Chapter 6
Discipline Specific Course Model for Grades Six Through Eight

2016 Science Framework

FOR CALIFORNIA PUBLIC SCHOOLS
Kindergarten Through Grade Twelve

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Items in this document that relate to crosscutting concepts are highlighted in green and followed by the abbreviation CCC in brackets, **[CCC]**, with a number corresponding to the concept. The same items that correspond to the science and engineering practices are highlighted in blue and followed by the abbreviation SEP in brackets, **[SEP]**, with a number corresponding to the practice.

The Web links in this document have been replaced with links that redirect the reader to a California Department of Education (CDE) Web page containing the actual Web addresses and short descriptions. Here the reader can access the Web page referenced in the text. This approach allows CDE to ensure the links remain current.

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Introduction to Grades Six Through Eight

The California Next Generation Science Standards (CA NGSS) define two possible progressions for the middle grades: the Preferred Integrated Course Model, which interweaves science disciplines in a developmentally appropriate progression and the Discipline Specific Model, in which each grade level focuses in depth on a different science discipline.

The two models differ only in the sequence; every student is expected to meet each middle grade performance expectation (PE) by the end of the grade. Sequence here refers to the course (grade six, seven, or eight) in which a particular performance expectation is mastered. This framework makes no requirements about the order in which performance expectations are taught within a given year. (The examples of course sequences in this framework describe possible storylines but they are not the only ones). Table 6.1 shows a comparison of which **disciplinary core ideas (DCIs)** are emphasized in the performance expectations required at each grade level in the two models. For both models, all eight **science and engineering practices (SEPs)** are developed and all seven **crosscutting concepts (CCCs)** are highlighted at some point during the course of every year (though each lesson may only focus on one or two and each year may have a slight emphasis on a particular subset).

As districts consider the progression that works best for their resources and local context, they should be aware of the historical context, rationale for each middle grade model, and potential limitations of each. This chapter outlines some of those issues.

Historical Background

The CA NGSS are aligned to the nationally developed NGSS. This nationwide effort identified specific performance expectations for kindergarten through grade five but presented middle grade performance expectations in a grade span of grades six through eight. Because California adopts instructional materials for kindergarten through grade eight on a statewide basis, performance expectations had to be placed at specific grade levels—grades six, seven, and eight. Therefore, the State Superintendent of Public Instruction (SSPI) recommended that the State Board of Education

(SBE) adopt specific placement of the standards for the middle grades at each grade level.

The SSPI convened the Science Expert Panel comprised of kindergarten through grade twelve teachers, scientists, educators, business and industry representatives, and informal science educators. This panel evaluated a range of options for the appropriate organization and sequence of the performance expectations. The public provided feedback to the Science Expert Panel via three open forums and a webinar. The Science Expert Panel concluded that an integrated model for grades six through eight would be the most effective model for optimizing student learning of CA NGSS; the panel subsequently reviewed the national model that had been developed by Achieve, and adapted it to better align with California's needs and recommended only the Preferred Integrated Model to the SBE. The full list of events that led to the adoption of the Preferred Integrated Course Model is described at the California Department of Education (CDE) Web site at https://www.cde.ca.gov/ci/sc/cf/ch6.asp#link1. On November 6, 2013, the SBE unanimously passed the following motion: "To adopt the CDE staff recommendation that the SBE adopt the proposed integrated model as the preferred model for middle grades (six, seven, and eight) science instruction, and requested that the CDE reconvene the Science Expert Panel to develop as an alternative, a discipline specific model based upon the domain-specific model outlined by Achieve in the NGSS appendix K." In December 2014, the Science Expert Panel reconvened to develop a discipline specific model of the CA NGSS.

The Board's intent in their November 2013 action was to identify one integrated model in California for grades six through eight that was preferred by both the SSPI and the SBE and one discipline specific model as an alternative.

Table 6.1. Comparison of When DCIs are Primarily Addressed in the Two Models for Middle Grades (x means included)

Blank		DISCIPLINARY CORE IDEA	SUBTOPIC	Preferred Integrated			Discipline Specific		
				6	7	8	6	7	8
EARTH AND SPACE SCIENCE	1	Earth's Place in the Universe	Universe, Stars, Solar System			x	x		
			History of Planet Earth			x	x		
	2	Earth Systems	Water Cycle, Weather, Climate	x			x		
			Rock Cycle, Plate Tectonics		x		x		
	3	Earth and Human Activity	Global Climate Change Causes	x			x		
			Resources Availability		x		x		
			Natural Hazards		x		x		
			Resource Consumption			x	x		
LIFE SCIENCE	1	From Molecules to Organisms: Structures and Processes	Cells & Body Systems	x				x	
			Photosynthesis and Respiration		x			x	
	2	Ecosystems: Interactions, Energy, and Dynamics			x			x	
	3	Heredity: Inheritance and Variation of Traits	Sexual Versus Asexual Reproduction	x				x	
			Mutations			x		x	
	4	Biological Evolution: Unity and Diversity				x		x	
PHYSICAL SCIENCE	1	Matter and Its Interactions	Atoms, Molecules, States of Matter		x				x
			Chemical Reactions		x				x
	2	Motion and Stability: Forces and Interactions				x			x
	3	Energy	Kinetic Energy and Collisions	x		x			x
		Blank	Heat and Heat Flow	x					x
		Blank	Potential Energies & Gravity			x			x
	4	Waves and Their Applications in Technologies for Information Transfer				x			x
ETS		Every course includes integrations with ETS		x	x	x	x	x	x
SEP		Every course utilizes all eight SEPs		x	x	x	x	x	x
CCC		Every course highlights all seven CCCs		x	x	x	x	x	x

Learning from Other Successful Countries

The Science Expert Panel preferred the Integrated Model based in part on evidence of the performance of other countries and provinces. Analyzing the science standards of ten countries that produced significant scientific innovations and scored highly on international benchmark tests, Achieve (2010) found that all ten of these countries used an integrated science model through the middle grades, and seven of the ten countries kept science integrated all the way through grade ten. Summarizing qualitative trends from their analysis, Achieve (2010) concluded that, "Standards based around 'unifying ideas' for Primary through Lower Secondary seem to confer more benefits than a discipline-based structure." This statement articulates part of the rationale behind the seven crosscutting concepts from the CA NGSS that link together all disciplines of science and engineering. Given that these crosscutting concepts cannot be understood within a single context or even a single scientific discipline, the SBE adopted the integrated model as the preferred model.

Matching University Training with Middle Grades Teaching

Many science teachers receive a university degree in a specific discipline of science within a specific university department (i.e., biology, chemistry, physics, geology), so they likely have stronger content knowledge in that discipline. Linda Darling-Hammond (2000) summarized the research on the weak but measurable link between a teacher's subject matter knowledge and student achievement by saying that, "the findings are not as strong and consistent as one might suppose … [perhaps] because subject matter knowledge is a positive influence up to some level of basic competence in the subject but is less important thereafter." Teachers with a general science certification teaching middle grades exceed that basic level of competence in all sciences and should be able to teach effectively in both models. Perhaps the pedagogical content knowledge (PCK) learned from years of experience teaching a specific subject area is more important than university learning within a discipline. Some of this pedagogical content knowledge is discipline specific such as awareness of specific preconceptions within one's discipline (Sadler et. al. 2013), but much of it relates to science and engineering practices and crosscutting concepts that span all disciplines of science and will transfer fluidly from one course model to the other. It was the judgment of the Science Expert Panel that teachers will remain highly qualified to teach in both the Preferred Integrated and Discipline Specific models.

Sequencing in a Developmentally Based Learning Progression

The CA NGSS is intentionally designed so that students slowly build up knowledge and skills in all three dimensions, addressing more sophisticated challenges or revisiting simple ones at a deeper level as they progress through the grades. Achieve also noted that even in exemplary standards, most countries paid insufficient attention to developmental learning progressions. They suggest "developers of new standards will need to tease out the prerequisite knowledge and skills, to provide a conceptual basis for understanding (Achieve 2010)." Appendix E of the CA NGSS spells out the developmental progression of ideas within each discipline, but there is also prerequisite knowledge from one domain that is applied in a separate domain within the CA NGSS. For example, it is difficult to fully understand photosynthesis, respiration, and how matter is rearranged as organisms consume other organisms without a firm understanding of atoms, molecules, and chemical reactions. In the Discipline Specific Model, the life science disciplinary core ideas appear in grade seven but core ideas about the nature of matter are not introduced until grade eight. The Preferred Integrated Course Model was arranged with this sequencing in mind, and the prerequisite knowledge is often placed within the same course so that it can be taught alongside the application. Successful implementation of the Discipline Specific Model will require some remediation of the missing prerequisite knowledge, and the specific courses in this framework identify when these situations occur in each course.

Introduction to the Discipline Specific Course Model for Grades Six Through Eight

The Discipline Specific Course Model allows students to focus in depth on specific subdisciplines of science during each year of their middle grades education. This model organizes the courses for grades six through eight into content-specific courses that match the three science domains:

- Grade Six: Earth and Space Sciences (ESS)
- Grade Seven: Life Science (LS)
- Grade Eight: Physical Science (PS)

Each course addresses only the performance expectations from its designated disciplinary domain (Earth and space science, life science, or physical science), though successful demonstration of these performance expectations often requires students to apply their understanding of the other domains. These courses are aligned with the cognitive demands of the California Common Core State Standards (CA CCSS) with a few significant exceptions discussed below.

Purpose and Limitations of this Example Course

The CA NGSS do not specify which phenomena to explore or the order to address topics because phenomena need to be relevant to the students that live in each community and should flow in an authentic manner. This chapter illustrates one possible set of phenomena that will help students achieve the CA NGSS performance expectations. The phenomena chosen for this statewide document will not be ideal for every classroom in a state as large and diverse as California. Teachers are therefore encouraged to select phenomena that will engage their students and use this chapter's examples as inspiration for designing their own instructional sequences.

In this chapter's examples, each year is divided into instructional segments (IS) centered on questions about observations of a specific phenomenon. Different phenomena require different amounts of investigation to explore and understand, so each instructional segment should take a different fraction of the school year. As students achieve the performance expectations within each instructional segment, they uncover **disciplinary core ideas (DCIs)** from the different disciplines of science (physical science, life science, and Earth and space science) and engineering. Students engage in multiple practices in each instructional segment, not only those explicitly indicated in the performance expectations. Students also focus on one or two **crosscutting concepts (CCCs)** as tools to make sense of their observations and investigations; the CCCs are recurring themes in all disciplines of science and engineering and help tie these seemingly disparate domains together. The science and engineering practices, disciplinary core ideas, and crosscutting concepts grow in sophistication and complexity throughout the K–12 sequence. While this chapter calls out examples of the three dimensions in the text using color coding, each element should be interpreted with this grade-appropriate complexity in mind (appendix 1 of this framework clarifies the expectations at each grade span in the developmental progression). Engineering, technology, and application of science (ETS) are a fundamental part of each course. As students explore their environment during this grade span, they develop their growing understanding of the interconnections and interdependence of Earth's natural systems and human social systems as outlined in California's Environmental Principles and Concepts (EP&Cs). All three of the CA NGSS dimensions and the EP&Cs will prepare students to make decisions about California's future and become sources of innovative solutions to the problems the state may face in the future.

Sequencing of Courses Within the Discipline Specific Model

The arrangement of the courses within the Discipline Specific Course Model provides opportunities, but also many challenges, some arising from the implementation of the Earth and space science (ESS) in grade six. The majority of research in Earth and space science is interdisciplinary in nature and is often organized into the categories of astrophysics, geophysics, geochemistry, and geobiology. Placing Earth and space science in grade six limits the ability to make rich or advanced connections to these other disciplines. As a result, **models [SEP-2]** of Earth **systems [CCC-4]** developed in the discipline specific presentation of middle-grade courses cannot be as deep, leaving students at a disadvantage when they face Earth and space science performance expectations on both middle grades and high school assessments. In order to continue to **develop models [SEP-2]** of the Earth system throughout the middle grades, teachers can use Earth and space science phenomenon introduced in grade six to motivate study of specific mechanisms in physical and life science during grades seven and eight. Teachers in all middle grades will need continued professional learning in Earth and space science to make these connections in their classrooms. Returning to Earth and space science concepts throughout all grades also helps alleviate another sequencing challenge of the Discipline Specific Model: Earth and space science involves some of the largest **scales [CCC-3]** of space and time (the size of the universe and the age of the Earth), but students do not learn the corresponding mathematical representations of numbers using scientific notation until grade eight in California's CCSS. Ways to confront these challenges are spelled out within the relevant instructional segment of each course.

The course titles in CA NGSS are similar to the California 1998 Science Content Standards (1998 Standards), but some notable changes to the sequencing of disciplinary content include the following:

- The new CA NGSS Discipline Specific Course Model may initially appear less interdisciplinary than the previous 1998 Standards. Performance expectations related to topics at the intersection between disciplines (such as ecology and organic chemistry) were once addressed in two different courses (grades six and seven, respectively, under the 1998 Standards). They are now concentrated in their respective discipline specific course. Effort has been made in this framework to illustrate possibilities for strong connections between disciplines even within this model, but teachers will need time for collaboration and guidance to ensure that they actually implement strong connections between grade levels at each school site.
- The discussion of the Earth in the solar system was included in grade eight under the 1998 Standards. In the CA NGSS Discipline Specific Course Model, the same topic (ESS1: Earth's Place in the Universe) is now introduced in grade six. In this context, educators at this grade level will have to make significant accommodations to their instruction as the mathematical ability of grade six students is not sufficiently

developed for teachers to emphasize gravity and then describe it as the force that holds together the solar system and the Milky Way galaxy, and controls the orbital motion of all objects (MS-ESS1-2). Therefore, the development and use of scientific **models [SEP-2]** related to these core ideas (MS-ESS1-1 and MS-ESS1-2) will only be described in qualitative terms; similarly, the **scale [CCC-3]** and **analysis of data [SEP-4]** related to the spatial and temporal dimension of the solar system and the Earth (MS-ESS1-3 and MS-ESS1-4) will only be partially explained. This is a limitation of the discipline specific middle grades sequence.

- In grade eight, the disciplinary core idea associated with waves and their applications in technologies for information transfer (PS4) partially overlaps with the content topics presented in grade seven in the 1998 Standards. In CA NGSS the core idea is extended further to include mathematical representation of waves (MS-PS4-1) and the qualitative analysis of digital and analog signals (MS-PS4-3).
- Many of the details related to disciplinary core ideas that were expected under the 1998 Standards are now addressed in high school rather than middle grades. Some examples include the following:
    - Details about the fossil record and radioactive dating have been moved to high school, while in grade seven more emphasis has been added to comparative anatomy (fossil evidence is still used, but the details of how that evidence was collected are saved until high school).
    - The internal structure of the atom and the periodic table have been moved to high school, and in grade eight more emphasis has been added to **developing models [SEP-2]** of how atoms rearrange during chemical reactions and how mass is conserved within a chemical system.

Structure of Each Course

The Discipline Specific Course Model authorized by the State Board of Education defines which performance expectations should be addressed during each grade level, but it does not dictate or prescribe the sequence of instruction within each course. This chapter outlines one possible organization of the performance expectations into instructional segments to create a coherent storyline. Teachers are not bound in any way to this example, but the goal is to provide guidance as teachers develop their own curriculum to suit their local circumstances.

The section for each grade-level course is broken down into four or five large instructional segments. Each of these instructional segments addresses more than one performance expectation, and the bundling of performance expectations into a single instructional segment is designed to build connected knowledge. Within any given course, the sequence of the instructional segments is also important as certain ideas and performance expectations are developed sequentially across multiple instructional segments. It is not appropriate in this context to ask which performance expectation is the focus of a particular lesson. Rather it is important to focus on which performance expectation is developed across the full instructional segment, bearing in mind that aspects of multiple performance expectations may be included. In some cases, the understanding needed to meet a single performance expectation may be addressed across more than one instructional segment because full understanding occurs only as students apply that understanding in novel situations.

In addition, in the domain-specific content for each course, the Science Expert Panel also specified disciplinary core ideas (DCIs) from the other science domains that need to be introduced to facilitate students' full understanding of each performance expectation. These disciplinary core ideas are indicated in some instructional segments with the designation "Other Necessary DCIs." For example, the core ideas associated with **conservation of energy [CCC-5]** and energy transfer (PS3.B) and components related to the concept of electromagnetic radiation (PS4.B) are necessary for students to understand the role of water cycling in Earth's surface processes (ESS2.C) or explain phenomena associated with weather and climate (ESS2.D).

Essential Shifts in the CA NGSS

The 1998 Science Standards were written at a low cognitive level ("Students know … "), with some attention paid to the process of science as a separate set of Investigation and Inquiry standards. In the CA NGSS, every performance expectation is "three-dimensional," meaning that it requires proficiency in science and engineering practices along with a deep understanding of disciplinary ideas and the ability to relate these ideas to crosscutting concepts that are common across the disciplines. As a result, instructional materials and strategies must shift. During the initial adoption of CA NGSS, districts adopting the Discipline Specific Course Model must be particularly attentive to these shifts because this model has the appearance on the surface of being quite similar to the 1998 Standards. While the core ideas are similar in scope and organization, the tasks students will be required to perform to demonstrate mastery of each performance expectation are much broader in scope and at a higher cognitive level. This growth is enabled by the CA NGSS vision of a strong developmental progression in which students spiral through the curriculum, revisiting ideas in increasing complexity and detail.

Some have described the CA NGSS as having "more depth and less breadth," but that may not be a precise description. In many of the instructional segments of these middle grades courses, the CA NGSS focus is shifted to richer reasoning and more opportunities to apply knowledge, so students may be expected to know *fewer* details about phenomena than they did in the 1998 Standards. These details are not missing from CA NGSS, they have just been moved from the middle grades to a more developmentally appropriate position in high school. The level of detail builds up slowly. As teachers, we often complain that our students do not remember concepts from year-to-year, but perhaps this forgetting is a consequence of our desire to provide self-contained instructional segments that answer all the questions raised by the time of the test, just like a 30-minute episode of a sitcom on television. The CA NGSS is more like a long-running drama series with a number of interwoven storylines developing over years. To accomplish this slow build up, teachers will likely have to make major modifications to some of their favorite lessons or even leave them behind because those lessons focus on providing all the answers, with students expected to memorize the details and jargon that represent the current state of understanding of science by scientists. The time they used to spend on those parts of the lessons will instead be invested in asking students to apply their mental **models [SEP-2]** of the physical world, like scientists grappling with new situations, and to talk like scientists not by using scientific words but by being able to provide **evidence [SEP-7]** to support their claims. Districts and schools will need to invest in significant resources for professional development to help teachers make these modifications in supportive, collaborative environments.

Grade Six Discipline Specific Course Model: Earth and Space Science

From the introduction to the Middle Grades Earth and Space Sciences Standards in the Next Generation Science Standards (NGSS):

> Students in middle school develop understanding of a wide range of topics in Earth and space science (ESS) that build upon science concepts from elementary school through more advanced content, practice, and crosscutting themes. There are six ESS standard topics in middle school: Space Systems, History of Earth, Earth's Interior Systems, Earth's Surface Systems, Weather and Climate, and Human Impacts. The content of the performance expectations are based on current community-based geoscience literacy efforts such as the Earth Science Literacy Principles (Wysession et al. 2012), and is presented with a greater emphasis on an Earth Systems Science approach. The performance expectations strongly reflect the many societally relevant aspects of ESS (resources, hazards, environmental impacts) as well as related connections to engineering and technology. While the performance expectations shown in middle school ESS couple particular practices with specific disciplinary core ideas, instructional decisions should include use of many practices that lead to the performance expectations. (NGSS Lead States 2013a)

A major emphasis of this course is to teach the principle of interacting components of Earth systems. According to the *National Science Education Standards*, "The natural and designed world is complex; it is too large and complicated to investigate and comprehend all at once. Scientists and students learn to define small portions for the convenience of investigation. The units of **investigations [SEP-3]** can be referred to as ***systems* [CCC-4]**. A system is an organized group of related objects or components that form a whole. Systems can consist, for example, of organisms, machines, fundamental particles, galaxies, ideas, and numbers. Systems have boundaries, components, resources, flow, and feedback" (National Research Council [NRC] 1996).

Although any real **system [CCC-4]** smaller than the entire universe interacts with and is dependent on other (external) systems, it is often useful to conceptually isolate a single system for study. To do this, scientists and engineers imagine an artificial boundary between the system in question and everything else. Then they examine the system in detail while treating the effects of things outside the boundary as either forces acting on the system or flows of matter and energy across it—for example, the gravitational force, due to Earth, on a book lying on a table or the carbon dioxide expelled by an organism. Consideration of flows into and out of the system is a crucial element of system design. In the laboratory or even in field research, the extent to which a system under study can be physically isolated or external conditions controlled is an important element of the design of an investigation and interpretation of results.

Often, the parts of a **system [CCC-4]** are interdependent—each one depends on or supports the functioning of the system's other parts. Yet the properties and behavior of the whole system can be very different from those of any of its parts, and large systems may have emergent properties, such as the shape of a tree, that cannot be predicted in detail from knowledge about the components and their interactions. Things viewed as subsystems at one **scale [CCC-3]** may themselves be viewed as whole systems at a smaller scale. For example, the circulatory system can be seen as an entity in itself or as a subsystem of the entire human body; a molecule can be studied as a stable configuration of atoms but also as a subsystem of a cell or a gas.

An explicit model of a system under study can be a useful tool not only for gaining understanding of the system but also for conveying it to others. **Models [SEP-2]** of a system can range in complexity from a list of a sequence of events to a simple sketch to detailed computer simulations or functioning prototypes. Table 6.2 shows the systems identified in the Earth and space sciences course.

Table 6.2. Earth Systems

EARTH SYSTEMS	EARTH'S MATERIALS
Geosphere	**Rocks, minerals, and landforms** at Earth's surface and in its interior, including soil, sediment, and molten rocks
Hydrosphere	**Water**, including ocean water, groundwater, glaciers and ice caps, rivers, lakes, etc.
Atmosphere	**Gases** surrounding the Earth (i.e., our air)
Biosphere	**Living organisms**, including humans
Anthrosphere	**Humanity** and all of its creations (This sphere is not specifically mentioned in the NRC Framework [2012] because it is primarily part of the biosphere. Separating this sphere out emphasizes the significant influences humans have on the rest of Earth's systems and is consistent with the Environmental Principles and Concepts [EP&Cs] that are part of the CA NGSS.)

Opportunities for ELA/ELD Connections

During grade six, students investigate and develop their understanding of Earth's systems (geosphere, hydrosphere, atmosphere, biosphere, and anthrosphere) and how each of these systems has components that intersect with each other. Each system's understanding could be developed through students using concept maps, word webs, or graphic organizer (e.g., Frayer Model) to identify corresponding types, examples and non-examples, definitions, illustrations of concept, essential (or non-essential) characteristics, and meanings of word parts (prefix/suffix) as they engage in academic discourse through their investigations. These strategies help all learners develop effective ways to express their understanding by using content vocabulary as they acquire content knowledge.

CA CCSS for ELA/Literacy Standards: L.6–8.4; RST.6–8.4

CA ELD Standards: ELD.PI.6–8.6

Table 6.3 provides a schematic organization of the instructional segments and the primary Earth systems discussed in each. The CA NGSS has titled this domain Earth and Space Sciences to emphasize that while Earth exists as a singular planet, its systems are strongly influenced by interactions with the broader universe.

Table 6.3. Illustration of How Different Instructional Segments Relate to Earth's Systems

INSTRUCTIONAL SEGMENT	ATMOS.	HYDRO.	GEO.	BIO.	ANTHRO.
IS1: Earth's Place in the Solar System	n/a	n/a	x	n/a	n/a
IS2: Atmosphere: Flows of Energy	x	x	n/a	n/a	x
IS3: Atmosphere/Hydrosphere: Cycles of Matter	x	x	n/a	n/a	x
IS4: Geosphere, External Processes	n/a	x	x	x	x
IS5: Geosphere: Internal Processes	n/a	n/a	x	n/a	x

Each of these **systems [CCC-4]** has components that interact with each other. Modeling the appropriate relationship between these components is at the center of each instructional segment in this course. Further, each system interacts with the others, originating the processes that shape our Earth.

In grade six, students apply and expand their prior understanding of these systems from their science experiences in grade five. Thus, along with grade-appropriate proficiency in using all the science and engineering practices and crosscutting concepts, students develop an understanding of Earth's major systems (5-ESS2-1; ESS2.A) aided by concepts in physical science (PS1: Structure and properties of matter; PS3.D: Energy in chemical processes and everyday life) and life science (LS2.B: Cycles of matter and energy transfer in ecosystems). Table 6.4 shows the disciplinary core ideas (DCIs) that students in grade six have experienced in grade five or earlier grades. Grade six teachers will have to probe the level of familiarity and mastery that their students have as they enter their grade six science classes.

