanations and Designing Solutions*

Highlighted Cross-cutting concepts:

- *Patterns*
- *Structure and Function*
- *Scale, Proportion, and Quantity*

Students who demonstrate understanding can:

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

MS-LS4-2. Apply scientific ideas to construct an explanation for the anatomical similarities and differences among modern organisms and between modern and fossil organisms to infer evolutionary relationships. [Clarification Statement: Emphasis is on explanations of the evolutionary relationships among organisms in terms of similarity or differences of the gross appearance of anatomical structures.]

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

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

Significant Connections to California's Environmental Principles and Concepts:

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

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

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

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

Background and Instructional Suggestions

All living organisms have cells that use the same basic ***structure*** made out of the same basic materials. How did that happen? One possibility is that each of these organisms independently arrived at this same ***system*** because it works so well, while the other option is that organisms all share a common origin and that species have been slowly revising and changing over time. These two possibilities would produce different ***patterns*** of ***change*** over time and can therefore be **investigated**, or a different evolutionary history. While it would be ideal to observe evolution happening in real time, evolution requires ***changes*** that span many generations, and can only be directly observed in organisms that reproduce very quickly such as bacteria in petri dishes. For the rest of organisms, scientists have sought other lines of **evidence**. Tracking evolutionary history through chemical markers (such as similarities in DNA) is at the forefront of modern biology, but in middle school students should be looking for more tangible expression of evolution. This evidence comes from the fossil record.

In sixth grade, students developed a **model** for interpreting layers of rock like pages of a history book. Scientists studying the history of life can look at the sequence of living organisms recorded as fossils in these layers, observing the sequence of how organisms have changed from layer to layer over time. The fossil record allows them to peer back over a very long ***time scale*** and discover transitional life forms as well as indications of organisms that no longer exist.

Even though dinosaur 'bones' look like bones, fossils are actually made out of rock minerals that have completely replaced the original bones. Molecule-by-molecule, bone material goes away and gets replaced by rock material. As a result, fossils tell us nothing about what bones are made of – they only preserve the shapes of hard shells and skeletons of organisms (soft tissues are usually decomposed too quickly and are rarely preserved in the fossil record). Before looking back too far back in time, it helps to start with an **investigation** comparing the shapes of different skeletons of modern organisms. **Figure 22** shows schematics of the appendages of many creatures, including humans. Students can recognize the ***pattern*** that even though all the organisms look very different overall, they share the exact same bone structure (including the number of bones and their relative position). There are of course differences in the relative and absolute sizes of each bone. The differences make sense because the ***structure*** of the bones relates to the ***function*** of the arm. In an organism like a bat that uses its front appendage for flight, certain bones must be much longer. Organisms that walk on four legs must have bones sturdy enough to support weight, while those that walk on two legs can have much lighter-weight front arms.

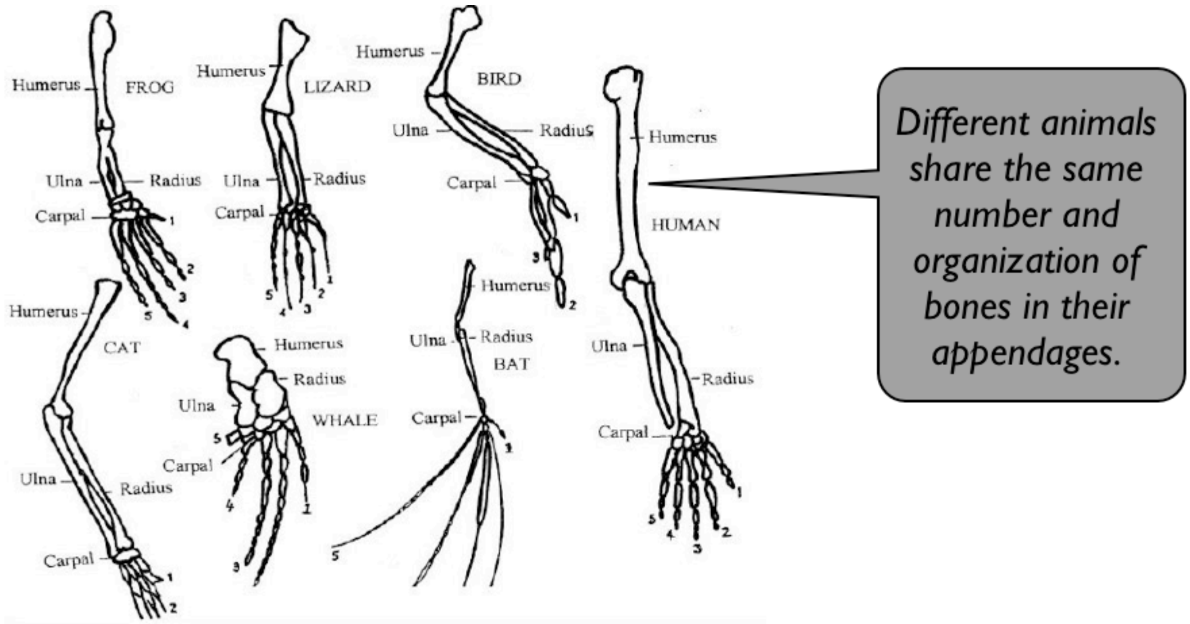


Figure 22. Bone structure of appendages from many different classes of animals. (Wikibooks 2015)

Common Core Connection: Structure and Function and Ratios

A monkey that swings through the trees needs to use its arms as levers to propel itself from branch to branch while arms play less of a role for humans. Students can look at these differences more quantitatively by comparing the ratio of forearm to upper arm length in various organisms. Students begin by measuring the lengths of each part of the arm on members of their class and compiling a whole class data set. They need to come to consensus on where to measure to ensure consistent data. They then compile whole class data (perhaps using an online spreadsheet) and graph forearm versus upper arm lengths (*CA CCSSM 7.RP.2*) to find that there is a relatively consistent constant of ***proportionality***. Even though each student is different and there is a range of sizes, what causes humans to have such remarkably similar ratio between the length of the two parts of our arms? Using simple pictures of various animals obtained from the internet, students measure the length of forearms and upper arms and calculate the ratio (*CA CCSSM7.RP.1*). When animals are grouped based on the way they move around, are there similarities? If so, why? And how did these similarities come about? These types of questions where neither student nor teacher knows the answer ahead of time are excellent examples of real scientific **investigations**. While some classic experiments are definitely worth conducting, **asking questions** whose answers are unknown to everyone (including internet search engines) is a more authentic representation of the way science is conducted by practicing scientists who are trying to discover new things based on the questions that they have asked (and there are no answers in the back of the book that they can consult to check if they are right because nobody knows the answers yet!). Note that the names of individual bones do not even need to be introduced -- the emphasis here is on looking for ***patterns*** in the measurements. Students use these patterns as **evidence** in an **explanation** that the ratio of forearm to upper arm length allows increase an organisms ability to survive in a specific environment, allowing them to swing from trees or race across a grassland (*MS-LS4-4*).

There must be some mechanism that ***causes*** all these diverse animals to share the same overall bone structure. Hints of this process come from looking at the progression of fossils over time. Looking back at the oldest rocks on Earth, there are no fossils (even in rock types that are similar to younger rocks that do preserve fossils). This tells us that there was a time when there was no life on Earth. The oldest rocks show only simple fossils, and organisms get more and more complex as geologic time passes. Around 500 million years ago, fossils of fish with internal skeletons begin to appear. From then on, there are distinct ***patterns*** in bone structures in related organisms over time. Students should be able to interpret examples from the fossil record to identify ***patterns*** of ***change*** (*MS-LS4-1*). Examples are rear leg bones that get shorter over the millions of years as marine mammals moved from land into the sea and shrinking tails as humans and other great apes moved from the trees to the ground. As students analyze images of the embryos of many of these organisms, they find that many of the differences tend to emerge late in the embryological development (*MS-LS4-3*), and that embryos of different species follow a surprisingly similar pattern of development. Students use ***patterns*** in bone ***structure*** and embryo development as **evidence** for a scientific **explanation** that these organisms are related through common ancestry and that species have evolved over time (*MS-LS4-2*). They will revisit this explanation in instructional segment 6 when they can add additional reasoning about the mechanism of natural selection that has caused some of these changes. At this point, students should end this instructional segment with a series of questions with a sense of wonder and a series of **questions** about how this systematic series of changes could have occurred.