Table 6.4. Disciplinary Core Ideas and Component Ideas From Grade Five

DCI	COMPONENT IDEA(S) OF THE DCI THAT WERE COVERED IN GRADE FIVE (IF ANY)
PS1: Matter and Its Interactions	PS1.A: Structure and Properties of Matter PS1.B: Chemical Reactions
PS2: Motion and Stability: Forces and Interactions	PS2.B: Types of Interactions (Gravitational Force)
PS3: Energy	PS3.D: Energy in Chemical Processes and Everyday Life
PS4: Waves and Their Applications in Technologies for Information Transfer	*(Not addressed in grade five. Previously addressed in grade four.)*
LS1: From Molecules to Organisms: Structures and Processes	LS1.C: Organization of Matter and Energy Flow in Organisms
LS2: Ecosystems: Interactions, Energy, and Dynamics	LS2.A: Interdependent Relationships in Ecosystems LS2.B: Cycles of Matter and Energy Transfer in Ecosystems
LS3: Heredity: Inheritance and Variation of Traits	*(Not addressed in grade five. Previously addressed in grade three)*
LS4: Biological Evolution: Unity and Diversity	*(Not addressed in grade five. Previously addressed in grade three)*
ESS1: Earth's Place in the Universe	ESS1.A: The Universe and Its Stars ESS1.B: Earth and the Solar System
ESS2: Earth's Systems	ESS2.A: Earth Materials and Systems ESS2.C: The Roles of Water in Earth's Surface Processes
ESS3: Earth and Human Activity	ESS3.C: Human Impacts on Earth Systems
ETS1: Engineering Design	ETS1.A: Defining and Delimiting Engineering Problems ETS1.B: Developing Possible Solutions ETS1.C: Optimizing the Design Solution

Earth and space sciences have much in common with other branches of science, but they also include a unique set of scientific pursuits. Inquiries into the physical sciences (e.g., forces, energy, gravity, magnetism) were conducted in part as a means of understanding the size, age, structure, composition, and behavior of Earth, Sun, and Moon; physics and chemistry later developed as separate disciplines. The life sciences likewise are partially rooted in Earth science, as Earth remains the only example of a biologically active planet, and the fossils found in the geological record are of interest to both life scientists and Earth scientists (LS4). As a result, the majority of research in Earth and space sciences is interdisciplinary in nature and is often organized into the categories of astrophysics, geophysics, geochemistry, and geobiology. However, the underlying traditional discipline of geology, involving the mapping and interpretation of rocks, remains a cornerstone of Earth and space sciences.

When adapting the CA NGSS, teachers have great opportunities to make the subject matter regionally relevant. Coastal communities may wish to focus on different spheres of interaction than farming communities in California's Central Valley. Despite these regional differences, large portions of California's students live in dense urban communities where ties to the natural environment are less apparent. When describing possible directions for meeting the performance expectations, this framework makes efforts to identify directions that will be most relevant for urban youth and mentions specific activities relevant to urban geoscience. Table 6.5 shows a sequence of five possible phenomenon-based instructional segments in a discipline specific grade six course.

Table 6.5. Overview of Instructional Segments for Discipline Specific Grade Six

	**1 Earth's Place in the Solar System** Students develop a model of the Earth-Sun-Moon system that allows them to explain patterns they identified in elementary school. They place this model in the context of the scale of the entire solar system and describe the role gravity plays to keep it together.
	**2 Atmosphere: Flows of Energy** Students develop a simple model that explains how energy flow into the Earth system explains climates in different parts of the globe. They ask questions about how humans are disrupting this natural energy balance.
	**3 Atmosphere/ Hydrosphere: Cycles of Matter** Students use data to show how the movement and interaction of air masses cause weather changes. Students then relate weather processes to a model of the water cycle, including the energy sources that drive it.
	**4 Geosphere: External Processes** Students explain how air and water can shape and sculpt the landscape. They model the movement and changes of rocks over Earth's history and in the present day as landslide hazards that can be forecasted and mitigated.
	**5 Geosphere: Internal Processes** Students use the shape of landforms at the surface as evidence that plates have moved in the past. They explain how these movements helped distribute resources like minerals and water and relate them to earthquake hazards.

Sources: Okada 2005; Bertola 2011; Oravecz 2013; Miller 2008; Kuring 2011

IS1 Discipline Specific Grade Six Instructional Segment 1: Earth's Place in the Solar System

People throughout history have been fascinated by the heavens. Each ancient civilization noticed **patterns [CCC-1]** in the movement of the Sun, Moon, and stars. Students themselves have recognized and described patterns of motion in the sky in earlier grades (1-ESS1-1, 5-ESS1-2). Teachers can begin by reviewing those patterns, perhaps working with English language arts (ELA) teachers to read stories about the way in which ancient civilizations used the patterns in the stars to predict their motion. In this instructional segment (IS), students construct **models [SEP-2]** that explain the size, shape, and timing of these motions. Students should be able to apply these models to qualitatively predict the motions of objects. In high school, they will extend this model by adding quantitative descriptions of the forces that cause the motion. Grade six lays the crucial foundation for that work.

DISCIPLINE SPECIFIC GRADE SIX INSTRUCTIONAL SEGMENT 1: EARTH'S PLACE IN THE SOLAR SYSTEM

Guiding Questions

- What causes the cycles of stars, planets, and moons?
- How can we represent the vastness of the solar system and compare objects as large as planets and moons?

Performance Expectations

Students who demonstrate understanding can do the following:

MS-ESS1-1. Develop and use a model of the Earth–Sun–Moon system to describe the cyclic patterns of lunar phases, eclipses of the Sun and Moon, and seasons. [Clarification Statement: Examples of models can be physical, graphical, or conceptual.]

MS-ESS1-2. Develop and use a model to describe the role of gravity in the motions within galaxies and the solar system. [Clarification Statement: Emphasis for the model is on gravity as the force that holds together the solar system and Milky Way galaxy and controls orbital motions within them. Examples of models can be physical (such as the analogy of distance along a football field or computer visualizations of elliptical orbits) or conceptual (such as mathematical proportions relative to the size of familiar objects such as their school or state).] [*Assessment Boundary: Assessment does not include Kepler's Laws of orbital motion or the apparent retrograde motion of the planets as viewed from Earth.*]

MS-ESS1-3. Analyze and interpret data to determine scale properties of objects in the solar system. [Clarification Statement: Emphasis is on the analysis of data from Earth-based instruments, space-based telescopes, and spacecraft to determine similarities and differences among solar system objects. Examples of scale properties include the sizes of an object's layers (such as crust and atmosphere), surface features (such as volcanoes), and orbital radius. Examples of data include statistical information, drawings and photographs, and models.] [*Assessment Boundary: Assessment does not include recalling facts about properties of the planets and other solar system bodies.*]

DISCIPLINE SPECIFIC GRADE SIX INSTRUCTIONAL SEGMENT 1: EARTH'S PLACE IN THE SOLAR SYSTEM

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

Highlighted Science and Engineering Practices	Highlighted Disciplinary Core Ideas	Highlighted Crosscutting Concepts
[SEP-2] Developing and Using Models [SEP-4] Analyzing and Interpreting Data	ESS1.A: The Universe and Its Stars ESS1.B: Earth and the Solar System *Other Necessary DCI(s):* PS2.B: Types of Interactions	[CCC-1] Patterns [CCC-2] Cause and Effect: Mechanism and Explanation [CCC-3] Scale, Proportion, and Quantity [CCC-4] Systems and System Models

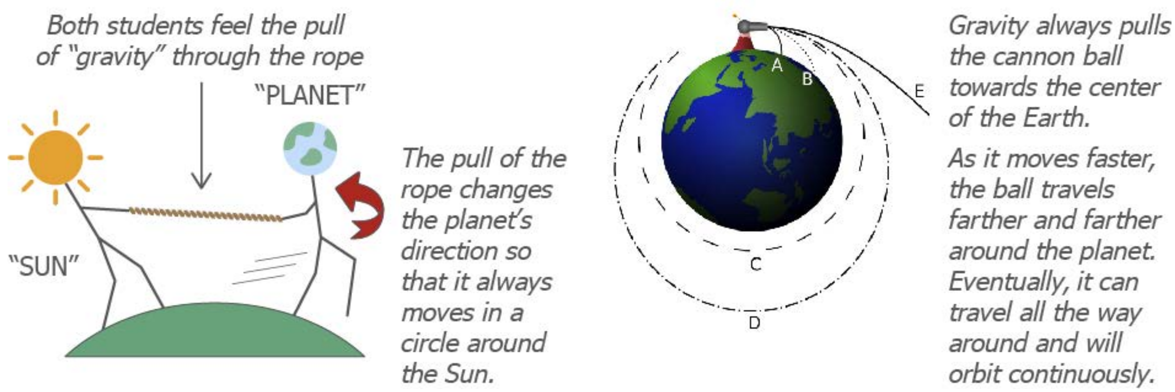
CA CCSS Math Connections: MP.2, MP.4, 6.RP.1, 7.RP.2a–d, 6.EE.6, 7.EE.4a–d

CA CCSS for ELA/Literacy Connections: RST.6–8.1, 7; SL.6.5

CA ELD Connections: ELD.PI.6.6a–b, 9, 10, 11a

Gravity is the driving force that shapes most motion in the universe. In grade three, students investigated gravity as a force that can pull objects downward (3-PS2-1). If that's the case, why doesn't the Moon fall down? (See NASA Ask an Astronomer, "Why doesn't the Moon fall down" accessed at https://www.cde.ca.gov/ci/sc/cf/ch6.asp#link2. How can a force that pulls an object downward give rise to the ordered **patterns [CCC-1]** we see in the movement of the stars in the sky? In this instructional segment, students **develop a model [SEP-2]** of this process (MS-ESS1-2). Essential components of the model are (1) gravity is a force that pulls massive objects toward one another, and (2) celestial objects move in elliptical patterns: planets in the solar system around the Sun and stars in galaxies around the centers of galaxies. Students can illustrate the relationship between these ideas with a rope (left side of figure 6.1). One person stands in the center and holds the rope while the other starts moving away. Once the rope is taut, both people feel the rope tugging them together. The pull of the rope changes the moving person's direction, constantly pulling that person back on course so that he or she moves only in a circular motion. Isaac Newton developed a conceptual model of this with the idea of a cannon shot from a tall mountain at different speeds. Gravity always pulls the cannon ball down, but the direction of down changes constantly (just like the direction of pull from the rope changes constantly as the student runs around the circle). Online interactive simulations of Newton's cannon can help students visualize the model even better.

Figure 6.1. Gravity and Orbiting Objects



Models showing the relationship between gravity and the circular motion of objects in orbits. The left side is a physical model with students representing planets. The right side shows Newton's cannon, a conceptual model illustrated in a diagram. Diagrams by d'Alessio and Brondel 2010.
Long description of Figure 6.1.

The clarification statement for MS-ESS1-2 may cause confusion, because many of the examples pertain to scale models that would help accomplish MS-ESS1-3 but do not explicitly help students understand the role of gravity in these systems. The two performance expectations are intricately connected because gravity and motion help define the shape and scale of recognizable bodies in our solar system. The next section describes some of these relationships.

Opportunities for Mathematics Connections: Solar System Scale

When pondering Earth's place within the solar system, **scale and proportion [CCC-3]** are repeating concepts, and they align well with the **mathematical thinking [SEP-5]** about ratios and proportions from grade six mathematics (CA CCSSM 6.RP.3). NASA has a series of activities on Solar System math (accessed at https://www.cde.ca.gov/ci/sc/cf/ch6.asp#link3) that allows students to **analyze data [SEP-4]** about solar system **scale [CCC-3]** and then build scale **models [SEP-2]**. The activity from day 1 in the vignette below is a related example pertaining to the Moon. Students also can get a tangible sense of the relative scale of the solar system by constructing a scale model on a 100-yard football field. Most of these examples provide solar system sizes as numbers in tables, but the clarification statement for MS-ESS1-3 identifies other ways that students can obtain their **data for analysis [SEP-4]**, including photographs, drawings, and models. For example, students can use online interactive models of the solar system to record the orbital distance and period of different planets. As the distance from the Sun increases, the time it takes for the planet to complete one orbit also increases. A similar activity can be done using a virtual telescope to analyze the orbital distance and orbital period of the moons of Jupiter. Project CLEA https://www.cde.ca.gov/ci/sc/cf/ch6.asp#link4 provides a detailed lesson plan that can be used with Web- or tablet-based Jupiter simulators such as https://www.cde.ca.gov/ci/sc/cf/ch6.asp#link5. A motivation for choosing to investigate orbital periods and radii is that it prepares students for calculating orbital periods using Kepler's Laws in high school (HS-ESS1-4).

Patterns in the Earth-Sun-Moon System

The study of the moon using the CA NGSS illustrates some of the shifts in expectations compared to the 1998 California Standards. Under the 1998 Standards, students in grade three should know the ways the Moon's appearance changes during the four-week lunar cycle. In the CA NGSS, students use observations to describe **patterns [CCC-1]** in the moon's motion in grade one (1-ESS1-1). Explaining the moon's appearance is now part of grade six, but the emphasis is on **developing a model [SEP-2]** that students can use to make and test predictions instead of simply describing the phases (MS-ESS1-1). The vignette below illustrates a teaching sequence that helps accomplish this model development.

DISCIPLINE SPECIFIC GRADE SIX VIGNETTE 6.1: USING MODELS OF SPACE SYSTEMS TO DESCRIBE AND EXPLAIN PATTERNS OF MOON'S PHASES

Performance Expectations

Students who demonstrate understanding can do the following:

MS-ESS1-1. Develop and use a model of the Earth-Sun-Moon system to describe the cyclic patterns of lunar phases, eclipses of the Sun and Moon, and seasons. [Clarification Statement: Examples of models can be physical, graphical, or conceptual.]

MS-ESS1-3. Analyze and interpret data to determine scale properties of objects in the solar system. [Clarification Statement: Emphasis is on the analysis of data from Earth-based instruments, space-based telescopes, and spacecraft to determine similarities and differences among solar system objects. Examples of scale properties include the sizes of an object's layers (such as crust and atmosphere), surface features (such as volcanoes), and orbital radius. Examples of data include statistical information, drawings and photographs, and models.] [*Assessment Boundary: Assessment does not include recalling facts about properties of the planets and other solar system bodies.*]

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

Highlighted Science and Engineering Practices	Highlighted Disciplinary Core Ideas	Highlighted Crosscutting Concepts
[SEP-2] Developing and Using Models [SEP-4] Analyzing and Interpreting Data	ESS1.A: The Universe and Its Stars ESS1.B: Earth and the Solar System	[CCC-1] Patterns [CCC-3] Scale, Proportion, and Quantity

CA CCSS Math Connections: MP. 1, MP. 2, MP. 3

CA CCSS for ELA/Literacy Connections: SL.6.1; RST.6–8.2, 3, 7

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

Introduction

The students in Mr. O's grade six classroom receive science instruction five days a week for 50 minutes each day. The students receive instruction in reading/language arts and mathematics in an integrated fashion. Strategic grouping of students provides opportunities for peer-to-peer collaboration, facilitating support for struggling students, including English language learner students.

In the lesson sequence in this vignette, Mr. O uses multiple means of representation that allow students to make sense of the view of Moon phases as seen from Earth. These representations include computer models using planetarium software (available free online at Stellarium accessed at https://www.cde.ca.gov/ci/sc/cf/ch6.asp#link6), physical models (foam balls, a lamp, golf balls), and diagrams such as foldables (three-dimensional interactive

DISCIPLINE SPECIFIC GRADE SIX VIGNETTE 6.1: USING MODELS OF SPACE SYSTEMS TO DESCRIBE AND EXPLAIN PATTERNS OF MOON'S PHASES

graphic representations with templates available online). Engaging the students in these multiple experiences to explain the same phenomenon and allowing them to **develop their own models [SEP-2]** or evaluate alternative representations of the same model facilitates students' development of a conceptual model of the Earth-Sun-Moon system. In addition, the multiple experiences support language development as students discuss and **ask questions [SEP-1]** about the experiences.

Mr. O has been preparing for this instructional segment for the past four months, and he strategically alerted students to look at the Moon in the sky throughout the week and notice changes in what they saw. Also, he often starts the day by showing pictures of the Moon he took with his cell phone or found online. He posts those pictures in a corner of the classroom with a label indicating date and time. Most of the students already know that the Moon has a different appearance on different days of the month. Most of them, however, have not observed the Moon during daytime, and they were surprised when Mr. O pointed out the Moon in the sky one morning while they were in the playground before class. Mr. O created a space in this corner for students to write questions about the Moon. He introduces the unit by projecting a sample of the student questions. Students are excited when he announces that later that day, the class would address this question of how big the Moon is.

Day 1: How Big is the Moon?

Students discuss their prior knowledge about the relative size of different objects in the solar system. They then create a scale model using a playground ball to represent Earth.

Day 2: Scale in the Earth-Sun-Moon System

Students extend their scale model to include the full Earth-Sun-Moon system, including their relative sizes and distances apart.

Day 3: Exploring Moon Phases: Computer Representation

Students make virtual observations of the moon using planetarium software. They analyze their data, recognize patterns, and use those to make and test predictions.

Day 4: Exploring Moon Phases: Physical Representation

Students make a physical model of the Earth-Sun-Moon system using their bodies to represent Earth.

Days 5–7: Developing a Model to Explain Moon Phases

Students use their physical model to explain moon phases and then depict their model using pictorial models that they refined.

Day 8: Solidify Learning About Moon Phases and Extend Learning Through Readings

Students obtain information about the moon's surface and ask questions about what they could see from Earth in relation to their model.

DISCIPLINE SPECIFIC GRADE SIX VIGNETTE 6.1: USING MODELS OF SPACE SYSTEMS TO DESCRIBE AND EXPLAIN PATTERNS OF MOON'S PHASES

Day 1: How Big is the Moon?

Anchoring phenomenon: Students look up at the Moon and wonder, How big is the Moon?

Mr. O initiated the instructional segment by asking students to open their notebooks, write the numbers 1–8 down the next blank page, and title it "Relative Diameters." On the interactive whiteboard, he projected a slide from a multi-media presentation *Two Astronomy Games* that showed nine images, each identified by a letter and a label (Morrow 2004). The images were the Sun, Earth, a space shuttle, the Moon, the solar system, Mars, a galaxy, and Jupiter. Students were asked to number the objects in order from smallest (number 1) to largest (number 8) and from nearest to the surface of the Earth to farthest from the surface of the Earth. As the students marked their choices on their own, Mr. O walked among the students to gain insight regarding their prior knowledge. He planned to have students come back to this page later. Kevin, one of the most talkative students, seemed pleased and announced, "I love to study space!"

Mr. O moved to the front of the classroom and picked up a standard-sized playground ball in his hand. He asked the class to imagine the ball was Earth and he wrote down the class's consensus of the ball's dimensions that they had measured in math class. The diameter of the ball was 42 cm. Then he presented the class with a box of seven balls in a variety of sizes and listed their dimensions on the interactive whiteboard. He asked, "If Earth were the size of this playground ball, which of these balls would be the size of the Moon?" One student from each table came up and chose the ball they thought would be correct. Their choices varied from a softball to a small marble.

Before going further, the class reviewed the term diameter, and Mr. O asked, "If you know that Earth's diameter is 12,756 kilometers and the Moon's diameter is 3,476 kilometers, with your table groups, come up with a method to see if the ball you chose is the right size for this size Earth (holding up the playground ball)." (**using mathematics and computational thinking [SEP-5]**) (**scale, proportion, and quantity [CCC-3]**) (CA CCSSM.6.RP.3)

After some discussion time, students reported their calculations. One group noticed that the ratio between the diameters was approximately 4:1, Earth to Moon. A student asked how they made that determination. Jeff responded, "If you estimate using 12,000 and 3,000, three goes into twelve four times." He showed on the interactive whiteboard how four circles of a Moon model fit across the diameter of an Earth model. Mr. O said, "Now look at your ball as a Moon model and decide if you think it is the correct size. What can you do to be sure? Decide on a process." He let them use the playground ball as needed. (MS-ESS1.A)

Each group reported its findings and methods for determining whether or not the choice would be correct. One group made lines on paper to represent the diameter of their ball and did the same for the playground ball. Using those measurements and the 4:1 ratio, they decided if their Moon was the correct size. Another group used string to measure the diameter of the

DISCIPLINE SPECIFIC GRADE SIX VIGNETTE 6.1: USING MODELS OF SPACE SYSTEMS TO DESCRIBE AND EXPLAIN PATTERNS OF MOON'S PHASES

balls and then determined whether or not it was correct. Still another group held its ball up against the playground ball and moved the ball four times while marking the playground ball with a finger to see if the ball was the correct size for the model of Earth.

All groups reported their findings to the classroom. Kevin was agitated as he explained, "I told my group they were not right. The racquetball is the only one that is possible as the Moon, but they wouldn't believe me." Mr. O asked Kevin to restate the rule for when his group disagrees. Kevin thought and said, "When my group disagrees, I listen and then tell them what I think." The classroom came to a consensus that the racquetball was the correct size ball to represent the Moon for the playground ball to represent the Earth.

Day 2: Scale in the Earth-Sun-Moon System

The next day, Mr. O showed the students a table with the results of careful scientific measurements of the distance from the Earth to the Moon and the diameter of Earth in kilometers. He asked them to figure out the distance between Earth and Moon in the model and to show it using string. Students were shocked at the distance the Moon was from Earth in this model. Their estimates had been much lower.

The class continued this activity by choosing balls of the correct sizes for the Sun and Earth. Students also considered the relative size of the Sun and the distance of the Sun from Earth in the model. They used the **evidence [SEP-7]** of the diameter of the Sun and its distance from Earth in the same way they determined the size and distance of the Moon from Earth. Some students were surprised at the size of the Sun and its distance from Earth in this model. Jeff decided that they could not fit the Sun in the room. He explained that it would take over 100 playground balls to approximate the Sun's diameter. Jeff was eager to share his mathematical skill at finding the answer: "I know the answer! It would take almost 12,000 playground balls lined up to show how far away the Sun would be in this model." (**scale, proportion, and quantity [CCC-3]**)

The students returned to their initial ideas on the "Relative Diameters" page in their notebooks, renumbered the objects, and wrote any ideas that had changed after making the model. After giving students time to record their responses, Mr. O showed images of the items on the interactive whiteboard and led a discussion about the great distances between objects in the solar system in preparation for modeling the Moon's phases (MS-ESS1.B).

Day 3: Exploring Moon Phases: Computer Representation

Investigative Phenomenon: The Moon rises and sets each day and changes phase throughout the month.

For this lesson sequence, Mr. O considered the makeup of the table groupings of students. He wanted all students to have support while determining methods to check their choice of the Moon model, so he grouped students with that concern in mind. He used physical representations of Earth and the Moon and had students represent the distance physically, thereby assisting them in visualization and comprehension.

DISCIPLINE SPECIFIC GRADE SIX VIGNETTE 6.1: USING MODELS OF SPACE SYSTEMS TO DESCRIBE AND EXPLAIN PATTERNS OF MOON'S PHASES

Mr. O downloaded open-source planetarium software onto his interactive whiteboard-connected computer as well as onto the 14 student computers in his classroom. Each student also received a one-page calendar, and the students were instructed to use it to collect data using the software. Mr. O launched the program on the interactive whiteboard, introduced the students to the software, and showed them how to change the date and set up the scale Moon so they could see the phases. Mr. O also showed how the Moon's and Earth's orbital planes are offset by five degrees in an effort to help students understand how light can illuminate the Moon when it is on the other side of Earth without being blocked by Earth's shadow.

Recording began on the first Sunday on the calendar and ended on the last Saturday, resulting in five weeks of **data to analyze [SEP-4]**. Mr. O modeled how to record data on the whiteboard next to the interactive whiteboard. Students recorded the time and direction of moonrise and moonset as well as the apparent shape of the Moon in the sky for each date. To make sure that students understood the process and were recording accurately, he walked through the room and checked student work throughout the lesson.

During this data-collection process, the students were told to focus their attention on the Sun-Moon relationship so they could see light from the Sun traveling in a straight line to the Moon. The Moon was in the sky as the Sun was rising, and they focused on the Moon so that they could use the model for predictions. Mr. O asked, "Does anyone know where the Sun is right now?" Brady responded, "It's more to the east and still rising." Using the time and date function in the program, Mr. O advanced the time to show the sunrise and said, "Look at the Sun and Moon. What pattern do you notice about the light on the Moon in relation to the Sun?" (**patterns [CCC-1]**) Hillary answered, "It is going from the Sun to the Moon." Mr. O responded, "Hmm. The light travels in a straight path from the Sun to the Moon. You have already learned that light travels in a straight line. Can we use that information to predict the position of the Sun even if we can't see it? Let's try as we continue."

Investigative Phenomenon: The Moon rises and sets at a different time each day.

After collecting six days of data, Mr. O asked students to look at the pattern in their data and predict the time and direction for moonrise and moonset on the next day. Bringing their attention to the patterns in the data he asked, "What time do you think the Moon will set on this day? The last time was 12:09." Mark said, "I think 12:59." Mr. O advanced the time in the software until the moonset—at 13:08. Jeff called out, "So it is setting about an hour later each time." To reinforce the language Mr. O will use on many occasions throughout the instructional segment, he asked the following question, "What does that tell us about the planets and the Moon? They all move …" and students responded, "… in predictable patterns."

A student said, "So let's see if that **pattern [CCC-1]** continues the whole month." Once Mr. O was satisfied that the students had a foundation for data collection and that they were not just copying numbers from the software into their worksheet calendar, he told them to move to their computers in partners so they could work more independently to complete the data collection on the calendar. The students continued to record data about sunrise and moonrise until all the days in the handout calendar were filled.

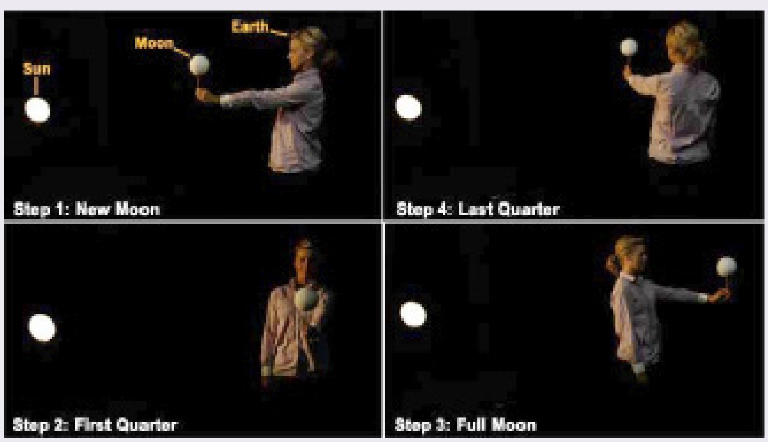
DISCIPLINE SPECIFIC GRADE SIX VIGNETTE 6.1: USING MODELS OF SPACE SYSTEMS TO DESCRIBE AND EXPLAIN PATTERNS OF MOON'S PHASES

Day 4: Exploring Moon Phases: Physical Representation

Investigative phenomenon: The Moon changes phase throughout the month.

After students completed the calendar using the computers, Mr. O started a related activity in which they modeled Moon phases using Styrofoam balls, their heads, and a lamp with a bare bulb. In small groups, students stood in a circle around a lamp representing the Sun, holding a Styrofoam ball on a stick representing the Moon. They held the ball at arm's length and rotated their bodies using their heads as a representation of Earth so they could see the Earth view of the Moon in all its phases in the lit portion of the ball. Mr. O directed Nicole to look at the Styrofoam ball and the changing shadow. "What? I don't see the shadow." Mr. O pointed out the curve of light on the Moon. "I see it!" Nicole said. The students went through the phases, drawing and naming each one in their notebooks. Having small groups allowed Mr. O to make sure that all students could see the lit portion on the Styrofoam balls for each phase and that they were able to accurately illustrate the phases in the model, giving him the opportunity to physically move them into position as necessary. He frequently checked with students in the groups to show them how to reproduce the position of the Styrofoam ball corresponding to the drawings in their notebook (figure 6.2)

Figure 6.2. Students Model Moon Phases



Source: NASA's Jet Propulsion Laboratory 2010
Long description of Figure 6.2.

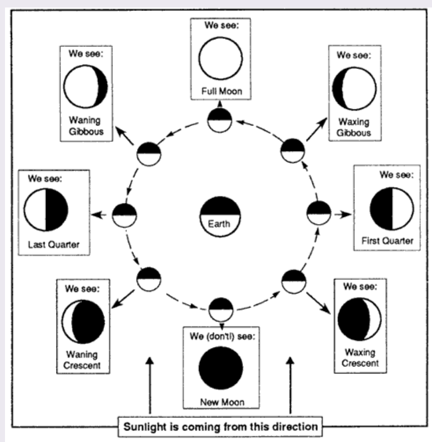
For this activity, Mr. O expected all students to observe that the lit segment of the Moon's face increased, decreased, and increased again relative to the part in shadow. He also expected students to notice that the lit side of the Moon was on the left after the full Moon phase and on the right after the new Moon phase, as viewed from Earth.

DISCIPLINE SPECIFIC GRADE SIX VIGNETTE 6.1: USING MODELS OF SPACE SYSTEMS TO DESCRIBE AND EXPLAIN PATTERNS OF MOON'S PHASES

Days 5–7: Developing a Model to Explain Moon Phases

The next day, Mr. O pulled out large whiteboards and instructed the students to collaborate on making a drawing that explained how the model of the Moon phases illustrated changes in the apparent shape of the Moon. Mr. O started the lesson telling students they were going to make their thinking public by producing small group models. Students first organized their individual understanding by sketching and labeling the apparent changes in the moon based on what they observed and discussed in class. Next they took turns sharing their ideas with their group, noting similarities and differences. Mr. O walked the classroom, listening to the progress as each group member shared. He reminded some groups of the classroom norms of respect and responsibility when participating in a group discussion. After each group reached a consensus on the elements that explained the apparent changes in the shape of the moon, the group acquired a large whiteboard and produced a consensus model to share with the class (figure 6.3). Based on what they learned in the previous days, they discussed limitations of the **models [SEP-2]**—the things that a model is unable to show accurately. For example, the students identified the relative sizes of the Sun, Earth, and Moon as well as the relative distances between each as being inaccurate in this model.

Figure 6.3. Group Consensus Model of Moon Phases



Source: Fraknoi/Astronomical Society of the Pacific 1989
Long description of Figure 6.3.

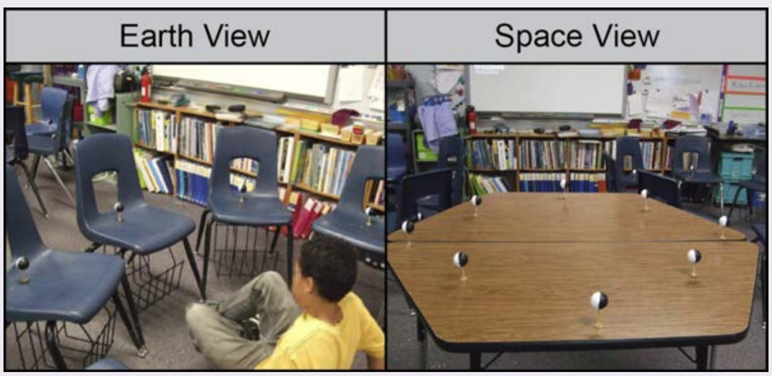
The following day, Mr. O announced they were doing a "Sticky Note" gallery walk of the models where each group would visit each of the models, consider and discuss them, and then provide feedback on a color-coded sticky note. Three different colors were used: one for questions, one for additions, and one for suggested revisions. Students were reminded that the purpose of the feedback was to help the authors clarify the thinking that went into their models. Mr. O provided sentence frames to help students form questions, additions, or suggested revisions. As the students walked and discussed, the use of color coding helped to focus their discussion and make it productive.

DISCIPLINE SPECIFIC GRADE SIX VIGNETTE 6.1: USING MODELS OF SPACE SYSTEMS TO DESCRIBE AND EXPLAIN PATTERNS OF MOON'S PHASES

After completing the gallery walk, each group organized the sticky notes it had received by the type of comment and then made revisions to their model based on the feedback.

Over the next two days, Mr. O called on small groups of students to use another physical **model [SEP-2]** showing Moon phases. This one used golf balls that were painted black on half of the sphere, leaving the other half showing the side of the Moon lit by the Sun (Young and Guy 2008). The golf balls were drilled and mounted on golf tees so they would stand up on a surface. Mr. O had two sets—one on a table that showed the Moon in orbit around the Earth in eight phase positions as the space-view model; the other placed the model Moons on eight chairs circled in the eight phase positions to show the Earth-view model (figure 6.4).

Figure 6.4. Space-View and Moon-View Models Showing Moon Phases



Source: NGSS Lead States 2013a, Case Study 3
Long description of Figure 6.4.

First, students were shown the space-view model and asked what they noticed about the representations of the Moon. Mr. O wanted them to notice that the white sides of all the balls (showing light) faced the same direction. He asked them to identify the direction of the Sun. Then Mr. O drew the students' attention to the model on the chairs, the earth-view model. All the balls in this model faced the same direction as those in the space-view model. Students again identified the direction of the Sun and noted that the position of the moons in both **models [SEP-2]** was the same (MS-ESS1.A). One at a time, students physically got into the center of the circle of chairs and viewed the phases at eye level, which simulated the Earth view of each phase. Also, students compared their drawing on the whiteboard illustrating the model of the Earth–Sun–Moon system with what they were seeing now. This activity made the diagram, often found in books and worksheets showing both views on the same diagram, less confusing to the students.

Throughout the lesson sequence, Mr. O continually formatively assessed students' progression of learning through observations and classroom discourse. If he noticed students needed more experience with Moon phases, he provided them with additional activities, such as videos and Moon-phase cards. In one formal assessment of understanding, Mr. O paired

DISCIPLINE SPECIFIC GRADE SIX VIGNETTE 6.1: USING MODELS OF SPACE SYSTEMS TO DESCRIBE AND EXPLAIN PATTERNS OF MOON'S PHASES

students so that one was assigned to be the Earth and the other the Moon. He designated one wall of the classroom as the Sun and then asked the Moons to show different phases. The students switched roles so that Mr. O could assess everyone. He also used this model to demonstrate the Moon's coincident rotation and revolution. In another formal assessment, he asked students to draw a model on whiteboards showing the relationship of the Earth, Moon, and Sun in full Moon phase.

Day 8: Solidify Learning About Moon Phases and Extend Learning Through Readings

Mr. O brought all students together the following day to create a foldable showing the Earth view of the Moon phases similar to diagrams found in books. Students created their Moon phases using eight black circles and four white circles, cutting the white circles to make two crescent moons, two gibbous Moons and two quarter Moons. The white circle pieces were placed on the black circles to create the phases and later glued on the foldable.

Students partnered to read *The Moon* by Seymour Simon (2003). Mr. O asked them to pay attention to how the book described the Moon's phases and asked them to write a reflection about how it related to their model in their science notebook. Students used the **information [SEP-8]** in the book to label the Moon's phases on their foldable, write about the Moon's surface, and record any new **questions [SEP-1]** that arose from their reading. Kevin asked, "When is the next solar eclipse? The next lunar eclipse?" Jeanette questioned, "What samples were brought back from the Moon?" And Nicole wanted to know, "Where did Americans land on the Moon?" To support their reading of the text, the teacher gave Hillary, Brady, and Jeff the option of being paired with students who had more advanced reading skills. The teacher allowed students who finished with the entire reading task to use text materials and Internet resources to research answers to the questions they developed when reading *The Moon*. The teacher planned to use the answers to these questions during the next few days. For example, Mr. O might have students revisit the physical model of the Earth–Sun–Moon system to explain solar and lunar eclipses (MS-ESS1-1).

Vignette Debrief

The two performance expectations that Mr. O selected in this vignette required students to develop models of objects in the solar system, but this vignette only addressed the Earth–Sun–Moon system. Assessment of these performance expectations could include any objects in the solar system, so Mr. O would need additional activities to fully prepare his students to meet the performance expectation. Mr. O would devote specific time for his students to relate this Earth–Sun–Moon model to the entire solar system. How were the relationships between the new components of the system similar to the Earth–Sun–Moon system? How did they differ?

SEPs. Students **developed and used models [SEP-2]** based on three different representations of the system: a computer animation (day 3), a kinesthetic model (day 4), and a pictorial model (days 5–7). In both the computer animation and the kinesthetic model, they viewed the model from an Earth-centered view (within the system) and a solar-system view (outside the system). They developed models collaboratively, using data they had

DISCIPLINE SPECIFIC GRADE SIX VIGNETTE 6.1: USING MODELS OF SPACE SYSTEMS TO DESCRIBE AND EXPLAIN PATTERNS OF MOON'S PHASES

collected and **analyzed [SEP-4]**, and then revised their models taking into account input from other groups of students. They considered how their models **explained [SEP-6]** or **related to information [SEP-8]** in texts on day 8.

DCIs. ESS1.A (The Universe and Its Stars) and ESS1.B (Earth and the Solar System) overlap in the middle grades, with both disciplinary core ideas emphasizing models of objects in the solar system. While students had observed patterns of motion in the night sky in earlier grades, they didn't really develop a detailed model that explained the motion until this vignette in the middle grades (ESS1.A). Understanding the relative size of solar system objects is an important precursor to more advanced understanding of gravity in high school (ESS1.B, PS2.B).

CCCs. Students began on days 1–2 focusing on **scale [CCC-3]** as they constructed **models [SEP-2]** of relative sizes and distance of the Sun and planets. With guidance from their teacher, students used the ratios of the diameters of Earth and its Moon to construct a class model of the relative sizes of the two objects. Using distance and Earth's diameter or circumference ratios, they also constructed a distance model of those objects. In addition, the relative size of the Sun and the relative distance from Earth in this model were calculated and described although not constructed (due to the constraints of the room and location). Throughout the vignette, a variety of **models [SEP-2]** were used to help students identify **patterns [CCC-1]** in the positions of the Earth, Moon, and Sun relative to one another and to explain moon phases.

Students made predictions about the data collected and recorded them on the calendar, using the lens of the crosscutting concept of **patterns [CCC-1]**. When analyzing and **interpreting the data [SEP-4]**, they identified the patterns in the Earth–Moon–Sun relationship. The pattern made by the lit portion of the Moon was observed and recorded.

CA CCSS Connections to English Language Arts and Mathematics. Students were engaged in small group work activities, both listening to their peers' ideas and sharing their own thoughts. Students used the text in *The Moon* book to label each phase of the Moon in their graphic organizer foldable (RI.6.7). In addition, they summarized information about the surface of the Moon inside their foldable (RST.6–8.2). Finally, students created models from data that they collected (RST.6–8.7).

When comparing sizes and distances, students were challenged to find ways of comparing numbers, applying MP.1. In addition, students used rounding and estimation to calculate the quotients in the ratios, both skills developed in earlier grades. Throughout the instructional segment, students reasoned quantitatively as they compared the sizes of the Earth and Moon (MP.2). As students made conclusions about which ball was the Moon, they argued for their selection and agreed or disagreed with each other using their calculation (MP.3).

Resources:

Adapted from NGSS Lead States. 2013a. Appendix D Case Studies, Case Study 3. https://www.cde.ca.gov/ci/sc/cf/ch6.asp#link7

Fraknoi, Andrew. 1989. "The Moon: It's Just a Phase It's Going Through…" *Universe in the Classroom 12* (Winter 1988–1989): 1–4. https://www.cde.ca.gov/ci/sc/cf/ch6.asp#link8

DISCIPLINE SPECIFIC GRADE SIX VIGNETTE 6.1: USING MODELS OF SPACE SYSTEMS TO DESCRIBE AND EXPLAIN PATTERNS OF MOON'S PHASES

Morrow, Cherilynn. 2004. Two Astronomy Games. Space Science Institute, https://www.cde.ca.gov/ci/sc/cf/ch6.asp#link9

NASA's Jet Propulsion Laboratory. 2010. Moon Phases Demonstration, full image demonstration. https://www.cde.ca.gov/ci/sc/cf/ch6.asp#link10

Simon, Seymour. 2003. *The Moon*. New York: Simon and Schuster.

Young, Timothy, and Mark Guy. 2008. "The Moon's Phases and the Self Shadow." *Science and Children* 46 (1): 30–35.

IS2 Discipline Specific Grade Six Instructional Segment 2: Atmosphere: Flows of Energy

During the middle grades, students identify some basic **patterns [CCC-1]** in Earth's climate and **develop a model [SEP-2]** of the factors that **cause [CCC-2]** those patterns. The model is simple and related primarily to one part of Earth's **energy [CCC-5]** balance, the input from the Sun. They extend this model in high school (HS-ESS2-4).

DISCIPLINE SPECIFIC GRADE SIX INSTRUCTIONAL SEGMENT 2: ATMOSPHERE: FLOWS OF ENERGY

Guiding Questions

- Why is it cold at the North Pole?
- What causes California's summers to be hot and dry? What causes the changes between summer and winter?
- Why is there more rain in Northern California than Southern California?
- What effect do humans have on Earth's climate?

Performance Expectations

Students who demonstrate understanding can do the following:

MS-ESS1-1. Develop and use a model of the Earth–Sun–Moon system to describe the cyclic patterns of lunar phases, eclipses of the Sun and Moon, and seasons. [Clarification Statement: Examples of models can be physical, graphical, or conceptual.] (Continued from IS1)

MS-ESS2-6. Develop and use a model to describe how unequal heating and rotation of the Earth cause patterns of atmospheric and oceanic circulation that determine regional climates. [Clarification Statement: Emphasis is on how patterns vary by latitude, altitude, and geographic land distribution. Emphasis of atmospheric circulation is on the sunlight-driven latitudinal banding, the Coriolis effect, and resulting prevailing winds; emphasis of ocean circulation is on the transfer of heat by the global ocean convection cycle, which is constrained by the Coriolis effect and the outlines of continents. Examples of models can be diagrams, maps and globes, or digital representations.] [*Assessment Boundary: Assessment does not include the dynamics of the Coriolis effect.*]

DISCIPLINE SPECIFIC GRADE SIX INSTRUCTIONAL SEGMENT 2: ATMOSPHERE: FLOWS OF ENERGY

MS-ESS3-4. Construct an argument supported by evidence for how increases in human population and per-capita consumption of natural resources impact Earth's systems. [Clarification Statement: Examples of evidence include grade-appropriate databases on human populations and the rates of consumption of food and natural resources (such as freshwater, mineral, and energy). Examples of impacts can include changes to the appearance, composition, and structure of Earth's systems as well as the rates at which they change. The consequences of increases in human populations and consumption of natural resources are described by science, but science does not make the decisions for the actions society takes.

MS-ESS3-5. Ask questions to clarify evidence of the factors that have caused the rise in global temperatures over the past century. [Clarification Statement: Examples of factors include human activities (such as fossil fuel combustion, cement production, and agricultural activity) and natural processes (such as changes in incoming solar radiation or volcanic activity). Examples of evidence can include tables, graphs, and maps of global and regional temperatures, atmospheric levels of gases such as carbon dioxide and methane, and the rates of human activities. Emphasis is on the major role that human activities play in causing the rise in global temperatures.]

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

Highlighted Science and Engineering Practices	Highlighted Disciplinary Core Ideas	Highlighted Crosscutting Concepts
[SEP-1] Asking Questions and Defining Problems [SEP-2] Developing and Using Models [SEP-7] Engaging in Argument from Evidence	ESS1.A: The Universe and Its Stars ESS1.B: Earth and the Solar System ESS2.C: The Role of Water in Earth's Surface Processes ESS2.D: Weather and Climate ESS3.C: Human Impacts on Earth Systems ESS3.D: Global Climate Change Other Necessary DCIs: PS3.B: Conservation of Energy and Energy Transfer PS4.B: Electromagnetic Radiation	[CCC-1] Patterns [CCC-2] Cause and Effect: Mechanism and Explanation [CCC-4] Systems and System Models [CCC-7] Stability and Change

Highlighted California Environmental Principles and Concepts:

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

DISCIPLINE SPECIFIC GRADE SIX INSTRUCTIONAL SEGMENT 2: ATMOSPHERE: FLOWS OF ENERGY

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

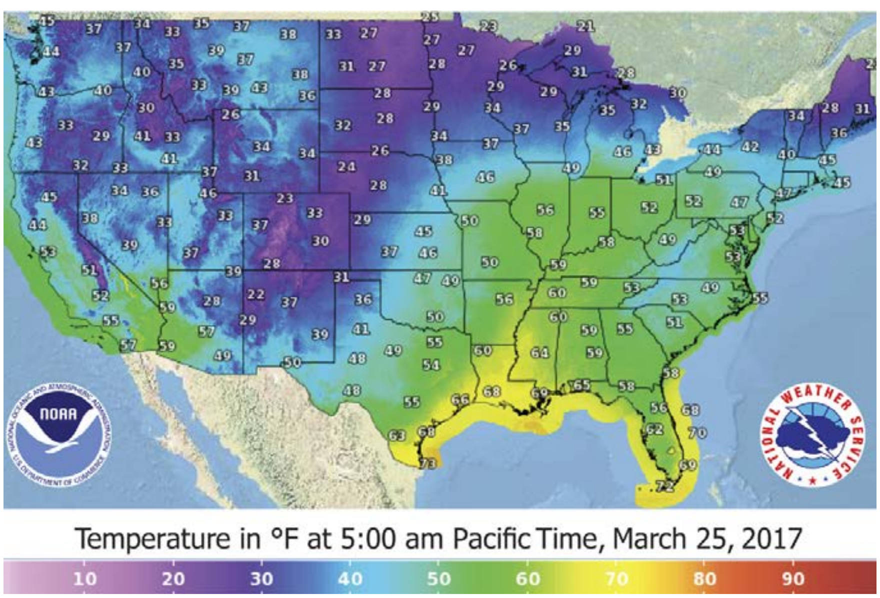
CA CCSS Math Connections: MP.2, MP.4, 6.RP.1, 6.EE.6, 7.EE.4a–b, 7.RP.2a–d

CA CCSS for ELA/Literacy Connections: SL.6.5, RST.6–8.1, WHST.6–8.1a–f, 9

CA ELD Connections: ELD.PI.6.6a–b, 9, 10, 11a

Student **models [SEP-2]** begin at the simplest level with recognizing that the Earth warms where it receives solar input. Students can discover this pattern by looking at a map of temperature in the early morning across the United States. Look at figure 6.5 and draw a line dividing the country in half. What explains this simple **pattern [CCC-1]**? The Sun has risen already across the East Coast and has warmed it up. Students can also identify other trends such as the warming towards the southern half of the country and the behavior of California, which appears warmer than its neighbors despite the fact that the Sun has not yet risen.

Figure 6.5. Sunlight and Temperature



Map of temperatures around the country recorded at 5:00 a.m. in California. The image reveals the importance of sunlight in affecting the temperature near Earth's surface. *Source*: National Weather Service 2017
[Long description of Figure 6.5.](#)

Average Temperature Versus Latitude

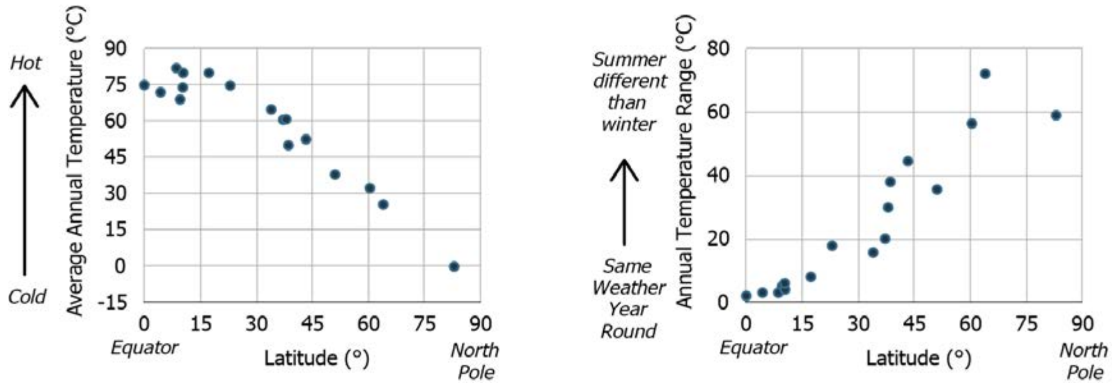
Figure 6.5 is just a snapshot in time that quickly changes, but there are also trends that last much longer. Should you bring beach clothes or a warm coat on a trip to Antarctica? How about San Diego, where it has only snowed five times there in the last 125 years? How about Lake Tahoe, which typically receives more than 10 feet of snow in the winter but is a popular recreation area for swimmers and boaters every summer. Different cities tend to have predictable **patterns [CCC-1]** in their weather that depend on the city's location and the time of year (their "climate"). Students **investigate [SEP-3]** these patterns across the globe by **obtaining temperature information [SEP-8]** from Web sources (such as National Oceanic and Atmospheric Administration (NOAA), National Centers for Environmental Information, *Global Historical Climatology Network-Monthly* (*GHCN-M*) accessed at https://www.cde.ca.gov/ci/sc/cf/ch6.asp#link11) or from a simplified version for teaching (see WebInquiry, "Temperature" accessed at https://www.cde.ca.gov/ci/sc/cf/ch6.asp#link12).