Grade 7 Instructional segment 5: Inheritance and Genetics

Instructional segment 5: Inheritance And Genetics

Guiding Questions:

- How do cells know what to do and how to accomplish it?
- Why do children look like their parents?
- What causes differences between individuals?

Highlighted Scientific and Engineering Practices:

- Asking Questions and Defining Problems
- Developing and Using Models
- Obtaining, Evaluating, and Communicating Information

Highlighted Cross-cutting concepts:

- Cause and Effect

Students who demonstrate understanding can:

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

MS-LS3-2. Develop and use a model to describe why asexual reproduction results in offspring with identical genetic information and sexual reproduction results in offspring with genetic variation. [Clarification Statement: Emphasis is on using models such as Punnett squares, diagrams, and simulations to describe the cause and effect relationship of gene transmission from parent(s) to offspring and resulting genetic variation.]

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

MS-ETS1-1. Define the criteria and constraints of a design problem with sufficient precision to ensure a successful solution, taking into

account relevant scientific principles and potential impacts on people and the natural environment that may limit possible solutions.
Significant Connections to California's Environmental Principles and Concepts: Principle V. Decisions affecting resources and natural systems are based on a wide range of considerations and decision-making processes.

Background and instructional Suggestions

In the previous instructional segment, students saw **evidence** that life has evolved over many generations. The next two instructional segments allow students to construct a **model** of the mechanism that allows evolution to occur. Each student in a classroom or a school is unique in their appearance and how they act. Organism structures and behaviors are features that generally apply to all members of a species. Examples of human features are eye color, personality such as body size, introversion/extroversion, and blood type. If a feature normally has a pattern of varying among individuals, then we describe those variations as being 'traits' of that feature. For example, each different blood type is a trait, as is each different eye color or hair color.

Common Core Connection

Many physical traits can be expressed by a measurable ***quantity*** such as height, arm length, and hand span. Students have the most prior knowledge with height as a visualizable quantity, but it also can be a sensitive topic for some students. Teachers should pick a measurable quantity that will be meaningful and socially comfortable for their classroom. For example, students estimate the average height of a seventh grader at their school by sampling students in this science class (*CA CCSSM 7.SP.1*). Being tall can be an advantage in some situations, but a disadvantage in others. Which students are better suited to reaching books on the top shelf in the library? Which students will likely be more comfortable on an airplane where seats are close together?

The discussion of student height introduces the idea that traits vary within a population and that certain traits give organisms an advantage in specific environmental conditions. It also raises some fundamental questions: What determines how big a person will grow? How does their body know when to stop growing?

Students probably have some prior knowledge that their height may depend in part on their parents' height. Students extend their statistical study by surveying their parents and creating a scatter plot of student height versus average height of their parents. With this in mind, humans can have some influence on the height of their children by who they choose as their 'mate.' While students may or may not see much advantage in having an impact on the height of their children, there are many other situations where humans have a strong influence on the traits of other organisms, especially plants and animals used for food, as pets, or as decoration.

Before delving into the mechanisms of genetic inheritance in detail, classes can motivate the study by researching some specific cases of this artificial human influence on traits. Individuals or groups of students choose a food, pet, or garden species and **obtain information** from internet resources about the specific desirable traits that humans have sought for their chosen species and how humans have used selective breeding and, more recently, genetic modifications to influence these traits (corn and cattle make great stories and can be linked to cultural histories as well). This **investigation** into interesting applications of the science to societal issues is not an 'optional sidetrack,' but an explicit performance expectation in the *CA NGSS* (*MS-LS4-5*). Students will return to their findings after learning more in the core of this instructional segment.

In their study of selective breeding and genetic modification, students will be exposed to the terms of genes and reproduction. They are ready to engage in a series of activities to help them **develop a model** for how reproduction relates to the inheritance of traits through genes (*MS-LS3-2*). Students typically learn about genes by analyzing the results of Mendel's experiments with pea plants. In analyzing these or other classic examples of genetic experiments, students often use Punnett squares (an example of a diagram as a **model)** to predict or explain the traits in progeny and then conclude based on **evidence** that some gene alleles are recessive, others are dominant, and some do not fit the dominant/recessive dichotomy.

7th Grade Snapshot: Asexual and Sexual Reproduction

Ms. Z wanted to use an engaging activity to help students to transition from their analyses of the ***causal*** connections between genes and traits into **models** comparing asexual and sexual reproduction (*MS-LS3-2*). Basing the activity on an interactive lesson from the University of Utah Learn.Genetics Web site[36], Ms. Z provided background information about reproduction in sunflowers, earthworms, strawberries, and whiptail lizards. Students discussed in teams how to describe the reproductive process in each organism (asexual, sexual, or both) and the **evidence** for their categorizations. Whole class sharing resulted in common answers and evidence. Small student teams then had time to explore the Web site (in a computer lab, in class with tablets, at home, or in a library) in order to select two organisms that have different processes of sexual reproduction.

The following day, student teams made ***system models*** of the reproduction processes for each of their two selected organisms. Each of the system models had to explain why the progeny would have identical or different genetic information from each other. Students posted one of their system models on the wall; they then individually walked around the room and analyzed each posted model. They pasted sticky notes next to the models with any **questions** or disagreements they had with respect to the conclusions and/or evidence. After the presenters had time to look at the sticky notes, the whole class paid attention as each presenting team appropriately responded to the comments.

Connections to the CA NGSS:

Science and engineering practices	Disciplinary core ideas	Cross cutting concepts

[36] Sexual vs. Asexual Reproduction accessed at: http://learn.genetics.utah.edu/content/variation/reproduction/

	Developing and Using a Model; Constructing Explanations; Engaging in Argument from Evidence	LS1.B: Growth and Development of Organisms; LS3.B: Variation of Traits	Patterns; Cause and effect
Connections to the CA CCSSM: Not applicable			
Connections to CA CCSS for ELA/Literacy: RST.6–8.1; WHST.6–8.7; SL.7.1,			
Connection to CA ELD Standards : ELD.PI.1.1, 5, 6b, 9			
Connections to the CA EP&Cs:			

Discussions of traits can get side-tracked by either/or arguments about the roles of genes and the environment in determining traits (the age-old “nature v. nurture” debate). In the case of organism traits, there are some traits that are essentially all genetic (e.g., blood type) and other traits that have a very large environmental component (e.g., large muscles due to exercise or being able to play the guitar). Most traits are a combination of genetic and environmental influence, and can be placed somewhere along the spectrum between the extremes examples (**Figure 23**).