Opportunities for Mathematics Connections

Students plot climatograms showing the average temperature for each month (CA CCSSM 6.SP.4). They calculate the average temperature of each city over the entire year, as well as the difference in temperature between the hottest month of the year and the coldest (CA CCSSM 6.SP.2, CA CCSSM 6.SP.3).

How much does the latitude affect a location's climate? Students can construct dot plots of both the average annual temperature versus latitude and the temperature range versus latitude (i.e., the difference between the hottest and coldest month) (figure 6.6). When they **analyze the data [SEP-4]**, they notice some **patterns [CCC-1]**. Students probably already knew that it was cold at the North Pole, but why is there such a large temperature range at the poles and not at the equator? Within 20 degrees of the equator and 20 degrees of the poles, latitude does not have a major impact on climate and cities share fairly similar climates to one another. In between these sections of the Earth, climate varies greatly with latitude. Students should start **asking questions [SEP-1]** about the cause of these differences.

Figure 6.6. How Much Does Latitude Affect Climate?



Graphs by M. d'Alessio with data from National Oceanic and Atmospheric Administration, National Centers for Environmental Information n.d.
Long description of Figure 6.6.

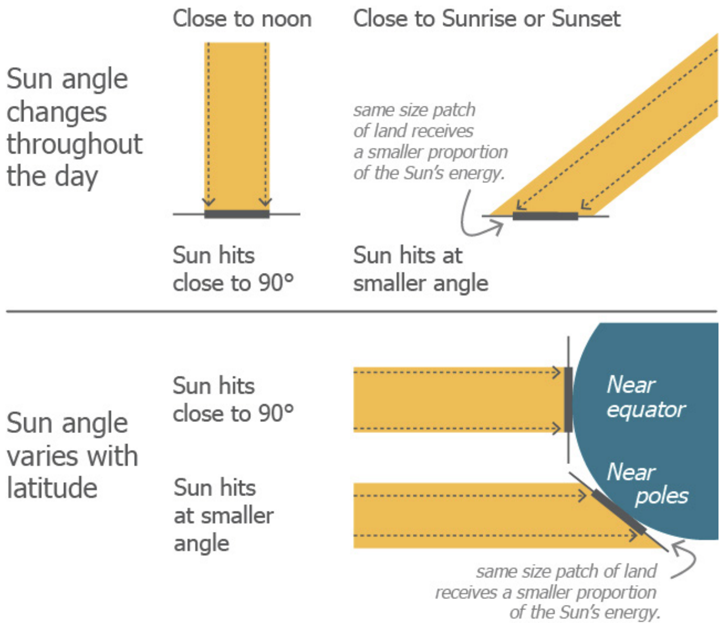
Like the temperature map in figure 6.5, these long-term temperature differences relate to the difference in energy received from the Sun. How can the equator appear to receive more energy than either of the poles despite the fact that they all receive their energy from the same Sun? The key is that the Earth is a sphere. Sunlight arrives at Earth as parallel rays (figure 6.7) but hits the surface at nearly a 90° angle near the equator and at flatter/smaller angles near the poles because of Earth's round shape. The light spreads out over a larger area near the poles (figure 6.8), meaning that each square foot patch of the surface receives a smaller **proportion [CCC-3]** of the energy coming from the Sun than that same patch does at the equator, which causes the sunlight on that patch to be less intense. When the sun shines down at a 90° angle, a patch of land receives twice the energy compared to a 30° angle, so this effect has a big impact on the temperature.

Figure 6.7. Earth–Sun System Scale

A scale illustration of the Earth–Sun system (top). The Sun is 5 pixels wide and the Earth is 1075 pixels away, but is only 0.05 pixels wide, which is too small to display. At this scale, it is easier to recognize that rays of sunlight arrive at Earth as parallel rays at all latitudes (bottom). Diagram by M. d'Alessio.
Long description of Figure 6.7.

Students **perform an investigation [SEP-3]** of the relationship between light intensity and angle by shining a flashlight at a piece of paper at different angles while keeping the distance between the light and the paper constant (NASA 2008). Students can directly observe how the patch of light gets dimmer when it strikes the page at a low angle and spreads out over a large area. While a piece of paper is flat, students simulate the parallel rays of sunlight arriving at Earth by shining their flashlight on a round ball and observing how the patch of light is small and intense near the equator but spreads out near the poles.

Figure 6.8. Angle of the Sun's Rays Affect Intensity



Effect of the angle of the Sun's rays on area of the Earth's surface it illuminates. At angles smaller than 90 degrees, the energy is spread out over a larger area. The effect is important as the Sun moves across the sky during one day (top) and at different latitudes across the planet (bottom). Diagram by M. d'Alessio.
Long description of Figure 6.8.

Engineering Connection: Solar Array Design

This concept has important engineering applications for solar energy. California hosts several of the world's largest arrays of solar panels. When people place solar panels on their roofs, the angle of the panels is usually fixed by the angle of the roof. To maximize efficiency at large solar power arrays, the motors constantly turn the panels so that they face the Sun at an angle as close to 90 degrees as possible to get the maximum energy output. Students can experience this effect in a classroom with a small solar panel hooked up to an electric motor. As they rotate the solar panel to change the angle of sunlight, the energy output **changes [CCC-7]** so that the motor turns at a different speed (New York State Energy Research and Development Authority 2015). Students could engage in an engineering challenge to design a rotating base for solar panels that has the necessary range of movement (both tilting and swiveling) and uses low-cost materials (MS-ETS1-1, MS-ETS1-2).

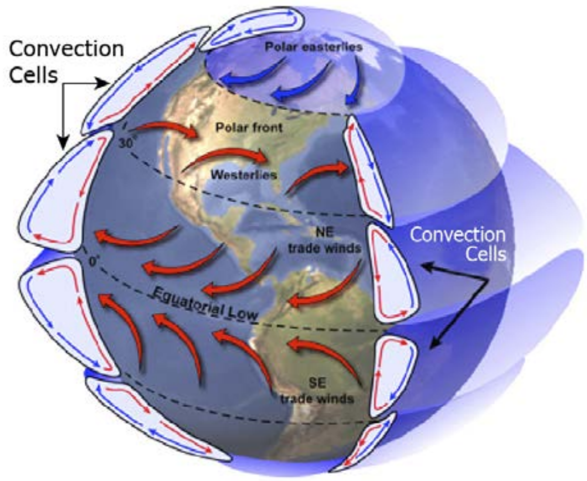
Uneven Heating and the Earth's Circulation System

The uneven heating between the equator and the poles is the root **cause [CCC-2]** of all Earth's ocean and wind currents. They carry hot material (water in the oceans and air in the atmosphere) from the equator towards the poles in a large-scale convection current. Convection is a **cycling of matter [CCC-5]** driven by the **flow of energy [CCC-5]** (connects to MS-ESS2-1, though assessment of that performance expectation focuses largely on the solid Earth). As hot material moves poleward, colder material moves towards the equator. Without currents, the temperature would be extremely hot at the equator and frigid toward the poles—and much less of Earth's land would be habitable. Sunlight heats Earth's surface, which in turn heats the atmosphere. At the global scale, wind currents are dominated by three different directions of motion: (1) hot material rising vertically upward and cold material sinking vertically downward due to convection; (2) hot material from the equator moving northward towards the poles and cold material moving southward towards the equator due to convection; and (3) east-west apparent motion of material driven by Earth's rotation. Ocean currents undergo similar motions modified by collisions with the coastlines that disrupt these ideal motions. While wind directions also change when they rise up and over mountains or flow around them, the difference is less than in the ocean where water cannot go above or below the coastline but must change direction completely (either turning along the coast or returning back the way it came as a current flowing at a different depth).

Under the 1998 California Science Standards, students discussed convection in both grades five and six, but under the CA NGSS this instructional segment is likely the first time students encounter the concept of convection. They will therefore need hands-on experience with the process to develop mental **models [SEP-2]** of convection. These models begin with simple visualizations of convection using miso soup, rheoscopic fluid, or food coloring with water that allow students to recognize some general **patterns [CCC-1]** of motion. They can then conduct more detailed **investigations [SEP-3]** mapping out the motion of individual particles to provide evidence that supports the **argument [SEP-7]** that uneven heating **causes [CCC-2]** these patterns (see UCAR, Atmospheric Processes-Convection at https://www.cde.ca.gov/ci/sc/cf/ch6.asp#link13). They can **conduct investigations [SEP-3]** of density and how objects expand when heated so that they can **explain [SEP-6]** how convection is driven by gas or liquid expanding and rising as it becomes less dense. Students should be able to apply their model of convection to predicting the direction wind or water will move when exposed to uneven heating at the regional **scale [CCC-3]** (a part of MS-ESS2-6). In India, changes in the heating differential between winter and summer cause the prevailing wind direction to reverse direction almost completely, creating their famous monsoons. Along the California coastline, we see this effect every day as the wind switches direction from morning to evening as the temperature difference between land and water switches direction.

Understanding how convection works at the global **scale [CCC-3]** helps explain many **patterns [CCC-1]** in wind and precipitation. The strong temperature difference between equator and poles sets up convection, but as air masses move northward, some of their **energy flows [CCC-5]** to their surroundings through cooling and drag. As a result, air from the equator does not make it all the way to the poles before it sinks back to the surface. Instead, our present-day atmosphere involves three major convection cells divided into latitudinal bands (figure 6.9). Regions at the boundary between these convection cells tend to be areas with more dramatic weather: where both convection cells have air rising, thunderstorms are generated while the convergence between air masses at the upper mid-latitudes typically gives rise to rainier weather patterns.

Figure 6.9. Latitudinal Bands



Latitudinal bands in Earth's atmospheric circulation. *Source*: Adapted from Summey n.d.
Long description of Figure 6.9.

Climate **patterns [CCC-1]** are not permanent, and **changes [CCC-7]** to the energy balance on the planet can **cause [CCC-2]** **changes [CCC-7]** to convection. The convection cells migrate with the seasons as well as with local temperature variations. We see these changes as migrations of the jet streams, high velocity winds that race in the upper atmosphere along the boundary between convection cells. In wintertime, the convection cell boundary moves towards the south, bringing California its rainy winters that dry up in the summer as the convection boundary migrates back northward. Southern Europe is located at a similar latitude, so it has a similar pattern of weather, which is why our climate is often referred to as a Mediterranean climate. Students may not realize that large portions of the planet actually get the majority of their rain in the summer and that our distinctive climate is due to our position on the globe.

In addition to seasonal **changes [CCC-7]** to the energy balance on the planet, **changes [CCC-7]** at longer **timescales [CCC-3]** can also occur. Computer simulations show that in periods of geologic history when there was a smaller temperature differential between the equator and poles, Earth may have had one large convection cell for each hemisphere spanning the entire region from equator to pole. Future climate changes may again disrupt wind and ocean currents.

Additional Background for Teachers on Coriolis Effects

If simple convection were the only process controlling air movements, all wind would flow in the north-south direction, but we know that is not true. Earth's rotation modifies this path. The assessment boundary for MS-ESS2-6 states, "Assessment does not include the dynamics of the Coriolis effect," so the exact details of this process are not essential for students but it may be desired by curious teachers and students. Air rotates around the Earth just like the solid planet beneath it rotates. Material races around the equator at 1,700 km/hr to complete one full rotation in 24 hours, but it hardly needs to move at all near the poles. As a parcel of air travels from the fast moving equator towards the poles, it is moving faster in the direction of Earth's rotation than the ground underneath it. From our perspective on the surface, it appears to be veering off in the direction of Earth's rotation. Air moving from the poles towards the equator is moving slower than the ground underneath it, so it gets "left behind" and appears to make a turn away from the rotation direction. Together, these deflections set up predictable bands of wind direction near the surface, and give rise to jet streams in the upper atmosphere.

Angle of Sunlight and Seasons

The angle of the Sun's rays is also important for determining the variations in temperature during Earth's seasons. Students combine their understanding of the effect of sunlight angle on energy input from this instructional segment with the orbital motions in the previous instructional segment to create a **model [SEP-2]** that explains the reason for Earth's repeating **pattern [CCC-1]** of seasons (MS-ESS1-1). Students can make these connections using a physical model where their own body represents the motion of the planet (see Space Science Institute, Kinesthetic Astronomy at https://www.cde.ca.gov/ci/sc/cf/ch6.asp#link14). They tilt their body towards or away from the Sun at the same 23.5 degrees tilt as the Earth and move around Earth's orbit, making sure that their tilt axis always points towards the North Star. As they move from one side of the Sun to the other, they see how the angle of the Sun's rays **changes [CCC-7]** in the different hemispheres: in the Northern Hemisphere summer, the tilt brings the angle of the Sun's rays closer to 90 degrees while it makes the angle smaller in the Southern Hemisphere. Computer simulations allow students another way to visualize these changes (see NOAA Climate.gov, Seasons and Ecliptic Simulator, accessed at https://www.cde.ca.gov/ci/sc/cf/ch6.asp#link15).

Learning a scientifically accurate model for the seasons is often impeded by students' incoming preconceptions (documented vividly in the short documentary *Private Universe* [Harvard-Smithsonian Center for Astrophysics 1987] and in review articles [Sneider, Bar, and Kavanagh 2011]). Most notably, students often incorrectly believe that the Earth is closer to the Sun in summer and farther in winter. In this example course sequence, seasons are deliberately placed in a separate instructional segment from the discussion of orbits specifically to increase the association between seasons and Sun angle instead of reinforcing an incorrect connection between seasons and orbital distance. Nonetheless, many students will still harbor this preconception and it must be addressed. Interactive 3-D simulations have been shown to help students confront this preconception (something similar to this simulation can be found at https://www.cde.ca.gov/ci/sc/cf/ch6.asp#link16; it is also described in Bakas and Mikropoulos 2003). In these virtual worlds, students view the Earth–Sun–Moon **system [CCC-4]** from various viewpoints and control different aspects, including rotation and revolution rates, and inclination of Earth's spin axis. The story of seasons is mostly a story of light and energy absorption. Emphasis should be placed on the intensity and duration that sunlight shines on a particular patch of Earth's surface. Because Earth's tilt causes the Sun to appear to travel across the sky along a different path during summer versus winter, the Sun shines for longer days (causing longer duration sunlight) and from higher angles in the sky (causing sunlight to appear more intense on a given patch of the surface). Together, these give rise to warmer summers and cooler winters.

Climate Change

Weather **changes [CCC-7]** on many different **timescales [CCC-3]**. There are trends and **patterns [CCC-1]** that occur over hours, days, seasons, years, decades, and millennia. Shorter-term variations are discussed in the next instructional segment. Scientists typically use the word *climate* to describe patterns of weather that change over longer timescales. Many textbooks overemphasize the difference between the terms weather and climate; they are not different things but instead describe patterns and changes in atmospheric conditions over different timescales. The exact timescale that separates weather patterns from climate patterns is not universally agreed upon, but climate typically includes patterns that persist for decades or longer. Often, climate not only refers to the average conditions for a given location, but also includes a sense of the range of variation throughout the seasons and from year-to-year. Some climate changes may involve relatively small shifts to the average conditions but substantially more frequent extreme weather (i.e., more severe droughts balanced by more extreme flooding or frequent heat waves balanced by frequent cold snaps).

Opportunities for Mathematics Connections

Because temperature is a tangible topic and students have experience with its variation, climate data make an excellent way to engage students in grade six mathematics standards about statistics (CA CCSSM 6.SP.1-5).

Changes [CCC-7] at each **timescale [CCC-3]** are driven by different **causes [CCC-2]**. Some climate changes in Earth's history were rapid shifts (caused by events such as volcanic eruptions and meteoric impacts that suddenly put a large amount of particulate matter into the atmosphere or by abrupt changes in ocean currents). Other climate changes were gradual and longer term—due, for example, to solar output variations, shifts in the tilt of Earth's axis, or atmospheric change due to the rise of plants and other life forms that modified the atmosphere via photosynthesis. Scientists can infer these changes from geological evidence. Students can **analyze data [SEP-4]** from these scientific observations to see how each process can correlate with observed changes in climate. Excellent data sets from tree rings and cherry blossoms exist showing how changes in sunspots and volcanic eruptions were recorded as changes in plant growth over the last 1,000 years (see National Center for Atmospheric Research, I*nvestigating Climate Past: The Little Ice Age Case Study* accessed at https://www.cde.ca.gov/ci/sc/cf/ch6.asp#link17).

Students begin to **analyze data [SEP-4]** showing the temperature history over the last century (figure 6.10). The focus in the middle grades is on **asking questions [SEP-1]** about the **patterns [CCC-1]** they see (MS-ESS3-5). In high school, students will build a **model [SEP-2]** that can help explain the mechanisms causing the **changes [CCC-7]** they see. While graphs like figure 6.10 are simple enough for students to interpret, scientists also use more sophisticated interactive displays of data that depict how temperatures have changed in space and time. More advanced visualizations allow students to zoom into areas of interest (such as regions within California) and watch the time progression (see California Energy Commission, Cal-Adapt at https://www.cde.ca.gov/ci/sc/cf/ch6.asp#link18). As students see the data depicted in new ways, they should be able to ask more detailed questions. For example, the bottom panel of figure 6.10 shows that the Northern Hemisphere has warmed more than the Southern Hemisphere. Why? The eastern part of South America warmed more than the west. Is that due to deforestation of the Amazon, or does it involve more complex interactions? The lowest temperatures are shortly after 1900. What caused that? Did it affect the whole planet equally? These are the types of **questions [SEP-1]** we want our students to start asking even though they won't have the tools to answer them in grade six.

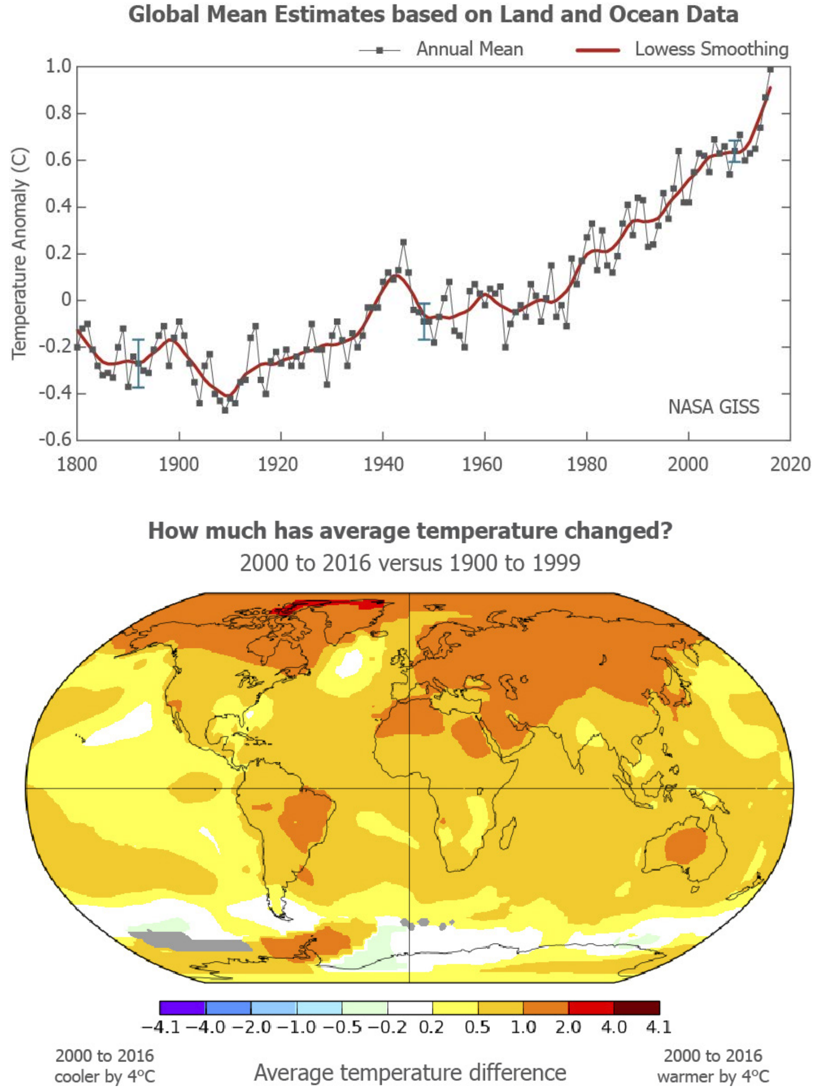
Opportunities for ELA/ELD Connections

The data on temperature changes can come alive when students obtain **information [SEP-8]** about the **effect [CCC-2]** temperature **changes [CCC-7]** have on sea level, glaciers, or storm intensity. Students can review a number of government reports summarizing these changes: EPA Climate Change Indicators accessed at https://www.cde.ca.gov/ci/sc/cf/ch6.asp#link19, National Climate Assessment found at https://www.cde.ca.gov/ci/sc/cf/ch6.asp#link20; or NASA's Climate Effects Web portal at https://www.cde.ca.gov/ci/sc/cf/ch6.asp#link21. Students individually research one aspect and prepare a summary product and present their findings in small groups. To ensure that students who may not volunteer to present have equitable opportunities to be heard, the teacher can strategically select 2-3 students to present to the whole class.

CA CCSS for ELA/Literacy Standards: WHST.6–8.7, 8, 9; RST.6–8.2, SL.6–8.5

CA ELD Standards: ELD.PI.6–8.6

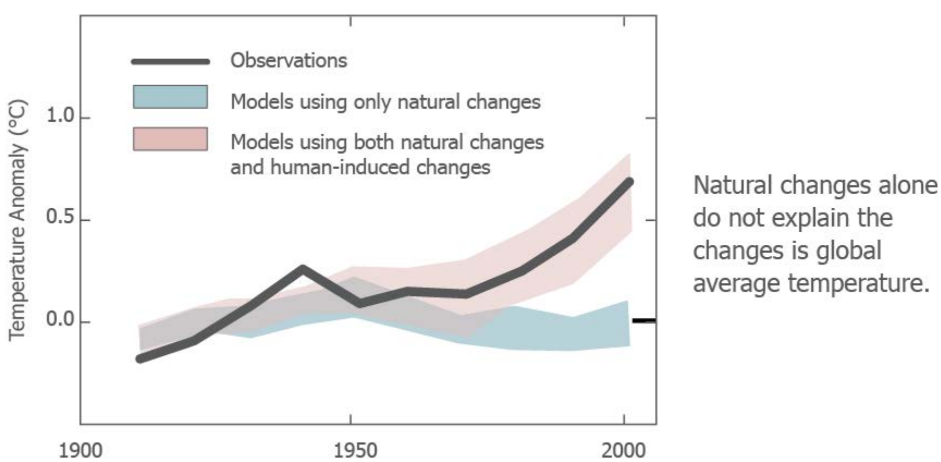
Figure 6.10. Temperature Changes Over Time



Temperature changes over time depicted as a graph of average annual temperatures for the entire globe since 1880 (top) and a map showing changes at different locations, comparing the average from the first portion of the twenty-first century to the twentieth century (bottom). The twenty-first century is warmer than the nineteenth and twentieth centuries. *Source:* NASA 2016
Long description of Figure 6.10.