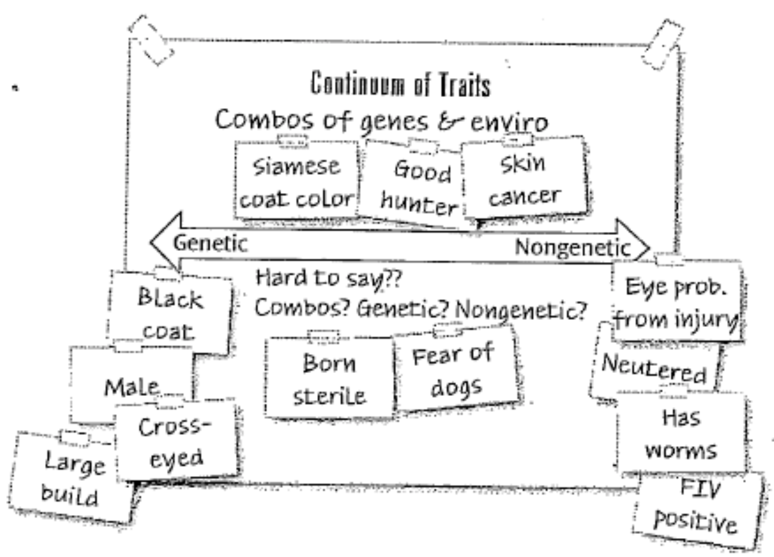


Figure 23. Some traits are essentially all genetic, and some are mostly environmental. Most traits are strongly influenced by genes and the environment. Image Credit: Illustrations from *Making Sense of Science Genes and Traits* course, courtesy of WestEd

Students should be able to draw connections between their **model** of the cell ***system*** and their model of reproduction. In particular, the genetic code is stored on chromosomes located within the cell nucleus. The chromosomes can be thought of as recipe books that contain the list of ingredients to make specific proteins and molecules needed for the cell to function. The recipe analogy is a conceptual model that students can develop and apply to help understand genetic inheritance and mutations (*MS-LS3-1*) because the rearrangement of food molecules into these essential molecules is what **causes** all ***changes*** to an organism's ***structure*** and behavior. The details of how this happens (including the discussion of DNA) is reserved for high school (*HS-LS1-1*), but understanding the role of protein synthesis in determining traits is part of 7th grade (*MS-LS3-1*). Despite this fundamental role, there are so many unanswered **questions** about the exact mechanisms by which proteins influence traits. For example, specific molecules described in our genetics trigger cell growth, but how exactly does the body know when to stop growing? In other words, scientists can't fully answer the question of why some students are shorter than others that was raised at the beginning of the instructional segment. Or how does this recipe book ensure that a person's left leg stops growing at the same time his or her right leg does? Puberty is triggered by the release of hormones encoded in the genetic code, but what determines when puberty will start? It appears that diet, including the diet of the person's mother while she was pregnant, can have an impact on when these molecules are synthesized using the recipe in the genetic code, but how that works remains a mystery. All of these big questions are listed as some of the 125 biggest unanswered questions in science, according to the journal Science (*Science* Magazine 2005). Teachers can emphasize that scientific inquiry will never answer all our questions because each piece of new knowledge leads to new **questions**.

The examples above primarily pertain to physical traits, but the genetic code also plays a role in regulating the behavior of organisms, including people. For example, when students are frightened, their bodies suddenly release the molecule norepinephrine into their blood stream, causing a cascade of ***changes*** to their heart rate, blood pressure, and breathing. This 'fight-or-flight' response is an important instinct for survival, and the same basic response also occurs during exercise or hard physical work. Imagine what would happen if a person's genetic code had an incorrect recipe for making norepinephrine. They would be unable to make sudden changes in their activity level. This genetic defect is extremely rare, but is called DBH deficiency and has been documented in fewer than 20 people in the world (Genetics Home Reference 2008). It happens when there is a small error copying the genetic code during sexual reproduction. This copying error is called a mutation. While DBH deficiency is caused by a rare mutation, other mutations are extremely common and cause a wide range of other changes in organisms. Students should be able to come up with other examples of changes that could benefit organisms, hurt them, or have neutral impacts on the organism's overall ***structure*** or behavior (*MS-LS3-1*).

Classic genetics tends to reinforce a preconception that each trait is caused by one gene. Students may also hold a parallel preconception that each gene influences only one trait. Students can cite as **evidence** countering that preconception that the ABCC11 gene on chromosome 16 helps create molecules that determine the type of earwax a person has and also the amount of underarm odor. Each of these processes may require the same proteins to be synthesized and therefore rely on the same section of DNA (the same ‘gene’), but they also require multiple other proteins stored in different segments of DNA and therefore rely on a number of genes. **Figure 24** contrasts incorrect and correct concepts about the ***causal*** linkages between genes and traits. This figure doesn’t capture the fact that large sections DNA appear to do nothing at all and are relicts left over by evolution. As much as 98% of human DNA may be ‘non-coding’ (meaning it is not used to synthesize proteins), though it is difficult to say for sure that these sequences are never utilized and many other organisms use a much higher portion of their DNA. Mutations that affect these inert, ‘non-coding’ sections of DNA may be passed on through reproduction but will have no impact at all on the way traits are expressed.

Incorrect and Correct Ideas about Genes and Traits

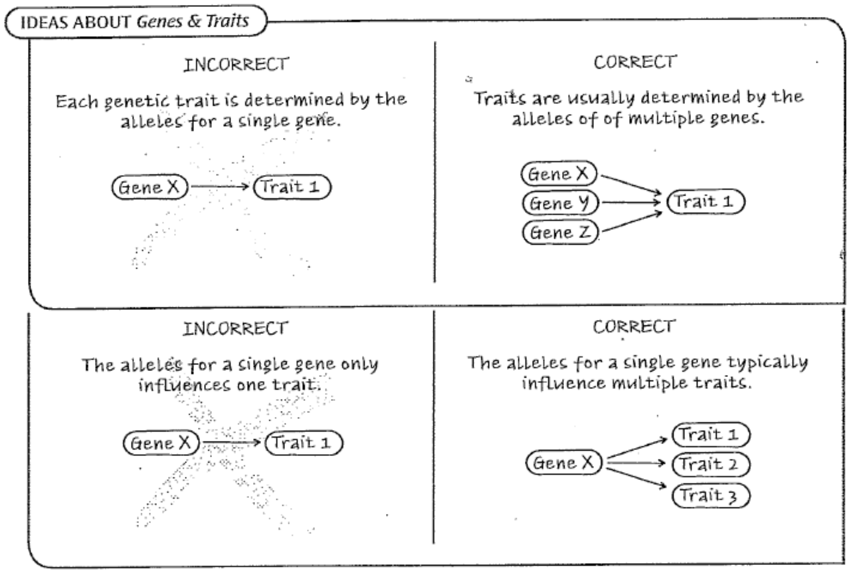


Figure 24. Multiple gene typically determine a specific trait, and an individual gene typically influences multiple traits. Image Credit: Illustration from Making Sense of Science *Genes and Traits* course, courtesy of WestEd.

Students can now revisit their project **investigating** how humans can influence traits and **apply their models** of genetic inheritance and mutations to **evaluating the information** they obtained earlier in the instructional segment (*MS-LS4-5*). By using selective breeding, humans influence the combinations during sexual selection. By genetic modification, humans induce specific 'mutations' (in this case, large ***scale changes*** to an organism's genetic code rather than simply copying errors). For example, the full genetic code from a jellyfish that allows it to glow green can be inserted into feline genetic code such that cats are born glowing green (Mayo Clinic 2011). While that modification is not very practical (nor harmful), those researchers simultaneously inserted genetic code that could also reduce the chances of the cats contracting AIDS (the green glow was used as a marker to visually demonstrate that the genetic sequences were successfully inserted). The work is in the exploratory stages and may one day help scientists find cures to AIDS in humans. Students can apply their models of genetic modifications to food products, such as corn that produces its own insecticide or canola plants that produce nutritious omega-3s with inserted genetic code from algae. These products could transform our food supply, but their long-term effects on human health and ecosystems are largely unstudied. Students of today will likely need to make important policy decisions about whether or not the benefits of these modifications outweigh their possible costs (*MS-ETS1-1***,** *EP&C V*). As students **evaluate the information** they find about these genetically modified products, they should search for specific ***measurements*** of the costs or benefits and favor resources that provide those over resources that make vague or general statements.

Grade 7 Instructional segment 6: Natural Selection

Instructional segment 6: Natural Selection
Guiding Questions: • How do specific traits help organisms access or utilize resources more efficiently? • How does a population benefit from having diversity within it? • What does it mean to have 'survival of the fittest'?
Highlighted Scientific and Engineering Practices: • *Analyzing and Interpreting Data* • *Using Mathematics and Computational Thinking*
Highlighted Cross-cutting concepts: • *Cause and Effect* • *Structure and Function* • *Stability and Change*
Students who demonstrate understanding can: **MS-LS1-4. Use argument based on empirical evidence and scientific reasoning to support an explanation for how characteristic animal behaviors and specialized plant structures affect the probability of successful reproduction of animals and plants respectively.** [Clarification Statement: Examples of behaviors that affect the probability of animal reproduction could include nest building to protect young from cold, herding of animals to protect young from predators, and vocalization of animals and colorful plumage to attract mates for breeding. Examples of animal behaviors that affect the probability of plant reproduction could include transferring pollen or seeds, and creating conditions for seed germination and growth. Examples of plant structures could include bright flowers attracting butterflies that transfer pollen, flower nectar and odors that attract insects that transfer pollen, and hard shells on nuts that squirrels bury.] **MS-LS2-1. Analyze and interpret data to provide evidence for the effects of resource availability on organisms and populations of organisms in an ecosystem.** [Clarification Statement: Emphasis is on cause and effect relationships between resources and growth of individual organisms and the numbers of organisms in ecosystems during periods of abundant and scarce resources.] **MS-LS4-4. Construct an explanation based on evidence that describes how**

genetic variations of traits in a population increase some individuals' probability of surviving and reproducing in a specific environment. [Clarification Statement: Emphasis is on using simple probability statements and proportional reasoning to construct explanations.]

MS-LS4-6. Use mathematical representations to support explanations of how natural selection may lead to increases and decreases of specific traits in populations over time. [Clarification Statement: Emphasis is on using mathematical models, probability statements, and proportional reasoning to support explanations of trends in changes to populations over time.] [Assessment Boundary: Assessment does not include Hardy Weinberg calculations.]

MS-ETS1-1. Define the criteria and constraints of a design problem with sufficient precision to ensure a successful solution, taking into account relevant scientific principles and potential impacts on people and the natural environment that may limit possible solutions.

MS-ETS1-2. Evaluate competing design solutions using a systematic process to determine how well they meet the criteria and constraints of the problem.

MS-ETS1-4. Develop a model to generate data for iterative testing and modification of a proposed object, tool, or process such that an optimal design can be achieved.

Significant Connections to California's Environmental Principles and Concepts:

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

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

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

Background and instructional Suggestions

This instructional segment builds from and extends the ideas developed in the prior instructional segment about inheritance and variation within and across species. The previous instructional segment began with students using graphical and mathematical representations of a trait such as height. This instructional segment focus on how the frequency of different traits *changes* over time in a population.

In the previous instructional segment, students were able to explain how humans identify certain favorable traits and try to encourage them by selective breeding or induced mutations. Natural populations follow a similar process in which adaptation of the population occurs through natural selection, which favors those traits which are the best fit to a given environment (i.e., they benefit survival). Natural selection exists at the intersection between genetic inheritance (from instructional segment 6) and ecosystem ***energy flows*** (from instructional segment 1). Selection within a population only occurs through the breeding over many generations when there are limited ***energy, matter***, or space resources within the ecosystem. Specific traits may allow animals to obtain or use resources more efficiently, and therefore improve an organism's chance to reproduce.

Students begin by **analyzing data** about how resource availability affects populations (*MS-LS2-1*). In California, many of the variations in resource availability relate to fluctuations in climatic conditions such as cycles of rainfall and drought, often tied to conditions in the ocean called El Niño[37]. Students can use existing data sets of duck[38] or deer[39] populations compared to annual rainfall during multiple cycles of drought, marine mammal or salmon populations during El Niño versus non-El Niño years, or even food prices such as corn and soy beans during El Niño cycles. Teachers should encourage students to **ask questions** about what might happen to these populations as climate changes and what impact humans might be having on these changes (*EP&C II, III*). While most answers are not within the scope of the middle school curriculum in the *CA NGSS*, they are a major focus of the high school standards for life and Earth science.

7th Grade Snapshot: Graphing fish populations
Mr. M. leads an activity where students **analyze population data** (*MS-LS2-1*) by showing a video clip of a news story about how large numbers of sea lion pups have

[37] https://www.wildlife.ca.gov/Conservation/Marine/El-Nino
[38] https://nrm.dfg.ca.gov/FileHandler.ashx?DocumentID=82683
[39] http://www.ndow.org/uploadedFiles/ndoworg/Content/public_documents/Wildlife_Education/Publications/muledeer.pdf

been showing up malnourished and abandoned by their parents on the beach in southern California. While this is known to happen, the newscast emphasized that this year had a lot more than usual. After the news story, Mr. M. asks students to suggest possible ***causes*** for this problem. Students had recently created a food web that included sea lions and they knew that the pups depended on sardine and anchovy as their primary food source. Freddy suggests that something caused these populations to drop.

Mr. M. provides students with a data table showing the number of sardines and anchovies caught every month over a ten-year period. He explains that the number of fish caught is a good way to estimate the total population size because nets will catch more fish when there are more fish in the ocean. He says that the nets are somewhat analogous to a random sample of the ocean's fish population density (*CA CCSSM 7.SP.1*).

He assigns different groups of students to plot different subsets of the data. One set of groups plots the total of fish per year while another set plots the total fish per month over a three year span. A third set calculates the total catch for two different five-year periods and creates a graph comparing them. By **analyzing** their own graphs, the groups plotting anchovies by year notice a general downward trend while the groups plotting sardines notice several years where the catch was incredibly high, with most other years having almost no fish at all. The groups plotting catch by month see that anchovies appear each year in early summer while sardines are usually caught in the early autumn. The groups plotting the total over five year periods find big differences between them; the first five years are dominated by anchovies while the latter 5 year period is dominated by sardines.

Mr. M. asks the students to provide **evidence** in favor or against the **argument** that "sardine and anchovy population stay the same over time." All groups strongly disagree with the statement and cite their own graphs as evidence. Mr. M. then has students do a gallery walk and **analyze** the different graphs created by each team. He then asks students to provide evidence in favor or against the **argument** that "each graph of anchovy data shows the same thing." Students then discuss how each graph reveals a slightly different pattern, and the conclusions they draw from these ***patterns*** differ.

Mr. M. then provides another graph showing cycles of ocean temperature along the California coast during the same time interval and they read an informational article about El Niño. Students recognize that the timing of ***pattern*** of surface temperatures caused by El Niño corresponds to patterns in the fish populations, which is evidence that it may be the ***cause*** of the ***changes*** over time. He asks students to speculate about what will happen to the different fish and sea lion populations if El Niño effects intensify due to global climate change. Students will work over the next few days to create an infographic **communicating** the complex chain of events that has been causing the sea lion population to change.

Based on California Academy of Sciences 2015

Connections to the CA NGSS:

Science and engineering practices	Disciplinary core ideas	Cross cutting concepts
Analyzing and interpreting data; Communicating information	LS2.A (analyzing data about populations in an ecosystem is part of MS-LS2-1)	Patterns; Cause and effect (the patterns in population changes give clues about the cause); Stability and Change

Connections to the CA CCSSM: Review of 6.SP.4, 7.SP.1, 7.SP.2

Connections to CA CCSS for ELA/Literacy: RST.6–8.1,7,8,9; WHST.6–8.9

Connection to CA ELD Standards : ELD.PI.1.1, 3, 6a, 6b, 11a

Connections to the CA EP&Cs:
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 III. Natural systems proceed through cycles that humans depend upon, benefit from and can alter.

Since there is natural variation within populations, students must gather **evidence** to make a scientific **argument** that some organisms may have traits that allow them to survive and pass on their genetic code (*MS-LS1-4*). These traits may be specific structural or behavioral features, and the clarification statement for *MS-LS1-4* offers a number of specific examples. Another way to categorize traits is that they some traits allow the organism to access resources more readily while others enable the organism to use their resources more efficiently. An example of resource access relevant to California in times of drought is that different plants within the same species can vary in the depth that their roots grow (Kell 2011), allowing some of these individuals to access more water. Darwin's classic observation of finch beak shape is another example where an organism's ***structure*** enables the ***function*** of accessing resources (though Darwin is most famous for documenting the end-result with differences between species rather than slight variations between individuals). Different traits epitomize the efficient use of resources. Returning to the example of students' height, statistical studies of baseline metabolic rate show that for every additional centimeter of height, a person requires about six additional Calories of food per day, on average (Frankenfield, Roth-Yousey, and Compher 2005). In other words, short people require less food to survive. There are also large variations from person to person in baseline ***energy*** requirements that may be caused by other genetic factors. In a massive food shortage, people that can survive on less food are more likely to live long enough to create offspring that are likely to have the same genetic code (assuming all other factors are equal; see the snapshot below for examples of other important pressures on physical traits that affect adaptation and survival). The previous examples all pertain to physical traits, but behavioral traits also play an important role in survival and affect an organism's ability to find food, remain safe from danger, and reproduce.