Several possible natural mechanisms do exist that can **cause [CCC-2]** climate **changes [CCC-7]** over human **timescale [CCC-3]** (tens or hundreds of years), including variations in the Sun's energy output, ocean circulation **patterns [CCC-1]**, atmospheric composition, and volcanic activity (see ESS3.D). When ocean currents change their flow **patterns [CCC-1]**, such as during El Niño Southern Oscillation conditions, some global regions become warmer or wetter and others become colder or drier. When scientists make computer simulations that include only these natural **changes [CCC-7]**, they cannot match the temperature changes from the last century (figure 6.10). But there are also changes caused by human activity (EP&Cs III, IV). Many aspects of modern society result in the release of carbon dioxide and other greenhouse gases. Sources of greenhouse gases include automobiles, power plants or factories that use coal, oil, or gas as an energy source, cement production for buildings and roads, burning forest and agricultural land, and even the raising of livestock, the digestive processes of which emit methane. Greenhouse gases increase the capacity of Earth to retain energy, so changes in these gases cause changes in Earth's average temperature. Changes in surface or atmospheric reflectivity change the amount of energy from the Sun that enters the planetary system. Icy surfaces, clouds, aerosols, and larger particles in the atmosphere, such as from volcanic ash, reflect sunlight and thereby decrease the amount of solar energy that can enter the weather/climate system. Many surfaces that humans construct (e.g., roads, most buildings, agricultural fields versus natural forests) absorb sunlight and thus increase the **energy [CCC-5]** in the **system [CCC-4]**. As students **analyze data [SEP-4]** about greenhouse gas concentrations in the atmosphere, they observe a very similar **pattern [CCC-1]** to the change in temperature (figure 6.10). In fact, computer models of climate show that human activities are an important part of the **cause [CCC-2]** of global temperature changes (figure 6.11).

Figure 6.11. Global Climate Outputs

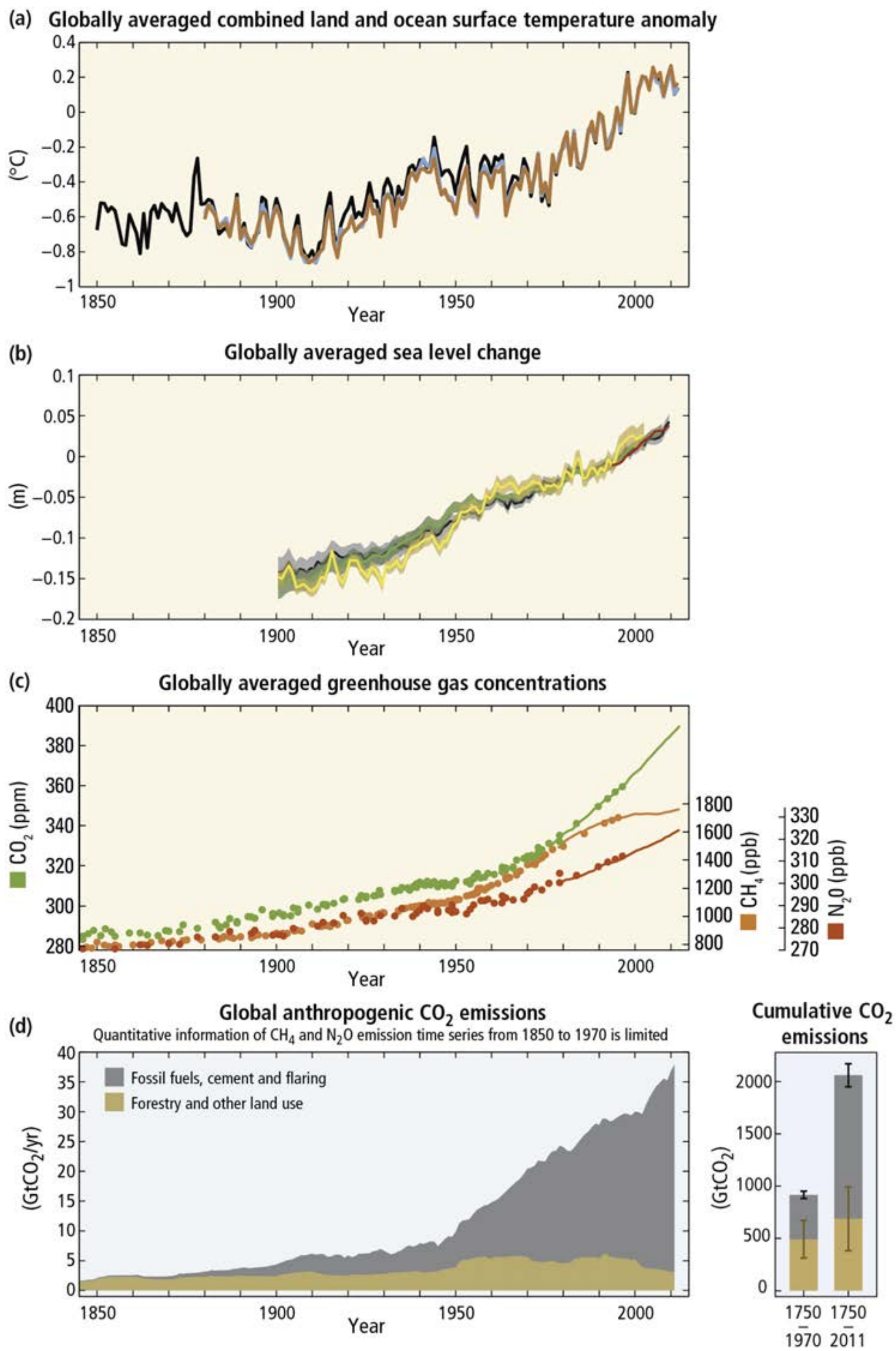


Outputs of different computer models of global climate compared to observations. The colored bands are thick because they represent hundreds of different models created by many different researchers using different assumptions. While the models have slight variations in their output, only models that include human-induced changes can explain the observed temperature record. *Source:* Adapted from figure SPM.4 from *Climate Change 2007: Synthesis Report. Contribution of Working Groups I, II and III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change* [Core Writing Team, Pachauri, R.K. and Reisinger, A. (eds.)]. IPCC, Geneva, Switzerland.
Long description of Figure 6.11.

Opportunities for Mathematics Connections

Global average temperature rises as human activity emits more greenhouse gases (figure 6.12). This rate of emission depends on two key variables: population growth, and **energy [CCC-5]** consumed per person. Students could **construct an argument from evidence [SEP-7]** that connects these population and energy use ideas to a significant impact on Earth's systems (MS-ESS3-4). To gather evidence for their argument, students **obtain information [SEP-8]** from online resources that list population and energy consumption **patterns [CCC-1]**. Students will use **mathematical thinking [SEP-5]** to create meaningful comparisons between the energy use in different states and countries. For example, energy use per person is an example of a unit rate, a term from ratio thinking in mathematics (CA CCSSM 6.RP.2). People in the United States use more than twice as much energy per person than the average European country (U.S. Energy Information Administration n.d.a), probably because our homes are bigger and spaced further apart. Californians, on average, use less energy per person than nearly every other state in the United States (U.S. Energy Information Administration n.d.b), partly due to our mild climate and partly due to effective energy efficiency programs. Despite this fact, the average Californian still uses more than 10 times more energy than the average person in the continent of Africa. These comparisons are examples of ratios and ratio language (CA CCSSM 6.RP.1). Many developing countries around the world have growing populations and are rapidly changing their lifestyles to include more energy intensive tools. They will start consuming energy at rates more like California or even the U.S. average, which could have a huge impact on global climate and global emissions. Computer **models [SEP-2]** that forecast **changes [CCC-7]** in global climate rely on accurate estimates about energy consumption in the future, and in high school students will use computer simulations to explore the effects of these assumptions (HS-ESS3-5).

Figure 6.12. Global Warming Cause and Effect



Graphs with similar trends and patterns illustrate global warming causes and effects. *Source:* Figure SPM.1 from *Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change* [Core Writing Team, Pachauri, R.K. and Meyer, L. (eds.)]. IPCC, Geneva, Switzerland.
Long description of Figure 6.12.

IS3

Integrated Grade Six Instructional Segment 3: Atmosphere/Hydrosphere: Cycles of Matter

California is known for its sunshine more often than its rain and snow, but it relies on both of these to support its extremely productive agricultural sector and supply water to its growing population (EP&C I). The previous instructional segment focused on **energy flows [CCC-5]** and briefly mentioned the **flow of matter [CCC-5]** that enabled some of the energy transfer. This instructional segment looks at the same processes from the perspective of the **cycling of matter [CCC-5]** in both the atmosphere and the hydrosphere (EP&C III).

DISCIPLINE SPECIFIC GRADE SIX INSTRUCTIONAL SEGMENT 3: ATMOSPHERE/HYDROSPHERE: CYCLES OF MATTER

Guiding Questions

- How do we predict tomorrow's weather?
- How do the atmosphere and hydrosphere interact to control our valuable water resources?

Performance Expectations

Students who demonstrate understanding can do the following:

MS-ESS2-1. Develop a model to describe the cycling of Earth's materials and the flow of energy that drives this process. [Clarification Statement: Emphasis is on the processes of melting, crystallization, weathering, deformation, and sedimentation, which act together to form minerals and rocks through the cycling of Earth's materials.] [*Assessment Boundary: Assessment does not include the identification and naming of minerals.*]

MS-ESS2-4. Develop a model to describe the cycling of water through Earth's systems driven by energy from the Sun and the force of gravity. [Clarification Statement: Emphasis is on the ways water changes its state as it moves through the multiple pathways of the hydrologic cycle. Examples of models can be conceptual or physical.] [*Assessment Boundary: A quantitative understanding of the latent heats of vaporization and fusion is not assessed.*]

MS-ESS2-5. Collect data to provide evidence for how the motions and complex interactions of air masses results in changes in weather conditions. [Clarification Statement: Emphasis is on how air masses flow from regions of high pressure to low pressure, causing weather (defined by temperature, pressure, humidity, precipitation, and wind) at a fixed location to change over time, and how sudden changes in weather can result when different air masses collide. Emphasis is on how weather can be predicted within probabilistic ranges. Examples of data can be provided to students (such as weather maps, diagrams, and visualizations) or obtained through laboratory experiments (such as with condensation).] [*Assessment Boundary: Assessment does not include recalling the names of cloud types or weather symbols used on weather maps or the reported diagrams from weather stations.*]

MS-ESS2-6. Develop and use a model to describe how unequal heating and rotation of the Earth cause patterns of atmospheric and oceanic circulation that determine regional climates. [Clarification Statement: Emphasis is on how patterns vary by latitude, altitude, and geographic land distribution. Emphasis of atmospheric circulation is on the sunlight-driven latitudinal banding,

DISCIPLINE SPECIFIC GRADE SIX INSTRUCTIONAL SEGMENT 3: ATMOSPHERE/HYDROSPHERE: CYCLES OF MATTER

the Coriolis effect, and resulting prevailing winds; emphasis of ocean circulation is on the transfer of heat by the global ocean convection cycle, which is constrained by the Coriolis effect and the outlines of continents. Examples of models can be diagrams, maps and globes, or digital representations.] [*Assessment Boundary: Assessment does not include the dynamics of the Coriolis effect*.]

MS-ESS3-2. Analyze and interpret data on natural hazards to forecast future catastrophic events and inform the development of technologies to mitigate their effects. [Clarification Statement: Emphasis is on how some natural hazards, such as volcanic eruptions and severe weather, are preceded by phenomena that allow for reliable predictions, but others, such as earthquakes, occur suddenly and with no notice, and thus are not yet predictable. Examples of natural hazards can be taken from interior processes (such as earthquakes and volcanic eruptions), surface processes (such as mass wasting and tsunamis), or severe weather events (such as hurricanes, tornadoes, and floods). Examples of data can include the locations, magnitudes, and frequencies of the natural hazards. Examples of technologies can be global (such as satellite systems to monitor hurricanes or forest fires) or local (such as building basements in tornado-prone regions or reservoirs to mitigate droughts).]

MS-ESS3-3. Apply scientific principles to design a method for monitoring and minimizing a human impact on the environment.* [Clarification Statement: Examples of the design process include examining human environmental impacts, assessing the kinds of solutions that are feasible, and designing and evaluating solutions that could reduce that impact. Examples of human impacts can include water usage (such as the withdrawal of water from streams and aquifers or the construction of dams and levees), land usage (such as urban development, agriculture, or the removal of wetlands), and pollution (such as of the air, water, or land).]

MS-ESS3-4. Construct an argument supported by evidence for how increases in human population and per-capita consumption of natural resources impact Earth's systems. [Clarification Statement: Examples of evidence include grade-appropriate databases on human populations and the rates of consumption of food and natural resources (such as freshwater, mineral, and energy). Examples of impacts can include changes to the appearance, composition, and structure of Earth's systems as well as the rates at which they change. The consequences of increases in human populations and consumption of natural resources are described by science, but science does not make the decisions for the actions society takes.]

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

Highlighted Science and Engineering Practices	Highlighted Disciplinary Core Ideas	Highlighted Crosscutting Concepts
[SEP-2] Developing and Using Models [SEP-3] Planning and Carrying Out Investigations [SEP-4] Analyzing and Interpreting Data [SEP-7] Engaging in Argument from Evidence	ESS2.A: Earth's Materials and Systems ESS2.C: The Role of Water in Earth's Surface Processes ESS2.D: Weather and Climate ESS3.B: Natural Hazards ESS3.C: Human Impacts on Earth Systems *Other Necessary DCIs:* PS3.B: Conservation of Energy and Energy Transfer	[CCC-1] Patterns [CCC-2] Cause and Effect: Mechanism and Explanation [CCC-4] Systems and System Models [CCC-5] Energy and Matter: Flows, Cycles, and Conservation [CCC-7] Stability and Change

DISCIPLINE SPECIFIC GRADE SIX INSTRUCTIONAL SEGMENT 3: ATMOSPHERE/HYDROSPHERE: CYCLES OF MATTER

Highlighted California Environmental Principles and Concepts:

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

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

CA CCSS Math Connections: MP.2, 6.NS.5, 6.EE.6, 6.RP.1, 7.RP.2a–d, 7.EE.4a–b

CA CCSS for ELA/Literacy Connections: SL.6.5, RST.6–8.1, 7, 9, WHST.6–8.2a–f, 8, 9

CA ELD Connections: ELD.PI.6.6a–b, 10, 9, 11a

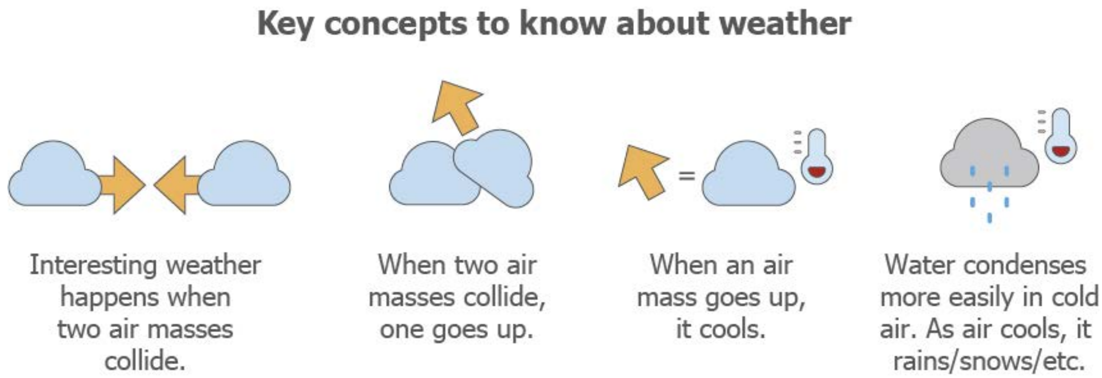
The instructional segment on weather can be structured around the goal of having students create a weather forecast for their community. Classroom instruction focuses on providing students the skills and background they need to complete that task. The forecast theme allows students to explicitly name the observable variables that describe their experience with weather: temperature, wind, humidity, precipitation, and air pressure. Even though the last variable, air pressure, is crucial to understanding weather **changes [CCC-7]**, an effective inquiry-based approach does not introduce it as a key variable at the beginning. After all, people do not directly sense or feel changes in air pressure. Teachers focus on the observable quantities and then encourage students to **ask questions [SEP-1]** about what causes them to change.

Students then **analyze data [SEP-4]**, searching for **patterns [CCC-1]** in the observable weather variables that give clues about the **causes [CCC-2]** of the **changes [CCC-7]** (MS-ESS2-5). Students can examine detailed maps of air pressure and wind patterns to discover that air moves from high pressure to low pressure (for example, see the American Meteorological Society, The Data Stream at https://www.cde.ca.gov/ci/sc/cf/ch6.asp#link22). Understanding why this is true requires some understanding of gases as particles. In grade five, students defined matter as particles that are too small to see (5-PS1-1). In the discipline specific course sequence, they have not yet **developed a model [SEP-2]** of how those particles behave (it comes in grade eight, MS-PS1-4), so a partial model will need to be developed for this discussion. This model simply defines high pressure as having lots of particles of air together in one place, all moving and pushing against one another like people on a crowded dance floor. Lower pressure regions are areas that have fewer particles packed together with more empty space between them. Air particles from the crowded regions will get bumped and pushed into those empty spaces such that there is an overall flow from high pressure to low pressure.

Students combine this **model [SEP-2]** with their model of global convection from the previous unit to create an even richer understanding of the movement of air and water on Earth (MS-ESS2-6). The problem is best illustrated at a small **scale [CCC-3]** along coastlines where landmasses are adjacent to water. Students conduct an **investigation [SEP-3]** into the thermal properties of land versus water to see how they heat and cool at different rates, setting up temperature differentials. This uneven heating **causes [CCC-2]** convection (the movement of air) along coastlines just like it did on the global **scale [CCC-3]** with the temperature differential between the equator and the poles. As air heats up, the particles spread out, and the less dense air begins to rise upwards. The area where air rises up is now lower pressure than its surroundings, so air begins to move from areas where the pressure is higher (typically colder areas). Wind (the movement of air) results from this convection cycle (figure 6.13).

The clarification statement for MS-ESS2-5 indicates that students will not be assessed on weather map symbols. This is largely a reaction to the fact that these symbols are no longer necessary for illustrating weather **patterns [CCC-1]** in the digital age. For example, real-time wind patterns are indicated with animations of the flow of individual particles (Viégas and Wattenberg 2016) or with familiar rainbow color scales (Beccario 2016). These visualization tools allow teachers to spend more time helping students recognize and explain patterns with less time devoted to memorizing symbols.

Figure 6.13. Air Mass Interactions



Important components of a model of weather that describes the interaction of air masses. Diagram by M. d'Alessio
Long description of Figure 6.13.

Using animations of real-time observations (such as satellite data from visible light that reveals clouds and other wavelengths that reveal water vapor, see NOAA Geostationary Satellite Server: Western U.S. Water Vapor accessed at https://www.cde.ca.gov/ci/sc/cf/ch6.asp#link23), students collect data about the movement of large air masses, noticing that the most intense precipitation and weather events occur where air masses collide (MS-ESS2-5). These observations form the **evidence [SEP-7]** that can be used to construct a complete **explanation [SEP-6]** or a **model [SEP-2]** of the relationship between air masses and changing weather conditions. The conceptual model in figure 6.13 shows that these explanations require further investigation into condensation and the movement of water within Earth's systems. For a vignette related to weather, please see grade six of the Preferred Integrated Model.

Water Cycle

At this point in Earth's history, very little water leaves the planet or arrives from space. We simply need to track the movement of the matter that is already here. The water cycle is therefore an example of a **cycle of matter [CCC-5]** within a relatively closed **system [CCC-4]**. In grade five, students created graphs to illustrate where water is located on Earth (5-ESS2-2) and they developed a **model [SEP-2]** for the cycling of matter within the biosphere (5-LS2-1). In grade six, they will extend their **model [SEP-2]** to include the exchange of water between all of Earth's **systems [CCC-4]**, which should enable them to explain the distribution of water they observed in grade five.

Students hold many preconceptions about the way water is cycled through Earth's systems (Ben-zvi-Assarf and Orion 2005). While they may be able to list the locations where water can be found, they often are lacking a **model [SEP-2]** for the interconnectedness between these **systems [CCC-4]** (i.e., water that is in the ground can flow into rivers, oceans, or reach the surface at springs), or a sense for the dynamic movement of water within each system (i.e., surface water does not just sit there waiting to evaporate, but flows constantly down toward the oceans due to the pull of gravity). Teachers can help illustrate the dynamic interconnectedness of the water cycle through a simple kinesthetic game. Students each play the role of a water molecule and will move around the room through different stations that represent places where water is found on Earth (ocean, lake, animal, plant, groundwater, atmosphere, ice cap, etc.). At each station, they roll a die and read from a table about the process that they will undergo so that they can move from one station to another (i.e., evaporation, infiltration into the ground, flow downhill, come to the surface at a mountain spring, etc.). In essence, they become a physical **model [SEP-2]** for all the processes in the water cycle (MS-ESS2-4). The model helps illustrate a number of concepts: (1) each of the reservoirs of groundwater are interconnected; (2) water is constantly moving and flowing within each system and between systems; (3) water is in different states (solid, liquid, and gas) in different reservoirs, and **changes [CCC-7]** in state (evaporation, condensation) are one key way that water can move between different reservoirs; (4) there is no start, end, or single path through the water cycle; and, (5) changes in one part of the water cycle will have a major impact on other parts of the system (e.g., if ice caps melt, sea level will rise; if the climate warms and causes more evaporation, that will lead to more precipitation, which will lead to more runoff).

A model of the water cycle that only describes the **cycling of matter [CCC-5]** does not completely fulfill MS-ESS2-4, which requires students to explain how **energy [CCC-5]** exchanged via sunlight and gravity drives much of the movement. Additional **investigations [SEP-3]** into several of the processes that cause movement of water through the water cycle will help students understand these processes well enough to integrate them into their **model [SEP-2]**.

Energy [CCC-5] from sunlight has an **effect [CCC-2]** on the water cycle because the increase in thermal energy that it **causes [CCC-2]** can in turn **cause [CCC-2]** phase **changes [CCC-7]**. Students conduct **investigations [SEP-3]** into evaporation and condensation to experience how they enable the cycling of water and how they relate to **energy flow [CCC-5]**. They recognize the **pattern [CCC-1]** that when water absorbs energy, it heats up and evaporates more readily. As water vapor cools, it condenses, releasing energy back into the surrounding air. Because a detailed model of matter and state changes is not introduced until grade eight (MS-PS1-4), many students come away from these activities believing the incorrect idea that water is the only material that can exist in all three states of matter (after all, we only conduct this experiment with water and not other materials). This preconception gets reinforced when students hear the true statement that water is the only material that exists in all three states at the range of natural temperatures and pressures at Earth's surface (they seem to ignore the last part about natural conditions on Earth).

The force of gravity **causes [CCC-2]** movement in the water cycle. Most students are able to explain the role of gravity in precipitation ("raindrops fall") or surface water ("rivers flow downhill"), but often overlook the crucial role that gravity plays in infiltration of surface water into the groundwater, the flow of groundwater itself through tiny pores (illustrated as a saturated sponge drips water down out the bottom), and the flow of ice downhill in glaciers (easily illustrated by time-lapse videos of glacier movement). To emphasize these **cause and effect [CCC-2]** relationships with gravity, students create skits of different processes within the water cycle in which one student is assigned to play gravity or sunlight and must interact with other characters in the skit, such as water molecules or grains of sand. Short dramatic performances have been shown to improve students' conceptual understanding in science classes (Ødegaard 2003) and should support language development. Drama comes in many forms, but can be particularly well suited to **developing models [SEP-2]** of **systems [CCC-4]** by having individual characters play the role of components within the system while their words and actions portray the relationships among the components. The exchange of props between characters can be a physical **model [SEP-2]** of **cycles of matter [CCC-5]**.

Engineering Connection: Solutions To Pollution Moved By The Water Cycle

Moving water often carries pollutants along with it (EP&C IV), but understanding the water cycle allows people to design measures to reduce or stop the flow of pollution. One possible engineering challenge for students is to deal with the flow of water and pollutants in urban areas. As water runs along road surfaces, it picks up oil, grit, and other pollutants that flow into storm drains and out into local waterways. During heavy rainstorms, those waterways can get overloaded and flood. Allowing a greater fraction of water to infiltrate into the ground can solve two problems. First it reduces the amount of water on the surface that causes flooding and, second, the soil filters out many harmful contaminants before they enter groundwater or surface water. Students can be given the challenge of designing a system that diverts waters into the ground and provides the maximum filtration of that water (for example, see *Engineering is Everywhere, Don't Runoff: Engineering An Urban Landscape* accessed at https://www.cde.ca.gov/ci/sc/cf/ch6.asp#link24). Students will have to define specific criteria to measure their success (MS-ETS1-1), brainstorm and compare different possibilities (MS-ETS1-2), test those possibilities (MS-ETS1-3), and make iterative improvements (MS-ETS1-4).