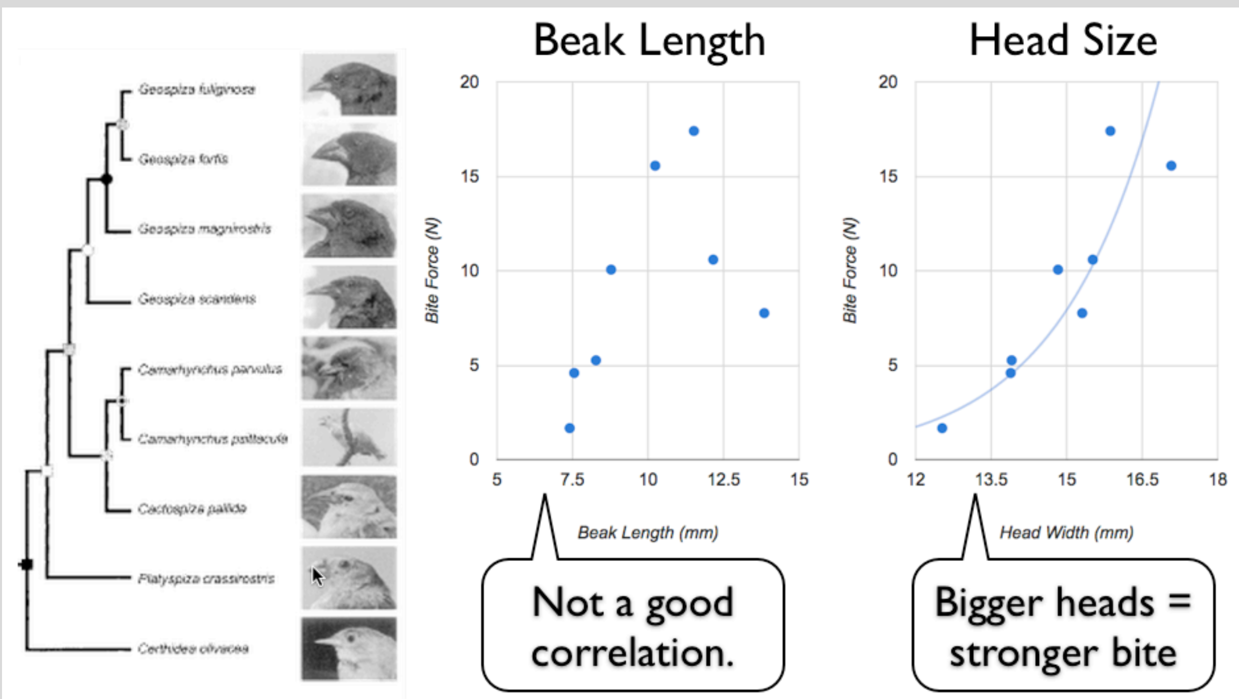
Organisms that survive are 'selected' by the environment to pass on their traits, causing the population to shift so that the beneficial traits occur in a greater fraction of the individuals than it did in previous generations. Selection also occurs on a very different ***scale***, and can be observed as microbes become increasingly resistant to antibiotics—a fact that has huge impacts on healthcare. Students can observe this resistance in the classroom as they **plan and conduct and investigation** to observe how microbe populations ***change over time***.

Engineering Challenge: Engineer a bird beak

In elementary school, students constructed arguments that internal and external structures of organisms that help them survive (*4-LS1-1*). In this activity, they engineer structures and use their own designs to make inferences about how the internal and external structures of an animal connect and interact. Different animals eat different types of food, and their bodies must have the correct **structures** to enable them to eat that food effectively. Birds in particular have large variation in their beak shapes based upon their food source. Students can design a "beak" from a fixed set of materials that will allow them to eat as much "food" as possible[40]. They begin by defining the problem and establishing the criteria they will use to measure success (*MS-ETS1-1, MS-ETS1-2*). Will they compare the amount of food in one bite or the amount of food in a set amount of time? Which of these criteria is probably a better approximation of what helps birds survive in nature? Are there any specific challenges that this particular type of food presents (powders, foods encased in hard shells, and foods that crumble easily all require different solutions)? Are there any obvious disadvantages to bigger or smaller beaks? (To represent the fact that bigger organisms require more ***energy*** to survive, the activity can be set up so that the amount of points a team receives depends on the ratio of food mass eaten to their beak mass). After testing their design, they make improvements to improve their chance of survival (*MS-ETS1-4*). They discuss the process of iterative improvement that they used and then compare and contrast it to

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

evolution by natural selection, which occurs over many generations. In their own engineering design, students might notice that certain modifications they made allowed them to eat food faster, allowing them to collect more food each day – a serious advantage for survival. Scientists have found that seed eating birds that have the strongest bite force can eat the fastest. What aspects of a bird’s structure allow it to bite more forcefully? Students analyze measurements of different physical characteristics of different species of finches from the Galapagos and compare them to the bite strength scientists measured in laboratories. Different students plot different variables to see if they can identify variables that correlate well with bite strength (Herrell et al. 2005). They find that the length of the beak doesn’t matter, but the size of the head does, probably because larger heads can support larger muscles. They can experiment with different modifications to their bird beaks that mimic these size differences and relate them to levers and forces.



7th Grade Snapshot: Physical environment shifts populations
One of the students in Ms. H’s class watched a documentary about pygmy

people and wanted to know why they were so short. Ms. H asks groups of students to come up with a list of ways in which an animal's size (large or small) can be an adaptation that helps them survive in a particular environment. The class determines that access to resources (like giraffes reaching food up high), ability to fight off predators (like a moose kicking a wolf), ability to dominate members of the same species (like sea lions battling for dominance), and ability to hide from predators. Ms. H did some Internet research and found a graph of moose weight versus latitude in Sweden. Students correctly interpreted the axes of the graph to see that the average size moose is larger in the northern part of Sweden compared to the southern parts. She shows pictures of Sweden to help students see how cold it gets in the winter and asks them why having more body mass would be an advantage. Students realize that they need to add heat management to their list of adaptations for size.

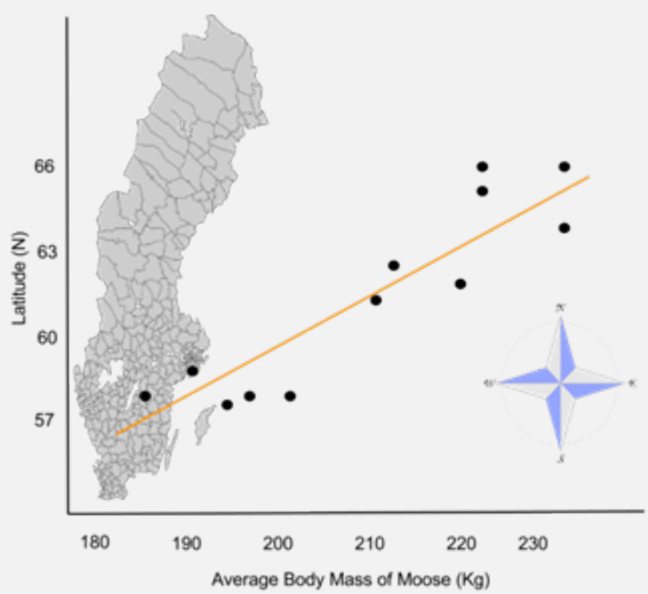


Image Credit: (CC-BY-SA) by Nmmcarthy16 2014

Ms. H asks students to research where different pygmy populations exist and plot them on a world map. They find that pygmies live in equatorial regions that should be hotter (*MS-ESS2-6*). Upon further investigation, they find that these areas are hot and moist, which means that pygmies don't lose heat as efficiently by sweating (because evaporation occurs slowly in damp, swampy conditions; ties to *MS-ESS2-4*). Unlike the moose in Sweden, pygmies want to generate and retain as little heat as possible to avoid overheating and the ineffectiveness of sweating makes heat management even more crucial. Since bodies cool where cool air touches skin, pygmy's bodies will operate most efficiently when they maximize their surface area to have as much exchange with the air as possible. At the same time, an overall huge body would be bad because an increase in volume and mass leads to more heat generated as the person moves. Over time, pygmy populations have evolved to maximize the ratio of surface area to body mass, which results in a shorter body. Since this body shape and size allows pygmies to move around to obtain food and survive, it gets passed from one generation to the next through their genetic code.