Human Interaction with the Water Cycle

Because of the water cycle, Californians are able to obtain a steady supply of fresh water for drinking, irrigation, industrial, and agricultural uses (EP&C III). Even in years with abundant precipitation, California still draws water from a total of seven nearby states in addition to its own supply (Klausmeyer and Fitzgerald 2012). Of the water extracted for human use (developed water), more than 75 percent of it goes to agriculture (California Department of Water Resources 2014). This helps California grow more food than any other state (United States Department of Agriculture 2015). While water is part of all agriculture, some foods require more water to grow than others. If people choose to eat more water efficient foods, California can cut back on its per-capita consumption of water. Looking at data tables showing the water required for different food types, students can compare the water footprint of several different meals. They will find that a diet rich in meat products requires nearly twice as much water as a diet based on vegetables and other plant products. For example, the average beef burger takes four times more water to produce than the same number of calories from an average soy burger (Ercin, Aldaya, and Hoekstra 2012). The difference goes beyond water usage, but includes other resources such as the land area required to grow the food and **energy [CCC-5]** resources to fertilize, transport, and process it. During their study of life science in grade seven and high school, students will learn more about food pyramids and the concept of trophic levels that will help them understand why this should be the case. In brief, predators inherently require more total energy input from the ecosystem than their prey because of the energy used by the prey during its lifetime that is not preserved within its biomass. Students can obtain global data about the relationship between urbanization, rising incomes, and large increases in the amount of meat consumed per person (expected to nearly double the levels from 1960 by the year 2030) (World Health Organization n.d.). With more people in the world eating more meat, there is increasing pressure on water and other resources. Each family makes lifestyle choices about the food they eat, and students should be able to construct an **argument [SEP-7]** that different lifestyle choices come at the price of increased resource consumption (MS-ESS3-4). To connect to health and nutrition, they might include evidence that many eating habits that use fewer resources are also healthier.

IS4

Integrated Grade Six Instructional Segment 4: Geosphere: Surface Processes

Every rock records a story. Earth scientists look at a landscape and **ask questions [SEP-1]** about both the processes that are actively shaping it today and the specific sequence of events in the past that led up to the present day. Scientists **plan and conduct investigations [SEP-3]** to answer those questions, but investigations in Earth and space science cannot always take the same experimental form for testing hypotheses that they might in analytical chemistry or experimental physics. Many Earth processes take millions of years and cover thousands of square miles; these time and distance **scales [CCC-3]** are too slow and too large to reproduce in a lab. Geologists often refer to the Earth as their “natural laboratory,” but they can only see the final result of its ancient experiments—Earth’s present-day landscape. Earth scientists often begin investigations with careful observations of what the Earth looks like today and then try to reproduce similar features in small-scale laboratory experiments or computer simulations.

DISCIPLINE SPECIFIC GRADE SIX INSTRUCTIONAL SEGMENT 4: GEOSPHERE: SURFACE PROCESSES

Guiding Questions

- How can we read layers of rock like the pages of a history book to reconstruct what happened during Earth's past?
- What is the relationship between the way rocks are built up (deposition) and the way rocks are broken down (erosion)?
- How does our understanding of erosion and deposition help us find valuable energy and water resources and make ourselves safer from landslides?

Performance Expectations

Students who demonstrate understanding can do the following:

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

MS-ESS2-1. Develop a model to describe the cycling of Earth's materials and the flow of energy that drives this process. [Clarification Statement: Emphasis is on the processes of melting, crystallization, weathering, deformation, and sedimentation, which act together to form minerals and rocks through the cycling of Earth's materials.] [*Assessment Boundary: Assessment does not include the identification and naming of minerals.*]

MS-ESS2-2. Construct an explanation based on evidence for how geoscience processes have changed Earth's surface at varying time and spatial scales. [Clarification Statement: Emphasis is on how processes change Earth's surface at time and spatial scales that can be large (such as slow plate motions or the uplift of large mountain ranges) or small (such as rapid landslides or microscopic geochemical reactions), and how many geoscience processes (such as earthquakes, volcanoes, and meteor impacts) usually behave gradually but are punctuated by catastrophic events. Examples of geoscience processes include surface weathering and deposition by the movements of water, ice, and wind. Emphasis is on geoscience processes that shape local geographic features, where appropriate.]

DISCIPLINE SPECIFIC GRADE SIX INSTRUCTIONAL SEGMENT 4: GEOSPHERE: SURFACE PROCESSES

MS-ESS3-1. Construct a scientific explanation based on evidence for how the uneven distributions of Earth's mineral, energy, and groundwater resources are the result of past and current geoscience processes. [Clarification Statement: Emphasis is on how these resources are limited and typically non-renewable, and how their distributions are significantly changing as a result of removal by humans. Examples of uneven distributions of resources as a result of past processes include but are not limited to petroleum (locations of the burial of organic marine sediments and subsequent geologic traps), metal ores (locations of past volcanic and hydrothermal activity associated with subduction zones), and soil (locations of active weathering and/or deposition of rock).]

MS-ESS3-2. Analyze and interpret data on natural hazards to forecast future catastrophic events and inform the development of technologies to mitigate their effects. [Clarification Statement: Emphasis is on how some natural hazards, such as volcanic eruptions and severe weather, are preceded by phenomena that allow for reliable predictions, but others, such as earthquakes, occur suddenly and with no notice, and thus are not yet predictable. Examples of natural hazards can be taken from interior processes (such as earthquakes and volcanic eruptions), surface processes (such as mass wasting and tsunamis), or severe weather events (such as hurricanes, tornadoes, and floods). Examples of data can include the locations, magnitudes, and frequencies of the natural hazards. Examples of technologies can be global (such as satellite systems to monitor hurricanes or forest fires) or local (such as building basements in tornado-prone regions or reservoirs to mitigate droughts).]

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

Highlighted Science and Engineering Practices	Highlighted Disciplinary Core Ideas	Highlighted Crosscutting Concepts
[SEP-2] Developing and Using Models [SEP-4] Analyzing and Interpreting Data [SEP-6] Constructing Explanations (for science) and Designing Solutions (for engineering)	ESS1.C: The History of Planet Earth ESS2.A: Earth's Materials and Systems ESS2.C: The Roles of Water in Earth's Surface Processes ESS3.A: Natural Resources ESS3.B: Natural Hazards *Other Necessary DCIs:* LS4.A: Evidence of Common Ancestry and Diversity	[CCC-1] Patterns [CCC-2] Cause and Effect: Mechanism and Explanation [CCC-3] Scale, Proportion, and Quantity [CCC-7] Stability and Change

DISCIPLINE SPECIFIC GRADE SIX INSTRUCTIONAL SEGMENT 4: GEOSPHERE: SURFACE PROCESSES

Highlighted California Environmental Principles and Concepts:

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

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

CA CCSS Math Connections: MP2, 6.EE.6, 7.EE.4a–b

CA CCSS for ELA/Literacy Connections: ELD.PI.6.6a–b, 10, 9, 11a

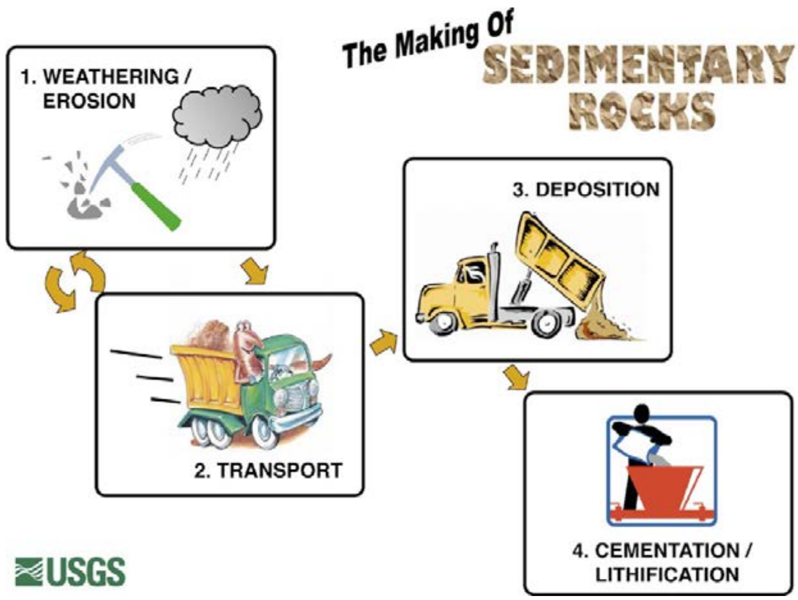
CA ELD Connections: SL.6.5, RST.6–8.1, 7, WHST.6–8.2a–f

Students can develop an Earth science mindset when walking around their own schoolyard and making observations about the familiar processes that led to its present-day state (United States Geological Survey [USGS] 2016b, Lesson 3). For example, students can probably picture a brick wall being built layer-by-layer, or that concrete starts off as grains of sand mixed with cement and water, and then hardens into a solid. Not only can they observe those processes directly in their everyday life, they can see evidence of those processes as they walk around the schoolyard. For example, by looking closely at concrete, they can see grains of sand of different sizes held together with a gray material. As they look at these features, they realize that they can **ask questions [SEP-1]** about the world around them and how it came to look the way that it does. Teachers can then introduce some natural geologic landscapes and processes that act on Earth and relate them to analogous processes from construction on the schoolyard.

Earth scientists try to read layers of rocks like the pages of a history book. The composition and texture of each layer of rock reveals a snapshot of what the world looked like when that layer formed, and the sequence of layers reveals major events that reshaped them. In Earth science, these layers are the expression of the crosscutting concept of **structure and function [CCC-6]**. While in life sciences and engineering, structures have specific shapes so that they can accomplish certain functions, in Earth science structure is often a direct consequence of the processes shaping the planet.

Each of these layers is built from material that came from somewhere else; this **cycle of matter [CCC-5]** is referred to as the rock cycle. This instructional segment focuses on a portion of the rock cycle that occurs near the surface of the Earth where existing rocks are broken into pieces that are then moved around, reshaped, and combined back into a solid rock again. Rocks that are made directly from pieces of other rocks in these processes are called sedimentary rocks (figure 6.14).

Figure 6.14. Sedimentary Rock Processes



Processes involved in the making of sedimentary rocks. *Source*: United States Geological Survey (USGS) 2016a
Long description of Figure 6.14.

Engineering Connection: Cement and Sedimentary Rocks

Students may not realize it, but they are already familiar with sedimentary rocks because most materials in the built environment such as roads, sidewalks, bricks, and concrete are essentially artificial sedimentary rocks with small pieces of rock material cemented together. The average American is responsible for the use of nearly 9 tons of crushed rock material every year of their life (USGS 1999b). These artificial materials are carefully engineered to have sufficient strength at the lowest cost. Students can **obtain information [SEP-8]** about where rock aggregate comes from in their community (it is very heavy and expensive to transport and usually quarried as locally as possible). The process of cementation of natural sedimentary rocks usually occurs slowly underground as mineral-rich water flows through pore spaces between grains, but it can be sped up by adding concentrated cement minerals and water in a concrete truck. To develop a **model [SEP-2]** of how sedimentary rocks form (such as figure 6.14; MS-ESS2-1), students can engage in an engineering challenge to create the most durable concrete from plaster of Paris and rock pieces of different sizes and shapes (sand, smooth pebbles, angular pebbles, etc …). (A short snippet for this idea is accessed at https://www.cde.ca.gov/ci/sc/cf/ch6.asp#link25.) They decide the ideal **proportions [CCC-3]** to mix the materials in small paper cups. After letting their “concrete” dry, they remove the paper cup and see whose material is strongest by piling on different amounts of weight or dropping it from different heights (MS-ETS1-2). This process helps motivate the rest of the instructional segment as it provides students a physical model for the steps of sedimentary rock formation as well as introducing them to the idea that rocks are broken down through the process of erosion.

Students are now ready to apply their **model [SEP-2]** for how sedimentary rocks form to **constructing explanations [SEP-6]** of how the Earth’s surface has **changed [CCC-7]** over time (MS-ESS2-2). The composition of the grains in a sedimentary rock matches the composition of the original source rock. For example, some conglomerate rocks called the Gualala Formation located near Point Arena in Northern California contain large chunks of a rock that appears to match the composition of the Gold Hill/Logan Gabbro in central California. As rocks are transported by wind, water, and gravity, the pieces are broken down into smaller pieces and jagged edges are smoothed over time. The Gualala Formation has grains that are large, so they could not have been transported very far by water before they were deposited and cemented into a solid rock. In this case, however, some pieces of the Gualala Formation are found hundreds of miles away from their matching source rock. In addition to the small amount of movement by water and gravity, scientists infer that these rocks were transported along half of California by the San Andreas Fault over millions of years. Students can **carry out an investigation [SEP-3]** similar to these scientists by examining a sedimentary rock (in hand sample or photographs) and trying to match it to different potential source rocks. They will have to **plan the investigation [SEP-3]** by deciding what features to observe in order to distinguish the different rocks and should consider things like the size, shape, and composition of the grains. This form of investigation where students are limited to observations and comparisons is common in Earth science, where it is often difficult to manipulate variables and experiments because the time and spatial **scales [CCC-3]** of Earth processes are so large.

There are situations where Earth scientists can perform **investigations [SEP-3]** that simulate real-world processes at the small **scale [CCC-3]**. A stream table (a sloped table or plastic bin covered with sand and other earth materials and flooded with water) is a platform for exploration about erosional processes and is an example of both a hands-on **investigation [SEP-3]** and a physical **model [SEP-2]** that can be used to predict possible outcomes. Students can use a stream table to investigate the factors that affect how quickly material is broken off (weathered) and transported (eroded). When the movement of water drives erosion, the steepness of the slope has a huge impact on the rate of erosion because the pull of gravity is less impeded and water flows more quickly down the steep hill (i.e., with more kinetic energy, PS2.A). As the water molecules collide with the soil and rock, they can dislodge individual pieces and carry them away. Students can also identify **patterns [CCC-1]** in the shapes of landforms in the stream table that might be similar to local landforms, such steeply carved river channels that make meandering bends or wedge-shaped delta and alluvial fan deposits that form when the river reaches a flat section at the bottom of a steep slope.

Forecasting Erosion Hazards: Landslides

Landslides are a rapid form of erosion that can damage property and put peoples' lives at risk. Thankfully, areas that are most at risk for landslide hazard are easy to recognize: steep slopes made of loose sediments are most at risk. Landslides are also much more likely to happen during periods of intense rainfall, so their timing can be forecast as well. Students can qualitatively explore these risk factors using a stream table (a plastic tub filled with sand to represent Earth's surface and cups of water as agents of erosion). They can **carry out an investigation [SEP-3]** varying slope steepness by changing the angle of the plastic tub, strength of different rocks by testing different mixtures of clay and sand, and different rainfall intensities by using water containers with different size holes. They can then **analyze data [SEP-4]** from real landslides in their local area using a state database of historical landslide studies (MS-ESS3-2) (see California Department of Conservation, Landslide and/or Liquefaction maps accessed at http://www.cde.ca.gov/ci/sc/cf/ch6.asp#link26). Depending on data availability in their area, their analysis could look for **patterns [CCC-1]** in the sizes or locations of landslides in comparison to the steepness of slopes or the types of rocks. Because landslides tend to occur over and over again in the same regions, this type of historical data helps inform the creation of maps of landslide hazards produced by the state. Students can also **obtain information [SEP-8]** from government agencies about efforts to provide real-time forecasts of landslides in California so that people can either instigate timely measures to reduce their hazard (these might include installing sandbags, pumping water, or evacuating) (see NOAA/USGS Demonstration Flash-Flood and Debris-Flow Early-Warning System found at http://www.cde.ca.gov/ci/sc/cf/ch6.asp#link27). This discussion has important ties to IS3's discussion of weather patterns and the water cycle, but also to IS1's discussion of climate **change [CCC-7]**. In high school, students will explore how landslide hazards could increase due to climate change (HS-ESS3-5).

Depositing New Layers

Pieces of rocks and minerals, often called "grains" when discussing rock formation, are transported by gravity or moving wind and water. Conditions can **change [CCC-7]** such that there is no longer enough **energy [CCC-5]** in these **systems [CCC-4]** to continue to carry the pieces, so they settle out and are deposited. For example, water moves quickly as it races down a steep hillside, but slows when it reaches a lake or the ocean at the bottom of the hill. As the water slows, bigger grains settle first because they take the most energy to move. In a classroom, the relationship between grain size and water velocity can be illustrated in a large bottle filled with sand, soil, and water. After being shaken, the largest grains of sand will fall out quickly, but the water at the top will remain muddy for hours. When left overnight, the water will slow down enough that even the fine grains will settle and leave clear, clean water at the top of the bottle. In nature, the deposition of layers also buries any dead organisms and leads to the formation of fossils. By looking at the types of organisms and the sizes of the grains, scientists can reconstruct the geologic conditions in which the layer formed (i.e., was it a steep slope, where the river meets the ocean, or far out to sea?). Sediment that is deposited later buries previously deposited layers like a row of bricks placed on top of previously laid bricks to construct a wall.

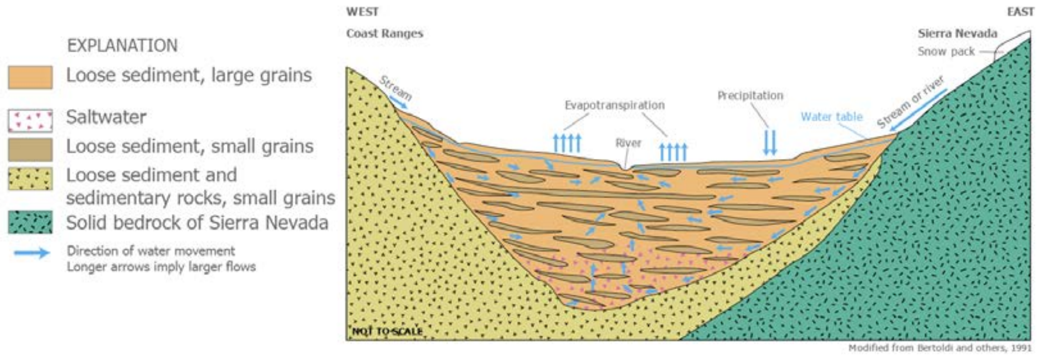
Observing how layers **change [CCC-7]** within a vertical sequence allows scientists to track **changes [CCC-7]** in the environment over time. The formation of mountain chains (that push up mountains and therefore increase erosion on steep slopes) and ocean basins (new places where rocks can settle out and be deposited) is gradual while volcanic eruptions, and asteroid impacts are more abrupt. Periods of glaciation and warming occur at intermediate timescales. **Changes [CCC-7]** of all **timescales [CCC-3]** are recorded as changes in the rock layers and the fossils trapped within them. From this progression of layers, geologists can reconstruct a timeline of the entire history of the Earth. Students likely have heard of the names of geologic periods like Jurassic, but exposure to these names in the middle grades is distracting from the overall goal of using layers to determine the relative timing of major events in Earth's history. For example, major extinction events are recorded in layers of rocks as decreases in the diversity of fossils around the world at the same period in geologic time. Students can **obtain information [SEP-8]** from movies, informational articles, or other resources in order to **construct an explanation [SEP-6]** of how evidence from layers of rock helped scientists identify a major event in geologic history (MS-ESS1-4). Examples with a strong California focus include the extinction of the dinosaurs 65 million years ago (a classic illustration of the nature of scientific discovery that follows the work of University of California scientists). Useful resources include Howard Hughes Medical Institute, *The Day the Mesozoic Died* accessed at https://www.cde.ca.gov/ci/sc/cf/ch6.asp#link28; and University of California Museum of Paleontology, *Asteroids and dinosaurs: Unexpected twists and an unfinished story* at https://www.cde.ca.gov/ci/sc/cf/ch6.asp#link29. The eruption history of a supervolcano like Long Valley caldera in Eastern California or the history of past glacial periods can be determined by looking at layers in sediment cores taken from lakes in the region.

Sediment Deposition, Groundwater Flow, and Energy Resources

The storage and flow of groundwater depends greatly on the materials that make up the layers of rock and soil and how they formed. When layers of sediment are first deposited, there is space between individual grains that water can flow through like pores of a sponge. Sediment deposited in slowly moving water has small grains like silt and mud with small and poorly interconnected pore spaces, so water does not flow well through them. In environments where larger grains are deposited, the larger spaces between grains tend to be well interconnected and water can flow through them easily. Students can probably visualize dumping a bucket of water in a sandbox and having the water flow quickly downward into the sand, but muddy soil prevents the flow of water and mud puddles can exist for hours after a rainstorm. A geologic setting where large particles are deposited will have layers of material that enable groundwater flow. However, as the climate and environment **change [CCC-7]** in cycles over time, one location can alternate between layers with small grains and layers with larger grains, so that the flow of water varies from layer to layer.

Students can combine their **models [SEP-2]** of sediment deposition and groundwater flow to **construct an explanation [SEP-6]** of how ancient geologic processes affect the present-day distribution of groundwater resources in California (MS-ESS3-1). Figure 6.15 shows California's Central Valley, which has accumulated thousands of feet of sediment that eroded off the Sierra Nevada during the last 100 million years. The sediments are not all the same, however. There was once a shallow sea covering the Central Valley, so only fine-grained sediments settled out to form layers. As plate movements and climate **changed [CCC-7]**, sea level changed and fast moving rivers flowing over the land brought larger grains. As rivers changed their courses over time, the size of grains being deposited at each individual location varied, leaving behind thin lens-shaped layers of fine-grained sediments that impede the flow of water. In some cases, these impermeable layers extend so far across the valley that they separate different pockets of groundwater from one another. These different pockets of groundwater are a major source of water for farming in the Central Valley, especially in years of drought when rain and snow do not provide sufficient surface water. While the details differ, similar processes occur in other valleys of all sizes throughout the state. When students look at a map showing the location of groundwater wells throughout the state (for example, see State Water Resources Control Board, Groundwater Ambient Monitoring and Assessment at https://www.cde.ca.gov/ci/sc/cf/ch6.asp#link30; USGS, National Water Information System Mapper at https://www.cde.ca.gov/ci/sc/cf/ch6.asp#link31), they should recognize the **pattern [CCC-1]** that the vast majority of them are on valley floors where layers of soft sediment have been recently deposited.

Figure 6.15. Groundwater and the Water Cycle

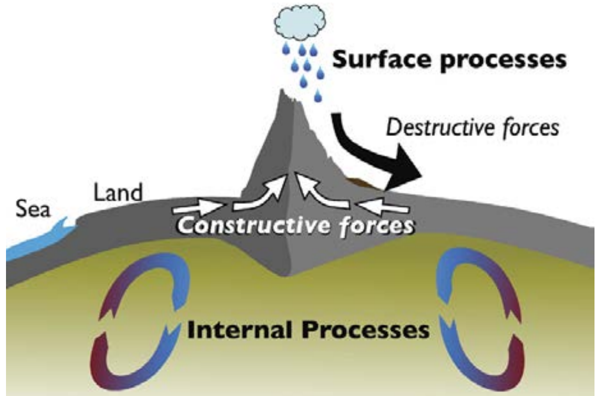


A slice through California's Central Valley emphasizing groundwater flow through sediment as part of the water cycle. Water flows easily through the loose sediment made of large grains but does not penetrate easily into the small-grained loose sediments or the rocks beneath them. Gravity causes water to flow downward on both sides of the valley, but gets pushed back up when these flows converge along the axis of the valley, contributing water to the rivers and marshland in the valley.
Source: Bertoldi, Johnston, and Evenson 1991
Long description of Figure 6.15.

Water is not the only important resource that can flow through rocks; students can apply the same conceptual **models [SEP-2]** to **explain [SEP-6]** how crude oil and natural gas flow through pore spaces in rocks and can become trapped by layers with low permeability (MS-ESS3-1). Scientists working for oil and gas companies study the geologic history of an area so that they can target their drilling towards pockets where oil and gas are trapped. These scientists must also consider whether or not the geologic history of an area includes the deposition of large amounts of organic material (dead organisms) along with the original sediments. That organic material slowly "matures" into oil or gas resources through a series of chemical reactions sped up by the heat and pressure of burial. The reason these **energy [CCC-5]** resources are so valuable is that it is rare for layers to be deposited in the ideal sequence for creating and preserving them: first a layer with abundant organic materials needs to be deposited, then a layer with large pore spaces through which oil and gas can flow and accumulate needs to be deposited on top of that, and finally a layer with tiny grains to block the flow of oil and trap it at the right depth underground where it can be preserved for millions of years needs to be deposited.

In this instructional segment, students have focused solely on the development of layers of sedimentary rock near Earth's surface and their relationship to the destructive force of erosion. Many of the **changes [CCC-7]** in what happens at the surface are in fact driven by major changes inside Earth (figure 6.16). The next instructional segment focuses on those processes.