Ms. H assesses whether or not students have mastered these ideas by asking them to write a complete scientific **explanation** answering the question, "Why are pygmies short?" including evidence and reasoning. Ms. H could extend this activity to include an engineering challenge in physical science where students design a person or organism that optimizes energy transfer for different environmental conditions (*MS-PS3-3*).

Connections to the CA NGSS:

Science and engineering practices	Disciplinary core ideas	Cross cutting concepts
Asking questions; Analyzing and interpreting data	MS.LS3.A Inheritance of traits MS.LS4.C Adaptation ESS2.C Role of water in Earth's surface processes ESS2.D Weather and climate	Patterns; Cause and effect (the patterns in population changes give clues about the cause); Scale, Proportion, and Quantity

		PS3.B: Conservation of Energy and Energy Transfer	
Connections to the CA CCSSM: 7.RP.2a			
Connections to CA CCSS for ELA/Literacy: RST.6–8.1, 8; WHST.6–8.1,7			
Connection to CA ELD Standards: ELD.PI.6a, 6b, 10b, 11a, ELD.PII.1			
Connections to the CA EP&Cs: 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.			

Common Core Connection: Compound probabilities of survival

When students know the distribution of traits within a population, they can calculate the probability that a given individual will have a desirable trait. That desirable trait will make it more likely that the organism will survive in a specific environment. Taken together, students can calculate the compound probability to figure out what fraction of individuals will likely survive (*CA CCSSM7.SP.8*). Such problems can be solved by multiplying rational numbers (*CA CCSSM.7.NS.2*; e.g., ½ of the population has trait X and ¼ of individuals with trait X are expected to survive, so therefore 1/8th the population is likely to survive). These calculations also lend themselves well to constructing simple computer simulations of population dynamics. This activity could be a good avenue for introducing students to computer programming. Even with minimal background in computer programming, students could apply **computational thinking** to interpret an existing computer code, perhaps spotting an error in the way the compound probability was calculated in the sample program and then eventually modifying it to calculate additional parameters. Students can use such simulations to gather **evidence** to **explain** that both genetic and environmental factors affect an organism's chance of survival (*MS-LS4-4*). They also use these simulations as evidence that can enhance their **explanations** that traits within populations change over many generations due to natural selection (*MS-LS4-6*). Even without a computer, the same step-wise **computational thinking** can be implemented in a game involving a deck of cards[41].

A common preconception that students hold is about the ***time scale*** of selection. Students incorrectly believe that individuals adapt to the environment as it changes. Students can construct an **argument** that organisms cannot change their traits such as height, position of their eyes, length of their wings, or ***energy*** required for living. Individual organisms can't change, but they can die off before they are able to reproduce. The rate of change depends on how quickly a population reproduces as well as whether or not the environment is ***stable or changing***. ***Stable*** environments can often lead to gradual changes in populations, while sudden environmental changes lead to more dramatic selection. Careful uses of language are important to minimize this preconception, such as using the phrase 'populations adapt' rather than referring to 'organisms adapting.'

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[41] NOVA Teachers, Dogs and more dogs classroom activity: http://www.pbs.org/wgbh/nova/education/activities/3103_dogs.html

Grade 7 Instructional segment 7: Ecosystem Interactions, Revisited

Instructional segment 7: Ecosystem Interactions, Revisited

Guiding Questions:

- How does natural selection relate to ecosystem changes?
- How do people affect ecosystems? Which activities have a positive impact and which negative?

Highlighted Scientific and Engineering Practices:

- *Asking Questions and Defining Problems*
- *Constructing Explanations and Designing Solutions*
- *Engaging in Argument from Evidence*
- *Obtaining, Evaluating, and Communicating Information*

Highlighted Cross-cutting concepts:

- *Systems and System Models*
- *Influence of Science, Engineering, and Technology on Society and the Natural World*

Students who demonstrate understanding can:

MS-LS2-4. Construct an argument supported by empirical evidence that changes to physical or biological components of an ecosystem affect populations. [Clarification Statement: Emphasis is on recognizing patterns in data and making warranted inferences about changes in populations, and on evaluating empirical evidence supporting arguments about changes to ecosystems.]

MS-LS2-5. Evaluate competing design solutions for maintaining biodiversity and ecosystem services.* [Clarification Statement: Examples of ecosystem services could include water purification, nutrient recycling, and prevention of soil erosion. Examples of design solution constraints could include scientific, economic, and social considerations.]

Significant Connections to California's Environmental Principles and Concepts:

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

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

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

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

Background and instructional Suggestion

Once students have **models** for the interconnectedness of ecosystem components and a sense of how limited resources within ecosystems affect populations (*MS-LS2-1*), they can construct **arguments** about how ***changes*** to one component in an ecosystem will affect other components (*MS-LS2-4*). The *CA NGSS* are designed to specifically emphasize some of the *human* induced changes under the heading within the crosscutting concepts box titled, "Influence of Science, Engineering, and Technology on Society and the Natural World." The *CA NGSS* include two bulleted points relating to this concept:

- All human activity draws on natural resources, and has both short- and long-term consequences, positive as well as negative for the health of people and the natural environment.
- The uses of technologies and limitations on their use are driven by individual or societal needs, desires, and values; by the findings of scientific research; and by the differences in such factors as climate, natural resources, and economic conditions.

These statements can help guide the discussions about designs that relate to protecting ecosystem services and biodiversity. The findings of scientific research provide necessary guidance, but they do not ultimately dictate actions. Student discussions should distinguish between the scientific information and the personal or societal values. A major teaching challenge in these design challenges is to foster a classroom climate where both the scientific and the social argumentation are passionate but also respectful and non-judgmental.

California's Environmental Principles and Concepts (EPC) can provide further guidance. All five of the Environmental Principles apply to the performance expectations bundled in this instructional segment. Students can refer to these general principles and the specific concepts associated with each principle as part of their analyses, evaluations and argumentation. Having extensively investigated cycles of matter and ecosystem processes, students are primed to apply California's EPCs. For example, the three concepts associated with Principle III state:

- Natural ***systems*** proceed through cycles and processes that are required for their functioning
- Human practices depend upon and benefit from the cycles and processes that operate within natural systems
- Human practices can alter the cycles and processes that operate within natural systems.

Engineering Challenge:

Some human activities have negative impacts on ecosystems, but some technologies enhance ecosystem productivity by providing valuable ecosystem services such as the purification of water, reducing soil erosion, or nutrient recycling. Students **investigate** competing technologies or various design alternatives of a given technology to see which benefits the ecosystem the most (*MS-LS2-5*). One classroom-friendly possibility is to explore different designs of compost ***systems*** that optimize nutrient recycling. Students can learn more about the valuable role of decomposers by performing a valuable service for their school, collaborating between their campus cafeteria and garden or facilities staff. Students can test competing compost systems to see which will produce nutrient-rich organic fertilizer the fastest. Their designs might explore different amounts of air circulation, mixing of compost material, ambient temperatures, and additions of water or other materials (such as coffee grounds), all of which might affect the rate of biochemical reactions that decompose food waste.