Figure 6.16. Processes That Shape Landscapes



Landscapes are shaped at a range of timescales by processes inside the Earth and on the surface. Diagram by M. d'Alessio.
Long description of Figure 6.16.

IS5 Integrated Grade Six Instructional Segment 5: Geosphere: Internal Processes

If erosion were the only process sculpting Earth's surface, all of the mountains would eventually wear away. While some of the mountains on Earth do look smooth and rounded because erosion has flattened them out, others look sharp and jagged as though they have not been exposed and weathered for very long at all. Is there a process that somehow renews mountain ranges, pushing them up so that erosion can then tear them down?

DISCIPLINE SPECIFIC GRADE SIX INSTRUCTIONAL SEGMENT 5: GEOSPHERE: INTERNAL PROCESSES

Guiding Questions

- How can the shapes of landforms at the surface help us understand processes that are going on deep within the Earth?
- How can understanding plate motions help us locate resources (energy, mineral, and water) and protect ourselves from natural hazards?

Performance Expectations

Students who demonstrate understanding can do the following:

MS-ESS2-1. Develop a model to describe the cycling of Earth's materials and the flow of energy that drives this process. [Clarification Statement: Emphasis is on the processes of melting, crystallization, weathering, deformation, and sedimentation, which act together to form minerals and rocks through the cycling of Earth's materials.] [*Assessment Boundary: Assessment does not include the identification and naming of minerals*.]

DISCIPLINE SPECIFIC GRADE SIX INSTRUCTIONAL SEGMENT 5: GEOSPHERE: INTERNAL PROCESSES

MS-ESS2-2. Construct an explanation based on evidence for how geoscience processes have changed Earth's surface at varying time and spatial scales. [Clarification Statement: Emphasis is on how processes change Earth's surface at time and spatial scales that can be large (such as slow plate motions or the uplift of large mountain ranges) or small (such as rapid landslides or microscopic geochemical reactions), and how many geoscience processes (such as earthquakes, volcanoes, and meteor impacts) usually behave gradually but are punctuated by catastrophic events. Examples of geoscience processes include surface weathering and deposition by the movements of water, ice, and wind. Emphasis is on geoscience processes that shape local geographic features, where appropriate.]

MS-ESS2-3. Analyze and interpret data on the distribution of fossils and rocks, continental shapes, and seafloor structures to provide evidence of the past plate motions. [Clarification Statement: Examples of data include similarities of rock and fossil types on different continents, the shapes of the continents (including continental shelves), and the locations of ocean structures (such as ridges, fracture zones, and trenches).] [*Assessment Boundary: Paleomagnetic anomalies in oceanic and continental crust are not assessed*.]

MS-ESS3-1. Construct a scientific explanation based on evidence for how the uneven distributions of Earth's mineral, energy, and groundwater resources are the result of past and current geoscience processes. [Clarification Statement: Emphasis is on how these resources are limited and typically non-renewable, and how their distributions are significantly changing as a result of removal by humans. Examples of uneven distributions of resources as a result of past processes include but are not limited to petroleum (locations of the burial of organic marine sediments and subsequent geologic traps), metal ores (locations of past volcanic and hydrothermal activity associated with subduction zones), and soil (locations of active weathering and/or deposition of rock).]

MS-ESS3-2. Analyze and interpret data on natural hazards to forecast future catastrophic events and inform the development of technologies to mitigate their effects. [Clarification Statement: Emphasis is on how some natural hazards, such as volcanic eruptions and severe weather, are preceded by phenomena that allow for reliable predictions, but others, such as earthquakes, occur suddenly and with no notice, and thus are not yet predictable. Examples of natural hazards can be taken from interior processes (such as earthquakes and volcanic eruptions), surface processes (such as mass wasting and tsunamis), or severe weather events (such as hurricanes, tornadoes, and floods). Examples of data can include the locations, magnitudes, and frequencies of the natural hazards. Examples of technologies can be global (such as satellite systems to monitor hurricanes or forest fires) or local (such as building basements in tornado-prone regions or reservoirs to mitigate droughts).]

DISCIPLINE SPECIFIC GRADE SIX INSTRUCTIONAL SEGMENT 5: GEOSPHERE: INTERNAL PROCESSES

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

Highlighted Science and Engineering Practices	Highlighted Disciplinary Core Ideas	Highlighted Crosscutting Concepts
[SEP-2] Developing and Using Models [SEP-3] Planning and Carrying Out Investigations [SEP-4] Analyzing and Interpreting Data [SEP-6] Constructing Explanations (for science) and Designing Solutions (for engineering)	ESS1.C: The History of Planet Earth ESS2.A: Earth's Materials and Systems ESS2.B: Plate Tectonics and Large-Scale System Interactions ESS2.C: The Roles of Water in Earth's Surface Processes ESS3.A: Natural Resources ESS3.B: Natural Hazards *Other Necessary DCIs:* LS4.A: Evidence of Common Ancestry and Diversity	[CCC-1] Patterns [CCC-2] Cause and Effect: Mechanism and Explanation [CCC-3] Scale, Proportion, and Quantity. [CCC-5] Energy and Matter: Flows, Cycles, and Conservation [CCC-7] Stability and Change

Highlighted California Environmental Principles and Concepts:

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

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

CA CCSS Math Connections: MP2, 6.EE.6, 7.EE.4a–b

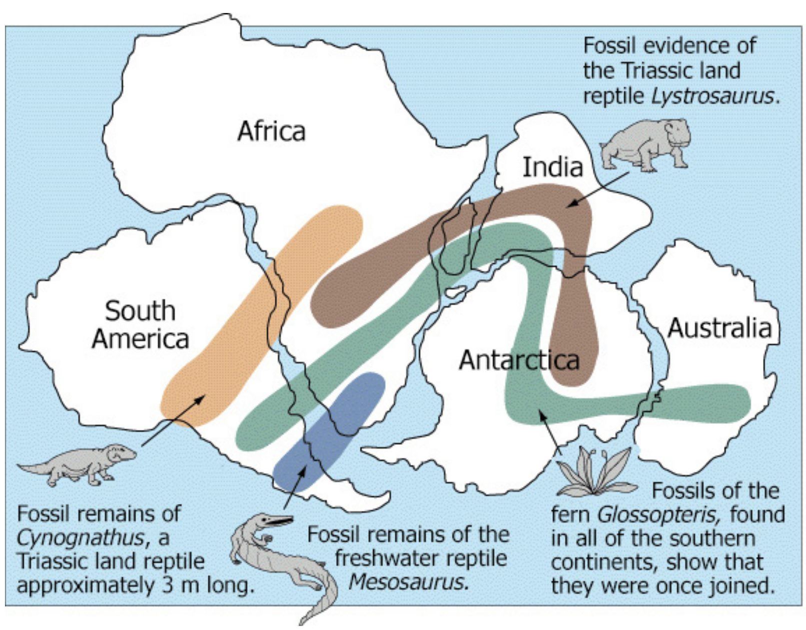
CA CCSS for ELA/Literacy Connections: SL.6.5, RST.6–8.1, 7, WHST.6–8.2a–f

CA ELD Connections: ELD.PI.6.6a–b, 10, 9, 11a

In the early 1900s, a scientist named Alfred Wegener looked at locations of mountain ranges and noticed some **patterns [CCC-1]**. He saw that the Appalachian Mountains were made of the same unique rock types as the Scottish Highlands across the Atlantic, and that a mountain range in South Africa was similar to one in Brazil. He **asked questions [SEP-1]** about what could possibly explain the large present-day separation, so he considered the idea that all of Earth's continents could have been connected together millions of years ago and subsequently moved to their current locations. He gathered substantial **evidence [SEP-7]** that supported this proposed **explanation [SEP-6]** and he began to refer to the idea as *continental drift*. (An English translation of Wegener's 1912 article outlines the full range of his evidence [Wegener 1912]). Some of this evidence came from using maps to show how well the continents fit together, especially including the submerged continental shelves in aligning the continents, and most obviously with South America and Africa.

Even more persuasive was **evidence [SEP-7]** from fossils and rocks. Figure 6.17 shows continents from the Southern Hemisphere and how they could have been joined together hundreds of millions of years ago. The colored areas correspond to fossils whose specific geographic locations indicate not only that these continents were joined together, but also specifically that the connection points match those predicted by matching the outlines of the continents. The current wide separation of these continents precludes other easy explanations for the locations of these fossils.

Figure 6.17. Fossil Evidence of Continental Drift



Source: United States Geological Survey (USGS) 1999a
Long description of Figure 6.17.

Wegener also traced the past positions and motions of ancient glaciers based on grooves cut by those glaciers in rocks, and also by rock deposits that the glaciers left on different continents. His **evidence [SEP-7]** indicated that if the continents had been in their current locations, the glaciers would have formed very close to the equator, an extremely unlikely situation. If the continents moved as he hypothesized, those glaciers would have formed much closer to the South Pole.

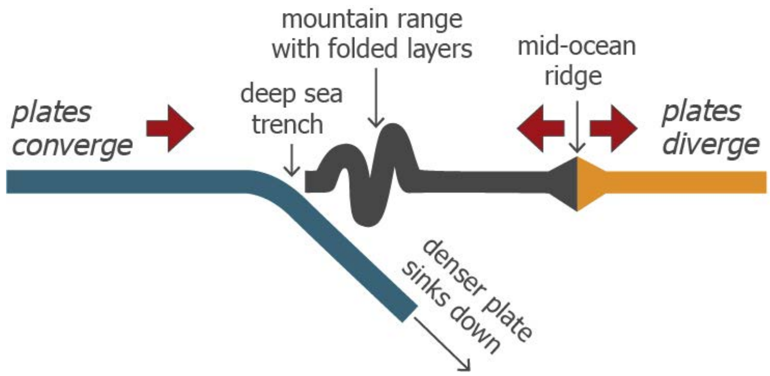
While we often say that Wegener compiled **evidence [SEP-7]**, it is important to note that he built on the work of dozens of scientists of the day. At the time Wegener lived, there was no way to determine the exact age of rocks, but geologists could reconstruct the relative timing of events by correlating sequences of rock layers from one place to another (MS-ESS1-4, as discussed in IS4). Even though Wegener never visited the Andes or the Atlantic coast of South America, other geologists had written that folding of rock layers in the Andes Mountain occurred at the same time as the Atlantic Ocean was becoming wider. Wegener **obtained and evaluated the information [SEP-8]** recorded by other scientists and then connected ideas in ways that nobody else had.

Despite the **evidence [SEP-7]** that he compiled, Wegener's theory was not accepted and was generally forgotten. While Wegener was using traditional science practices of **analyzing data [SEP-4]** and **constructing explanations [SEP-6]** based on **evidence [SEP-7]**, the other geologists were viewing his claims through the lens of the crosscutting concept of **cause and effect: mechanism and explanation [CCC-2]**. Wegener could not propose any possible mechanism that would cause continents to plow through the ocean over great distances. In the absence of a mechanism to cause the proposed movements of continents, the early twentieth century geologists rejected Wegener's claims. Middle grades students focus first on **analyzing [SEP-4]** the **evidence [SEP-7]** accumulated since Wegener's time that provide even more definitive evidence that there has been motion of plates (MS-ESS2-3), then they develop a **model [SEP-2]** relating that motion to the **cycling of matter [CCC-5]** (MS-ESS2-1), and finally they can use that model to help explain **changes [CCC-7]** in the Earth's surface (MS-ESS2-1), the distribution of mineral resources (MS-ESS3-1), and to forecast the occurrence of natural disasters (MS-ESS3-2). In high school, they will look in more detail at some of the evidence and finally address the mechanism that drives all this motion (HS-ESS2-1, HS-ESS2-3).

Technological developments approximately 50 years later allowed detailed mapping of the shape of the sea floor, which revealed new information that supported Wegener's claims and also provided the missing mechanism. Students can investigate undersea topography and notice **patterns [CCC-1]** using a program like Google Earth. They can discover that the largest mountain ranges on the planet actually exist below the surface of the ocean. One of the most obvious of these is the Mid-Atlantic Ridge, which rises about 3 kilometers in height above the ocean floor and has a length of about 10,000 kilometers running from a few degrees south of the North Pole down almost all the way to the Antarctic Circle. While basically continuous across a huge part of the planet, it is far from straight. By tracing out the shape of the continental shelves on either side of the Atlantic and the axis of the Mid-Atlantic Ridge, students can notice the ridge roughly parallels the turns of the coastlines. By measuring the distance from the center of the mountain range to the continental shelf, students can notice that the highest point of the mountains lies half way between the two coastlines, as if the two coasts were spreading apart from this central point. The idea that oceans were growing in size made it easier to understand how the continents could move away from each other.

If some ocean basins were expanding, it did not make sense for the entire planet to be growing larger, so scientists began to look at how the growth could be balanced by the surface becoming smaller in other locations. Scientists had long recognized **evidence [SEP-7]** for *shortening* on Earth because of evidence from sedimentary rock layers. In IS4, students created **models [SEP-2]** for how sedimentary rocks form in flat layers, but these layers are often observed to be folded and curved, which could only happen by some sort of squeezing that would push up mountains. At the time Wegener lived, the only process that scientists could conceive of that could cause such squeezing was the overall contraction of the Earth as it cooled after being formed long ago. However, if the seafloor was known to spread apart at some locations, it makes sense that plates must crash together at others. This would explain why mountain ranges formed long bands perpendicular to the spreading directions. For example, the Andes Mountains are not oriented randomly—they are at exactly the orientation you would expect if South America were spreading away uniformly from the Mid-Atlantic Ridge and crashing into the Pacific Ocean on the other side. Seafloor structures also give one more key piece of **evidence [SEP-7]** about plate motions: there are very deep canyons in the ocean that parallel coastlines and island chains in many locations. Just off the west coast of South America, students can notice a very deep trench in the ocean floor. A physical **model [SEP-2]** with two foam blocks (or even notebooks) representing plates helps illustrate why such a trench forms where one of the plates sinks down beneath the other due to density. It is a simple consequence of the geometry of a bending block, with the trench forming at the inflection point where the down-going block starts to curve (figure 6.18). Students can use maps of global topography and bathymetry to see if they notice any **patterns [CCC-1]** between the location of these deep sea trenches and their relationship to continents, mountain ranges, and islands.

Figure 6.18. Plate Motions Shape Landforms and Seafloor Features



Schematic slice through the Earth's lithosphere showing three different plates with key seafloor and land features caused by their motion. Diagram by M. d'Alessio.
[Long description of Figure 6.18.](#)

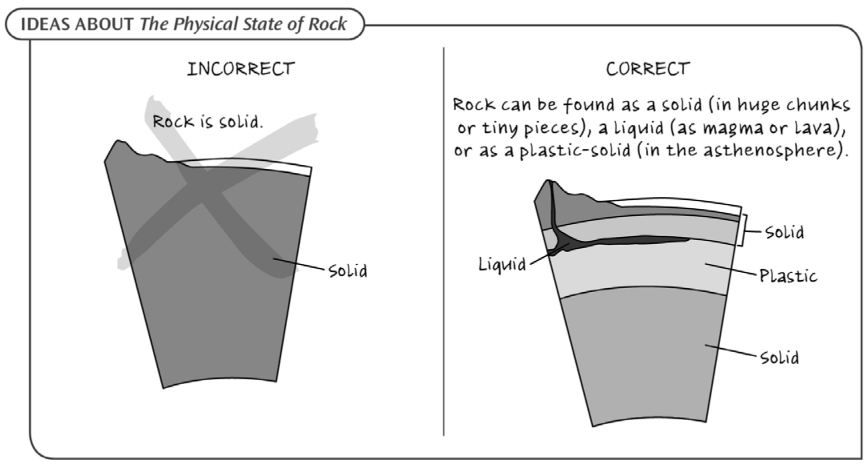
Taken together, the fit of the continental shelves, the separation of similar rocks and fossils across vast oceans, the location of mid-ocean ridges running precisely along the center of oceans basins, and the location of deep sea trenches along the coasts of some continents are strong **evidence [SEP-7]** that plates move apart at some locations, move together at others, and slide past one another in other locations. These motions are the driving forces for a wide range of processes that shape Earth's surface and cause interactions with the anthrosphere.

Plate Tectonics Drives the Rock Cycle

One of the most important effects of plate motions is the **cycling of matter [CCC-5]** that accompanies the motion. The geoscience processes that form rocks and minerals include volcanic eruptions, the heating and compaction of rock deep underground, the cooling of very hot underground rock, the evaporation of mineral-rich water, and the physical and chemical breakdown of surface rock by wind and water. All but the last of these geoscience processes are driven by the transfer of Earth's internal thermal **energy [CCC-5]**. This internal thermal energy resulted from the immense heating of Earth's interior during its cataclysmic formation billions of years ago, the gravitational compaction of Earth in its early history, and the energy released by radioactive decay of buried Earth materials. In high school, students will develop a model that relates these heat transport processes to the driving motions of plate tectonics (HS-ESS2-3).

Rock at Earth's surface is almost exclusively a solid, except the few locations where it flows as liquid lava. As shown in figure 6.19, liquid rock is also located underground, where it is called magma. Even in that illustration, the amount of liquid is exaggerated for visual effect. A significant percentage of the rock underground exists in a form that acts similar in some ways to a common children's toy, silicone putty. It is not clearly a solid or a liquid. This state of matter is sometimes called a plastic solid because it slowly flows and deforms under pressure like a liquid but retains its shape like a solid. Even deeper underground, the immense pressure causes the rock to exist as a solid.

Figure 6.19. Ideas About the Physical States of Rock



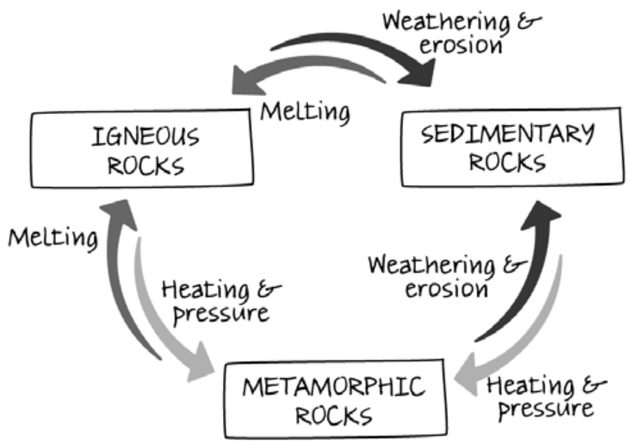
Source: From *Making Sense of SCIENCE: Earth Systems* (WestEd.org/mss) by Daehler and Folsom. Copyright © 2013 WestEd. Reproduced with permission.
Long description of Figure 6.19.

Sometimes, everyday language differs from scientific language and can lead to confusion. In figure 6.19, the word plastic refers to an easily shaped material. Discussion should include that this definition existed in dictionaries long before the invention of petroleum-based plastics that we use so commonly in everyday materials, like beverage bottles or bags. The modern material called plastic earned its name because it could be easily melted and formed into different shapes.

Many of the **changes [CCC-7]** that happen to the geosphere (Earth's nonliving solid material excluding ice) are due to movement of tectonic plates. As the plates push together, spread apart, and slide against one another, a variety of geologic processes occur including earthquakes, volcanic activity, mountain building, seafloor spreading, and subduction (sinking of a plate into the underlying mantle). All of these geoscience processes change Earth's rock—some form new rock and others break down existing rock.

These physical and chemical transformations of rock are often summarized as the rock cycle. Figure 6.20 shows a classic rock-cycle diagram with the three major rock types of igneous (melted in Earth's interior), sedimentary (compacted from broken pieces), and metamorphic (rearranged by Earth's internal pressure and thermal energy).

Figure 6.20. Classic Rock Cycle Diagram



Source: From *Making Sense of SCIENCE: Earth Systems* (WestEd.org/mss) by Daehler and Folsom. Copyright © 2013 WestEd. Reproduced with permission.
Long description of Figure 6.20.

As summarized in table 6.6, the classic rock cycle diagram is a good summary of some of the key interactions of the geosphere. However, like most **models [SEP-2]**, it has inaccuracies and can foster preconceptions. Students can mistakenly surmise that every rock has experienced or will experience the same cycle. However, rock does not move through the rock cycle in a specific order, like a product on a conveyor belt moving through a factory. The Geological Society in Britain has a very useful rock cycle Web site at https://www.cde.ca.gov/ci/sc/cf/ch6.asp#link32, a very useful resource for students, who could then be challenged to find examples in California of the British rocks and landforms.

Table 6.6. Benefits and Limitations of Classic Rock Cycle Diagram

BENEFITS	LIMITATIONS
Provides a good summary of key geosphere interactions.	Does not show the many interactions the geosphere has with other Earth systems.
Easy to read and understand.	Does not show the timeframe for each geologic process, implying that they have similar timeframes.
Shows how each type of rock can become the other types of rock.	Does not show the locations where each geologic process takes place.
Helps dispel the incorrect idea that rock is “steady as a rock” and never changes.	Suggests that rock never leaves the rock cycle, yet rocks often do leave the rock cycle, such as when they are incorporated into organisms, other Earth systems, and human-made materials.

Source: From *Making Sense of SCIENCE: Land and Water* (WestEd.org/mss) by Folsom and Daehler. Copyright © 2012 WestEd. Adapted with permission.

The physical and chemical **changes [CCC-7]** that happen to minerals and rocks reinforce the principle of the **conservation of matter [CCC-5]**. Almost three-quarters of Earth's crust is made of oxygen and silicon. Just six elements (aluminum, iron, magnesium, calcium, sodium, and potassium) make up nearly all the rest of Earth's crust. Atoms of these eight elements combine to form Earth's rocks and minerals. Throughout all the physical and chemical interactions, none of these atoms are lost or destroyed. Even as the appearance and behavior of the rocks **change [CCC-7]**, their overall composition remains **stable [CCC-7]**.

Students can demonstrate that they understand the relationship between plate motion and the rock cycle by placing different types of rocks on an illustration showing typical plate boundaries (MS-ESS2-1, MS-ESS2-2). Magma solidifies to form igneous rocks at places where magma can reach the surface such as mid-ocean ridges. Rocks experience increases in temperature and pressure that can transform them into metamorphic rocks as they are dragged deep into the Earth when plates collide. Sedimentary rocks form all over Earth's surface, but especially in zones where mountains are actively being pushed up where plates collide.

Plate Tectonics and Resources

Plate tectonics plays an important role in the uneven distribution of Earth's natural resources (MS-ESS3-1). Volcanic and uplift processes can bring important minerals onto or near the surface where they can be profitably mined. For example, students can compare the location of the world's largest copper mines to the location of plate boundaries and see that there is a general **pattern [CCC-1]**: mines are often located near plate boundaries. The prospector's shout that "there's gold in them thar hills" directly connects gold distribution with the plate tectonics that created "them thar hills."

Fossil fuel distribution is one the most politically important uneven distributions of natural resources, and it is also tied to plate tectonics. The Middle East has about two-thirds of the world's proven reserves of crude oil. Petroleum and natural gas are generally associated with sedimentary rocks. These fuels formed from soft-bodied sea organisms whose remains sank to the ocean floor, decomposed in the relative absence of air, and were further transformed by heat and pressure deep underground. Even areas on dry land today can be the sites of ancient ocean basins that have been uplifted by plate collisions. These same collisions can deform the rock layers in ways that allow oil and gas to accumulate in concentrated locations (where they can be easily extracted) and remain trapped there for millions of years. Students will **investigate [SEP-3]** this process in high school.

Plate boundaries are often places where hotter material rises up from Earth's interior to near the surface. This heat can be harnessed to generate electricity and as a source of **energy [CCC-5]** for heating buildings and commercial purposes. California is home to some of the world's largest geothermal power plants, with production in both Northern and Southern California that provide a total of 6 percent of the state's electricity (with potential for even more). Other western states also use geothermal resources, but there are no geothermal power plants east of North Dakota in the United States, largely because these areas are far from plate boundaries.

In IS4, students learned about groundwater as an important resource as water percolates into the spaces between pores in sediments and rock. The distribution of groundwater basins is also affected by plate motions. The best groundwater basins are in valleys where a large amount of sediment has continuously been deposited, such as the Central Valley receiving sediment from the Sierra Nevada. Plate motions typically determine the shapes of these basins and are the cause of mountains being uplifted in the first place. The faster they are pushed up, the faster they erode (because rapid uplift produces steep slopes that erode more quickly). Of course, groundwater also requires an abundant source of water. In addition to the important latitudinal controls on precipitation discussed in IS1, mountains have a strong impact on where precipitation occurs; moist air flowing up mountains tends to precipitate on the windward side of the mountains leaving a rain shadow further downwind. The mountains that squeeze moisture out are often recently uplifted by plate motions.