Human cycles can best be put in the context of other changes. The ***systems*** thinking and modeling introduced in instructional segment 1 provide a scientific framework for evaluating these impacts at a range of ***scales*** from individual ecosystems up to the entire Earth. All of Earth's ecosystems are linked with each other through their sharing of the atmosphere and the hydrosphere. What happens when humans cause changes to these two systems that occur faster than populations can adapt? The fossil record shows major extinction events when changes have occurred too rapidly in the past. Which species will be most susceptible to extinction when future changes happen? What can humans do to help minimize the effects on these species?

Middle School Vignette

Analyzing the past, present, and future of marine mammal evolution

Introduction

The vignette below begins with a look at natural ***cycles and changes*** and ends with the dramatic impact humans can have. The vignette is designed to be a culmination of the entire course, so it draws on a wide range of PEs. In some cases, PEs are listed in parentheses even when the scientific practice in the vignette differs slightly from the practice specified in the PE. In such cases, the activity described will support successful completion of the PE even if it is not a direct exemplification of it.

In this series of activities, students will explore the amazing story of marine mammal evolution. While there are a number of different categories of marine mammals, this study focuses on three: cetaceans (whales and dolphins), sireneans (manatees and dugongs), and pinnipeds (seals and sea lions). For simplicity, this activity refers to each by their common names. Despite their many similarities, these organisms evolved independently from different land mammals all around the same times and in response to the same environmental conditions. Alongside the expansion of marine mammals was the explosion of large sharks that preyed upon the new proliferation of large sea life.

Lesson Hook

Ms. L assigns students to a group for a jigsaw format activity about each of the types of marine mammals so that they can be familiar with what they eat and the environments in which they live. Each person is assigned to a group that becomes an expert on one of these groups of animals. They reorganize into new groups with one expert from each group and play a game called “Name that Marine Organism,” in which they are given a list of behaviors and characteristics and must match them to the correct animal. Once familiar with all the animals, Ms. L gives each student a notecard and asks them to write one **question** about these creatures. She warns them that they may not be able to answer all of the questions, but she is excited to see what they want to know. She then shares some of the questions she has about the evolutionary history of marine mammals, such as: How are these animals related? Do they share a common marine mammal ancestor? Why do they live in the ocean if they are mammals? How long did it take for marine mammals to evolve?

Day 1 – Measuring biodiversity

Ms. L gives each pair of students receives a stack of fossil cards. Each stack represents all the fossils found in a certain layer of rock at a certain location, but the students are not told which layer or which location just yet. To make the problem more manageable for her middle school students, Ms. L found pictures that show the entire skeleton of a fossil marine creature rather than incomplete bone fragments like researchers would actually find. For sharks, the cards only show the teeth because it is much more common to find teeth than any other fossilized part. This is because shark bones are made of cartilage and softer than most other vertebrates’, but also because a shark’s mouth is set up so that it has several layers of teeth and each layer falls out every few weeks. This adaptation prevents its teeth from ever getting too dull to pierce the bodies of its prey, but it also means that a shark will lose thousands or even tens of thousands of teeth over its lifetime.

Fossils from a given layer allow scientists to figure out who lived together in an ecosystem. Ms. L asks the students to sort the cards from their pile into different species, determining the number of species present and the relative ***proportion*** of each. She has not provided the students any species names or shown them pictures of what the different species look like; they are simply identifying skeletons that look similar and grouping them into the same species. Students submit their findings into an online collaborative spreadsheet that automatically generates a graph comparing the data from all the groups. Ms. L points to the graph displayed on her computer projector and emphasizes that some groups have very similar findings to one another and some groups have very different results. She then asks students to **interpret** these ***patterns*** in the **data** and to identify which groups they think were collected from nearby locations and/or adjacent layers. A real paleontologist keeps meticulous track of this information and always interprets fossils in the context of where and when they lived, but Ms. L has hidden this information to give her students practice at **data analysis**. She leads a class discussion addressing a series of **questions**: What might cause one site to have a different distribution of animals than another if they came from the same layer representing the same time in Earth's history? What would cause the distribution of animals to change over time from layer to layer if you stay at the same site?

Day 2: Predator-prey relationships

Ms. L reminds students that the fossils in each pile of cards lived in the same place at the same time, so they must have interacted. In an ecosystem, one form of interaction is that organisms eat one another (*MS-LS2-3*). For homework, students **obtained information** from an interactive tutorial about how to interpret fossils to infer the eating habits of an organism. They use the shape of the teeth and mouth, the relative size of the different animals, and other adaptations apparent in their body ***structure*** (such as inferring the relative speed that each would run or swim). In the classroom, groups then apply this knowledge to construct a **model** of ***energy flow*** in the form of a food web that includes the different species at their site (*MS-LS2-2*). Who ate whom? Who was predator and who was prey?

Days 3-4 – Establishing a picture of past environments

Students continue the **investigation** of their fossil site and Ms. L guides the next few lessons with the question, "What were the environmental conditions like at this site at the time that this particular layer formed?" She gives a short lecture about modern tools that scientists use to help answer this question very specifically. As the enamel on the teeth of marine mammals grow, it incorporates chemical information about the water in which the organism lived. In particular, scientists can infer the temperature and salinity of the water from the chemical signatures in the enamel. A paleontologist might collaborate with an isotope geochemist to make measurements of these chemical signatures. Ms. L hands each group a sheet with chemical signatures for several of their fossils. Students **analyze the data**, looking for similarities and outliers. Do all the species have similar measurements? (Some species migrate over long distances and live in different environments during their lifetime.) How much difference is there between individuals within each species? Students calculate the average conditions of all the fossils and report their result in an online spreadsheet. They **communicate** their **interpretation of the data** by drawing a picture illustrating what the environment probably looked like at the time these animals lived (*MS-LS2-4*). How deep was the water? What types of plants would they expect to find there? What other types of animals might there be that were not fossilized?

Day 5: Evidence of evolution

How have organisms changed over time? The next day, Ms. L gives each group a different stack of fossil cards that have of an evolutionary progression of different species, but she has shuffled them into a random order. Students use detailed observations of the animal anatomy to place the organisms in the order in which they evolved, noting how the different species ***change over time*** (*MS-LS4-1*). Students then identify features that remain ***constant*** throughout the entire evolutionary sequence (*MS-LS4-2*). Ms. L then gives them a new fossil and has them **construct an argument** that supports or refutes the idea that this new fossil belongs in the evolutionary sequence in their cards. What is most amazing about this example is that all three different marine mammal categories, whales, dolphins, and manatees have similar adaptations to their marine environment. Ms. L then has the students to compare the oldest fossil in each sequence and asks them, “Did all of these organisms originate from a common marine ancestor?” The answer is no. They all independently adapted to marine environments, a fantastic example of convergent evolution. Ms. L assigns them homework to read more about other examples of convergent evolution.

Day 6: Adaptations and evolution

Ms. L reminds the students that different organisms are adapted to live in different environments, and that many of these adaptations are at the individual cell level. Ms. L explains one cellular adaptation of marine mammals like the ones they have been studying. Cells depend on diffusion ***caused*** by concentration differences between inside and outside of the cell to exchange many atoms across their cell membranes (*MS-LS1-2*). The body ***system*** includes organs such as the kidney whose role is to maintain the optimum concentration of salt and other materials within the system to ensure that every cell in their body is surrounded by a fluid with an optimal concentration (*MS-LS1-3*). Kidneys have specific ***structures*** that help them accomplish this ***function***, including a loop of a tissue called 'Henle' that helps concentrate sodium and other ions in the urine and retain fresh water in the body. Animals living in saltwater require more efficient kidney ***systems***, and there is **evidence** that one way they accomplish this is with longer Henle loops than their freshwater counterparts. Like all body parts, there are slight variations from individual to individual in the length of this tube. Ms. L gives students data about the length of Henle tubes in a set of organisms and asks them to **apply their model** of sexual reproduction to play 'matchmaker.' They need to select the two individuals that are most likely to produce offspring that will survive if the ocean becomes slightly more salty (*MS-LS3-2*). For homework, she assigns students to write a paragraph **explaining** how sexual reproduction enabled freshwater ancestors of whales to evolve so that modern whales can now live in saltwater (*MS-LS4-4*). Their **explanation** should also consider the role that mutations may have played in speeding up and/or slowing down this process (*MS-LS3-1*). She also invites her students to consider the fact that all three of the marine mammal types they have been studying (whales, manatees, and seals) must have independently evolved more efficient kidneys to deal with the salt water.

Days 7-8: Connecting changes in environment to evolutionary changes

Ms. L is very excited because the students are finally ready to put together all these pieces of information to create an evolutionary story showing the interaction of all these marine organisms. She demonstrates how students will construct a timeline to **communicate** when whales, manatees, seals, and sharks evolved and when they transitioned from fresh water (for the marine mammals). She instructs them to depict the relative abundance of each type of organism during different time periods (From Day 1) and how the temperature of the environment changed over time (from Days 3-4). They will need to draw on the data from the whole class spreadsheets collected by their own group and the other groups in the class. Ms. L emphasizes that science is a human endeavor that depends on collaboration. Students identify many times when changes in climate seem to cause changes in the diversity of all four types of animals. There are also inter-relations between the different animal types that relate to their predator-prey relationships. Students' timelines reveal several key features: 1) Manatees and whales left land around the same time during a period when the temperature were warming; 2) Shortly after the marine mammals evolved, shark populations expanded; 3) Whales and manatees both had large expansions in their diversity around the same time as seals first evolved; 3) The diversity of sharks drops dramatically as climate cools. Students **analyze the data** depicted on the timeline and identify some of these ***patterns*** of existence, diversity, and extinction (*MS-LS4-1; EP&C III*). Ms. L then asks students to choose one of these events and **construct an argument** that the ***change*** in the environment would have ***caused*** the growth of individual organisms (*MS-LS1-5*) and ***caused*** changes in the populations of each species that existed at the time (*MS-LS2-4*).

Day 9: Human impacts

Ms. L tells students that today they will fast-forward to historical times to examine the fate of one specific species of manatee. Students review videos and Internet resources to **obtain information** about the Steller's sea cow, finding that it was first discovered in the Bering Sea in 1741, and is the largest manatee species known (growing up to 9 meters – nearly three times the size of Florida's well known manatees). It is also one of the few manatees that can withstand cold water. When explorers first encountered it, it was abundant but only found in a few isolated pockets around uninhabited islands off the far west tip of the Aleutian Islands close to Russia. Within 27 years after it was first discovered by Europeans, it was hunted to extinction. It is the last branch on part of the 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. Scientists speculate that the rapid advance of human hunting in the last 10,000 years may have contributed to their demise (an impact of a technology on the natural wo**rld** that parallels the debate about the cause of the extinction of the wooly mammoth). The fact that Steller's sea cows were so abundant around the one island with no known population of humans certainly supports that theory. Students collect **evidence** and engage in a debate about whether early humans, European explorers, or natural climate change were most responsible for their extinction (*MS-LS2-4; EP&C II*).

Day 10: Human solutions

Ms. L tells students that in a few years they will be in high school. In their high school science courses, they will explore the effect of modern-day climate change on ecosystems, which might explore the future outlook for marine mammals in light of changing global temperatures and ocean circulation ***patterns***. Ms. L tells the students that they will finish this instructional segment evaluating competing design solutions for maintaining biodiversity in marine mammal populations (*MS-LS2-5*). She asks her 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. They choose the problem related to humpback whales. She presents teams with handouts summarizing the problem and one of several different alternatives and asks them to create a presentation **communicating** the key elements of the plan. The students will continue this activity next week.

Performance Expectations		
MS-LS1-2, MS-LS1-3, MS-LS1-5, MS-LS2-2, MS-LS2-3, MS-LS2-4, MS-LS2-5, MS-LS3-1, MS-LS3-2, MS-LS4-1, MS-LS4-2, MS-LS4-4		
Science and engineering practices	**Disciplinary core ideas** LS1A Structure and	**Cross cutting concepts** Patterns; Cause and Effect;

Analyze and interpret data; Obtain, Evaluate, and Communicate Information	Function; LS2C Ecosystem Dynamics, Functioning, and Resilience; LS4A Evidence of Common Ancestry; LS4B Natural Selection; LS4C Adaptation; LS4D Biodiversity and Humans; ESS1C The History of ESS2D Weather and Climate; ESS2E Biogeology; ESS3D Global Climate Change	Stability and Change
Connections to the CA CCSSM: 7.RP.1, 7.RP.2, 7.RP.3, 7.SP.1, 7.SP.2, 7.SP.3, 7.SP.4, 8.SP.1		
Connections to CA CCSS for ELA/Literacy: RST.6-8.1, 2, 7; WHST.6–8.7; SL.7.4		
Connection to CA ELD Standards: ELD.PI.6a, 6b, 11a,		

Connections to the CA EP&Cs:

Principle II. 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 III. Natural systems proceed through cycles that humans depend upon, benefit from and can alter.
Principle V: Decisions affecting resources and natural systems are based on a wide range of considerations and decision-making processes.

Vignette Debrief

As the culmination of the entire course, this vignette tries to establish the links between a large number of DCIs through a series of **investigations** about marine mammals. The vignette itself is too brief to illustrate all of these connections, so the description of each day may sound disconnected in the written narrative above. The implementation of the lesson should try to emphasize these connections. For example, evolution in kidney ***structure*** was in response to direct environmental pressures revealed in the temperature data on days 3-4. These adaptations allowed organisms to shift from freshwater environments to food-rich saltwater environments, a process recorded in the salinity data on days 3-4. The loss of megatooth sharks as the climate warmed may parallel some of the pressures felt by the Steller's sea cow described on Day 9. These relationships all reflect responses to **changes** in environmental conditions related to global climate change (*ESS3.D*). If teachers feel that some of these connections are too complicated, they could extract smaller lessons from this activity sequence.

The basic premise of this vignette is to reproduce a number of scientific practices starting with **data analysis and interpretation** and moving towards **explanations, arguments**, and communications products. Students **analyze** fossil discovery data on day 1 as they quantify biodveristy, **interpret** fossils to determine the eating habits of each organism during day 2 and **analyze data** when they look at chemical signatures during days 3-4, Note that this vignette has very little data collection, illustrating the shift in the *CA NGSS* from simply receiving information or doing hands-on activities to an emphasis on making sense of data and **communicating** it. This communication takes the form of presentations during the lesson hook, drawings during days 3-4, and a presentation again on Day 10. They do more than simply share information, they must support positions as they **construct arguments supported by evidence** in a written form on day 5 when they establish an evolutionary link between different organisms based on structural similarities and in a debate on day 9 when they try to convince others about the root cause of the demise of the Stellar's sea cow.

Resources for the Vignette

About the evolutionary relationship between sharks and marine mammals: http://www.scirp.org/journal/PaperInformation.aspx?paperID=39487

About kidney functions in marine mammals: Kenney, R. 2001. "How Can Sea Mammals Drink Saltwater?" Scientific American. http://www.scientificamerican.com/article/how-can-sea-mammals-drink/ (accessed August 5, 2015).

Newsome, S., M. Clementz, and P. Koch. 2010. "Using Stable Isotope Biogeochemistry to Study Marine Mammal Ecology." *Marine Mammal Science* 26 (3): 509–572. http://onlinelibrary.wiley.com/doi/10.1111/j.1748-7692.2009.00354.x/full (accessed October 27, 2015).

Turvey, S.T., and C.L. Risley. 2006. "Modelling the Extinction of Steller's Sea Cow." Biology Letters 2 (1): 94–97. https://www.ncbi.nlm.nih.gov/pmc/articles/PMC1617197/ (accessed August 5, 2015).

About the Steller's sea cow and its extinction:

Whitmore, Jr., F.C., and L.M. Gard, Jr. 1977. "Steller's Sea Cow *(Hydrodamalis gigas)* of Late Pleistocene Age from Amchitka, Aleutian Islands, Alaska." Geological Survey Professional Paper 1036. Washington, DC: United States Government Printing Office. http://pubs.usgs.gov/pp/1036/report.pdf (accessed August 5, 2015).