Understanding Plate Motions Allows Hazard Mitigation

In grade four, students analyzed **patterns [CCC-1]** in maps and may have **investigated [SEP-3]** the distribution of earthquakes on the planet (4-ESS2-2). With an understanding of the patterns of plate motions and previous events, scientists are better able to forecast natural disasters such as earthquakes and volcanoes. The process is somewhat analogous to asking students to predict where in California it will snow next January. With a basic understanding of the patterns of geography, they could very reliably identify places where it will almost certainly not snow (downtown Los Angeles, for example) and where it is more likely to snow (perhaps along the high peaks in the Sierra Nevada). Whether it actually snows during that month depends on specific physical processes, such as the location of the jet stream, which are difficult or impossible to predict far in advance. Earthquakes occur because friction causes plates to stick together where they touch. Even though forces deep within the Earth try to pull them along, the plates remain stuck until the strain builds up so much that they suddenly slide past one another in a single violent lurch. Students can build a physical **model [SEP-2]** of this process with a brick, a bungee cord, and sand paper (see Earthquake Demonstration at https://www.cde.ca.gov/ci/sc/cf/ch6.asp#link33), or explore a virtual physical model using an online simulator (see The Earthquake Machine at https://www.cde.ca.gov/ci/sc/cf/ch6.asp#link34). Scientists can monitor the amount of strain built up along plate boundaries using high-precision GPS and can calculate the amount of strain that is likely to be released in the next large earthquake at different locations. In other words, scientists can predict where earthquakes could be and how big they could be with relatively high reliability. State and local authorities have published maps showing the likelihood of different size earthquakes in locations throughout California (see UCERF3: A New Earthquake Forecast for California's Complex Fault System, USGS Fact Sheet 2015-3009 at https://www.cde.ca.gov/ci/sc/cf/ch6.asp#link35). Students could use this map to hold a mock session of the state legislature debating the allocation of earthquake preparedness funding. Different students representing different districts around the state use information about their population, their economic contributions, and the earthquake forecasts to **argue [SEP-7]** that their district is deserving of a larger share of the funding. Students can then prepare disaster kits for home and school (CA Health Education Standard 6.1.4S).

Engineering Connection: Earthquake Early-Warning System

The only part of the process that is not yet predictable is the exact timing of the earthquakes. While scientists have **investigated [SEP-3]** a wide range of monitoring strategies, it appears that many earthquakes occur without any perceivable trigger. That means that the soonest we can know about earthquakes is the moment that they first start. Earthquake waves do take time to travel through the Earth, so there is one more way that understanding earthquakes can help us mitigate their effects. The moment a seismic recording station detects shaking, it can send a signal at the speed of light to a central processing center that can issue a warning of the impending earthquake. Such warnings can be distributed to schools, businesses, and individuals via the Internet, mobile phones, and other broadcast systems, providing them warning of a few seconds to a minute. Such systems have been in successful operation in Japan and Mexico City, and a prototype is being tested in California. After investigating **patterns [CCC-1]** of earthquake occurrence in their region, students can make decisions about where to place seismic recording devices to design their own earthquake early-warning network that provides the maximum advance warning (MS-ESS3-2) (d'Alessio and Horey 2013). Using an online simulator (see Earthquake Early-Warning Simulator at https://www.cde.ca.gov/ci/sc/cf/ch6.asp#link36), students test their network's performance in sample earthquakes, compare network designs with their peers (MS-ETS1-2) and iteratively improve them (MS-ETS1-3).

Opportunities for Mathematics Connections

Students can use simple equations of distance, speed, and time to calculate the amount of warning they can expect when a seismic recording station is a given distance away from the earthquake source (CA CCSSM 6.EE.2.c, 6.EE.7).

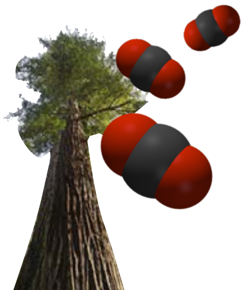
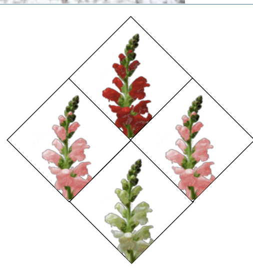
Grade Seven Discipline Specific Course Model: Life Science

From the introduction to the Middle Grades Life Sciences Storyline in the NGSS:

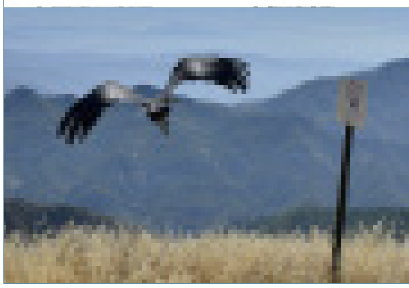
> Students in middle school develop understanding of key concepts to help them make sense of life science. The ideas build upon students' science understanding from earlier grades and from the disciplinary core ideas, science and engineering practices, and crosscutting concepts of other experiences with physical and earth sciences. There are four life science disciplinary core ideas in middle school: (1) From Molecules to Organisms: Structures and Processes, (2) Ecosystems: Interactions, Energy, and Dynamics, (3) Heredity: Inheritance and Variation of Traits, (4) Biological Evolution: Unity and Diversity. The performance expectations in middle school blend the 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 school 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. Described in *A Framework for K-12 Science Education.* (NGSS Lead States 2013a)

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 performance expectations (PEs) into related groups that can form the basis for instruction. While there are seven instructional segments (IS) in this course, no prescription of the relative amount of time to be spent on each instructional segment is made in this section. Table 6.7 shows a sequence of seven possible phenomenon-based instructional segments in a discipline specific grade seven course.

Table 6.7. Overview of Instructional Segments for Discipline Specific Grade Seven

	**1 Interdependent Ecosystems** Students view ecosystems as systems. They analyze the exchanges of energy and matter in the system and recognize patterns in the way different organisms interact.
	**2 Photosynthesis and Respiration** Students zoom into the most important processes that allow the exchange of energy and matter in ecosystems, photosynthesis and respiration. They develop models of how organisms rearrange molecules during these chemical reactions to survive and grow. They explain how reactions at the molecular scale explain the interactions at the ecosystem scale.
	**3 Cells and Body Systems** Students conduct investigations to gather evidence that living things are made of cells. They develop a model of how cells work as self-contained systems and as part of broader body systems.
	**4 Evidence of Evolution** Students analyze structures of different organisms to notice evolutionary patterns. Their data come from the fossil record, anatomical similarities, and embryological development.
	**5 Inheritance and Genetics** Students develop a model that explains how cells store and use their genetic code. They extend the model so that it can explain variation in traits caused by reproduction and mutation.

6 Natural Selection
Students analyze data that show evidence of natural selection. They develop conceptual and mathematical models that explain how the traits of organisms and the availability of resources affect the survival of specific individuals, and how that translates into broader shifts in populations.



7 Ecosystem Interactions, Revisited
Students revisit ecosystem interactions as a capstone to develop solutions that maintain biodiversity and ecosystem services in the face of human impacts on ecosystems.

Sources: Savery 1628; adapted from Caulfield 2012; Peters 2007; Grant 2010; adapted from Rafandalucia 2016; adapted from Castro 2008; Gould 1845; Myatt/USFWS 2014

Throughout the instructional segments in grade seven, students engage in the **disciplinary core ideas (DCIs)** using a variety of **science and engineering practices (SEPs)** and **crosscutting concepts (CCCs)** However, teachers should mostly develop conceptual and qualitative understanding of those core ideas as grade seven students may not have developed the capacity yet to use more advanced disciplinary core ideas associated with physical science to fully understand the processes at the molecular **scale [CCC-3]**. For example, in grade seven students develop understanding of the functioning of cells during respiration. However, their understanding of processes such as photosynthesis or movement of **matter and energy [CCC-5]** in and out of cells will only be developed qualitatively in grade seven because the chemical reactions occurring within cells to explain these processes will not be introduced until grade eight.

IS1

Discipline Specific Grade Seven Instructional Segment 1: Interdependent Ecosystems

Life science is about what comprises living things, how they work, and how they depend on one another. Seen through the crosscutting concept of **systems and system models [CCC-4]**, living organisms are systems with components that interact. This instructional segment develops students' understanding of systems alongside key life science disciplinary core ideas.

DISCIPLINE SPECIFIC GRADE SEVEN INSTRUCTIONAL SEGMENT 1: INTERDEPENDENT ECOSYSTEMS

Guiding Questions

- How do parts of an ecosystem interact?

Performance Expectations

Students who demonstrate understanding can do the following:

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*.]

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

Highlighted Science and Engineering Practices	Highlighted Disciplinary Core Ideas	Highlighted Crosscutting Concepts
[SEP-2] Developing and Using Models [SEP-6] Constructing Explanations (for science) and Designing Solutions (for engineering)	LS2.A: Interdependent Relationships in Ecosystems LS2.B: Cycle of Matter and Energy Transfer in Ecosystems	[CCC-1] Patterns [CCC-4] Systems and System Models [CCC-5] Energy and Matter: Flows, Cycles, and Conservation

DISCIPLINE SPECIFIC GRADE SEVEN INSTRUCTIONAL SEGMENT 1: INTERDEPENDENT ECOSYSTEMS

Highlighted California Environmental Principles and Concepts:

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

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

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

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

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

CA CCSS Math Connections: 6.EE.9, 6.SP.5a–d

CA CCSS for ELA/Literacy Connections: SL.7.1a–d, 4, 5; RST.6–8.1, WHST.6–8.2a–f, 9

CA ELD Connections: ELD.PI.7.6a–b, 9, 10, 11a

As described in the 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 includes the very word *system*) are interactions between different organisms and nonliving components. In this course, students **develop models [SEP-2]** of these living systems at this full range of **scales [CCC-3]**.

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

Opportunities for ELA/ELD Connections

Have students explore the classroom and find examples of what they predict are systems (e.g., sound, computer, body, ecosystems). Provide students with a graphic organizer in which they write the reasons they identified it as a system, using words, phrases or sentences depending on their level of English proficiency. Place students in groups, and using their graphic organizer, have students take turns reporting the information they gathered. Next, have them read an appropriate science text and identify the five features of systems within the text. Using evidence from text and language frames, have students discuss the connections between their classroom example and textual evidence gathered that either confirm or refute it as a system. Ask students in their groups to revisit their classroom examples and reach consensus on whether or not each meets the criteria of a system based on the five important features of **systems and system models [CCC-4]**: boundaries, components, interactions, inputs/outputs, and one or more system properties.

CA CCSS for ELA/Literacy Standards: RST.6–8.1, 2, 4; SL.6–8.1
CA ELD Standards: ELD.PI.6–8.1, 3

While the life science disciplinary core ideas are organized with the smallest **scales [CCC-3]** 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 [CCC-5]** exchange are familiar to students (predator eats prey, for example).

A system **model [SEP-2]** provides a way of thinking about and simplifying the real world. 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 6.21).

Figure 6.21. A River Environment

Source: From *Making Sense of SCIENCE: Earth Systems* (WestEd.org/mss) by Daehler and Folsom. Copyright © 2013 WestEd. Reproduced with permission.
Long description of Figure 6.21.

As students identify the different objects involved, they might recognize that the objects fall into different categories such as living and nonliving objects. Many students struggle to decide if nonliving objects should be included in the **system model [SEP-2]** 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.

Students can illustrate these interactions in many ways through different styles of diagrams. Instructional segment 2 from the Preferred Integrated Course Model for grade seven (chapter 5) 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 [CCC-5]**, some the exchange of **energy [CCC-5]**, 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 grade five (5-LS2-1). Now, they will begin to make distinctions between **matter and energy [CCC-5]**.

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 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 [CCC-5]**.

Discipline Specific Grade Seven Snapshot 6.1: Matter and Energy in the Wolverine Habitat.

Mr. R's students had already read the informational text *Where Are the Wolverines?* from the California Education and the Environment Initiative (EEI) curriculum, *Energy: Pass it On!* He instructed them to read the first part of the story again 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 wolverines live and get their food, preparing the students for the second half of the text in which they would look at how damage to that habitat affects the cycling of matter and transferring of energy in that ecosystem. He then had them use the information from the reading to construct a complete food web for the wolverine's habitat.

Investigative phenomenon: Students confront multiple phenomena in the *Human Practices* cards. Example: Human activities that prevent natural forest fires have led to denser forests with fewer shrubs and fewer plants that bears eat.

Mr. R followed up by distributing 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 distribute the cards among the team members, with the students taking turns presenting the information about their first card and leading a brief team discussion about how the particular human activity might affect relationships in the food web. Mr. R instructed students to describe at least one **cause and effect [CCC-2]** relationship from each card.

After they had discussed the different human activities, students placed all of the cards in the center of the table so that each of them could access the cards. Mr. R told the students that they were going to individually complete the *Human Practices and the Wolverine Food Web*. As they completed the prediction column, they were instructed 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 [CCC-5]** in the wolverine's habitat.

Resources

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 [CCC-5]** 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 is exchanged between components in ecosystems is through the flow of thermal energy. In particular, most organisms give off waste heat. We can easily conceptualize how warm-blooded organisms like us heat up the air around their bodies, 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 [SEP-3]** this relationship **mathematically [SEP-5]** 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 they eat there. As they return to the river in which they were born, they bring biomass built from ocean material into the river. Most species of salmon die after they spawn, and the biomass from their decaying carcasses fertilizes areas surrounding the streams. Scientists can actually quantify the size of this **effect [CCC-2]** 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, 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, scientists do not detect ocean biomass far from the rivers. Human activities have therefore disrupted the movement of biomass (California Environmental Principles and Concepts [EP&Cs] II, III, IV).

After considering one example ecosystem as a whole class, smaller groups of students **investigate [SEP-3]** different ecosystems. During reports, students look for common **patterns [CCC-1]** 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 [SEP-1]** 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 [SEP-2]** of **energy and matter flow [CCC-5]**, students should be able to explain how these relationships relate to the flow of energy and matter within ecosystems (MS-LS2-3).

IS2 Discipline Specific Grade Seven Instructional Segment 2: Photosynthesis and Respiration

In this instructional segment, students **develop a model [SEP-2]** of the two key chemical processes used to **cycle energy and matter [CCC-5]** 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.

DISCIPLINE SPECIFIC GRADE SEVEN INSTRUCTIONAL SEGMENT 2: PHOTOSYNTHESIS AND RESPIRATION

Guiding Questions

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

Performance Expectations

Students who demonstrate understanding can do the following:

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.*]

DISCIPLINE SPECIFIC GRADE SEVEN INSTRUCTIONAL SEGMENT 2: PHOTOSYNTHESIS AND RESPIRATION

Other necessary performance expectations introduced, but not assessed until grade eight:

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.]

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

Highlighted Science and Engineering Practices	Highlighted Disciplinary Core Ideas	Highlighted Crosscutting Concepts
[SEP-2] Developing and Using Models [SEP-5] Using Mathematics and Computational Thinking [SEP-6] Constructing Explanations (for science) and Designing Solutions (for engineering)	LS1.C: Organization for Matter and Energy Flow in Organisms PS3.D: Energy in Chemical Processes and Everyday Life *Other Necessary DCIs:* PS1.A: Structure and Properties of Matter PS1.B: Chemical Reactions	[CCC-4] Systems and System Models [CCC-5] Energy and Matter: Flows, Cycles, and Conservation

Highlighted California Environmental Principles and Concepts:
Principle III Natural systems proceed through cycles that humans depend upon, benefit from and can alter.

CA CCSS Math Connections: 6.EE.9

CA CCSS for ELA/Literacy Connections: SL.7.1a–d, 4, 5; RST.6–8.1, 2, WHST.6–8.2a–f, 9

CA ELD Connections: ELD.PI.7.6a–b, 9, 10, 11a

The assessment boundaries for 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 performance expectations requires 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 [CCC-5]** in chemical reactions and conservation of matter in chemical equations. These chemical processes are at the core of **energy and matter flow [CCC-5]** within ecosystems (EP&C III).

The discipline specific middle grades course sequence presents some challenges for teaching these performance expectations in the CA NGSS. Students **developed a model [SEP-2]** that matter is made up of particles that are too small to see during grade five (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 grade eight in the discipline specific middle grades sequence). It is very difficult to fully address performance expectations that **model [SEP-2]** how molecules are rearranged without introduction to these essential concepts. The snapshot below is one example of how the essential physical science concepts can be integrated alongside the teaching of the life science.

Discipline Specific Grade Seven Snapshot 6.2: Modeling Chemical Reactions

Anchoring phenomenon: Maple syrup made from tree sap is sweet and sugary.

Mr. G's class had been investigating photosynthesis for several days to identify what ingredients plants took in and what waste products they gave off. In the first day of the lesson, Mr. G wrote a balanced equation for photosynthesis on the board using both element symbols and common names for each compound. He described how the glucose in the equation represented the sugary sap that the students agreed is a product created by the tree. He told students that this equation is how scientists represent the chemical **change [CCC-7]** going on inside the tree. He used 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 [SEP-2]** that reaction using a common children's 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, **communicated [SEP-8]** 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 [SEP-2]** 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 brick (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.

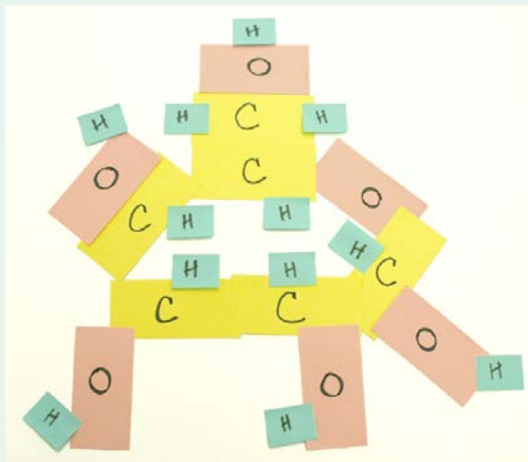
Mr. G then had everybody gather around the group that included Juanita and Alex. Alex explained that they had tried to use models where each color of toy brick represented a different kind of atom in the chemical equation. "Each letter in the chemical names is a different color," described Alex, "so we only used three colors." Juanita interjected, "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 [SEP-2]** 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

Discipline Specific Grade Seven Snapshot 6.2: Modeling Chemical Reactions

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 (figure 6.22). Mr. G told them they could use smaller sticky notes to represent hydrogen atoms since they are the smallest atoms. Students discovered that the number of sticky notes they used is related to the subscripts and superscripts indicating the **proportional relationships [CCC-3]** in the chemical equation.

Figure 6.22. Example of a Student Group Model of Glucose



Source: Dr. Art Sussman, courtesy of WestEd
Long description of Figure 6.22.

IS3

Discipline Specific Grade Seven Instructional Segment 3: Cells and Body Systems

Students continue investigating the crosscutting concept of **systems [CCC-4]** at a smaller **scale [CCC-3]** by **investigating [SEP-3]** systems within individual organisms. They investigate systems at two major scales: the operations of individual cells and the operation of the entire organism.

DISCIPLINE SPECIFIC GRADE SEVEN INSTRUCTIONAL SEGMENT 3: CELLS AND BODY SYSTEMS

Guiding Questions

- How do the parts of a cell sustain life?
- How do cells work together to make a complex organism?

Performance Expectations

Students who demonstrate understanding can do the following:

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*** **(CA)** 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*.]

DISCIPLINE SPECIFIC GRADE SEVEN INSTRUCTIONAL SEGMENT 3: CELLS AND BODY SYSTEMS

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

Highlighted Science and Engineering Practices	Highlighted Disciplinary Core Ideas	Highlighted Crosscutting Concepts
[SEP-2] Developing and Using Models [SEP-3] Planning and Carrying Out Investigations [SEP-7] Engaging in Argument from Evidence [SEP-8] Obtaining, Evaluating, and Communicating Information	LS1.A: Structure and Function LS1.B: Growth and Development of Organisms LS1.D: Information Processing	[CCC-2] Cause and Effect [CCC-3] Scale, Proportion, and Quantity [CCC-4] Systems and System Models [CCC-6] Structure and Function

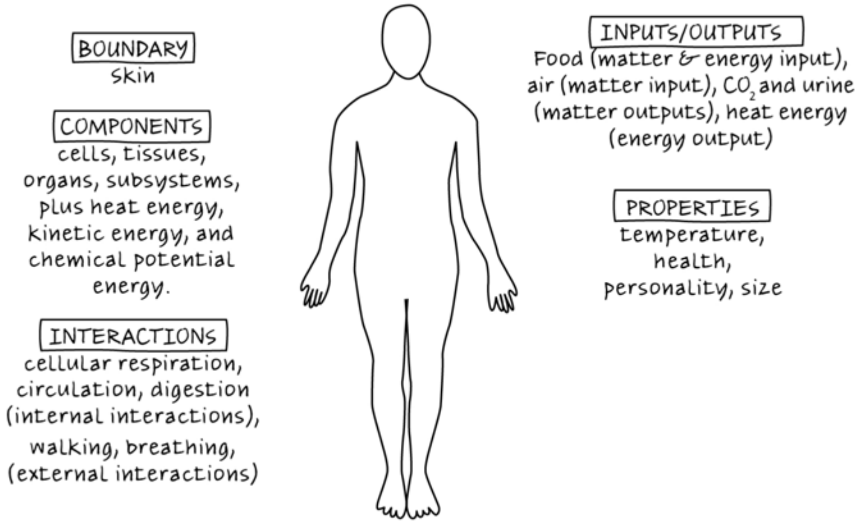
CA CCSS Math Connections: 6.EE.9

CA CCSS for ELA/Literacy Connections: RI.7.8, SL.7.1a–d, 4, 5; RST.6–8.1, WHST.6–8.1a–e, 2a–f, 7, 8, 9

CA ELD Connections: ELD.PI.7.6a–b, 9, 10, 11a

Students can easily recognize that their own body is a system. Figure 6.23 illustrates all five of the key elements of a **system [CCC-4]** 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 parts. 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 [CCC-3]** within the body: the cell. They can then return to the body's subsystems, ready to understand some of the mechanisms that allow them to interact.

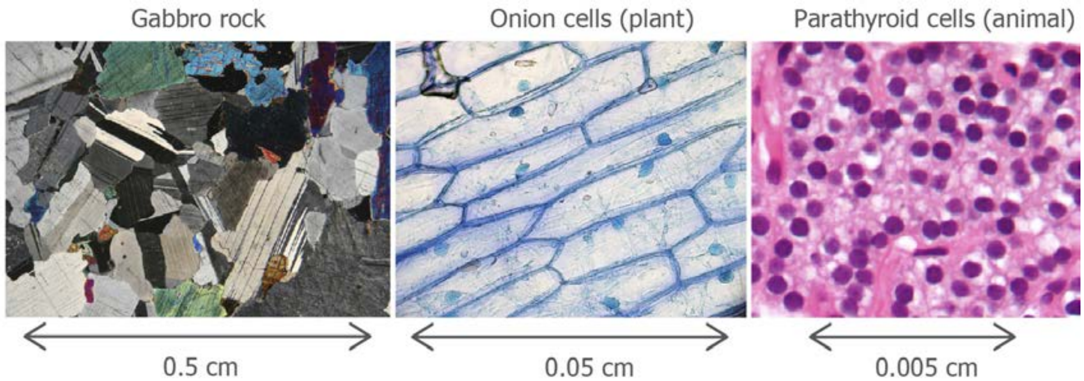
Figure 6.23. Features of a Human Person System



Source: From *Making Sense of SCIENCE: Water and Climate* (WestEd.org/mss) by Folsom and Daehler. Copyright © 2012 WestEd. Adapted with permission.
Long description of Figure 6.23.

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 [CCC-6]** 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 [CCC-3]** that can be readily **investigated [SEP-3]** and directly observed in a middle grades classroom. Students **conduct an investigation [SEP-3]** into different objects, living and nonliving, to see their differences at the microscopic scale (MS-LS1-1). Figure 6.24 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 [CCC-1]** to their shapes and observable parts within them that are absent from the rock sample. Which of the differences are important for sustaining life?

Figure 6.24. Microscopic View of Rock, Plant, and Animal Cells



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. *Source*: M. d'Alessio with images from Sepp 2006, Salvagnin 2009, and Bonert 2009
Long description of Figure 6.24.

When adopting the CA 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 treatments. Viruses carry their own DNA and once inside a functioning cell of another organism, they basically hijack its **functions [CCC-6]** to reproduce themselves. During this process, short sequences of virus DNA are sometimes inserted into the host organism's DNA and then are passed on to its descendants. Maps of the human genome show that about 10 percent 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 grades 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 [CCC-4]** with important interacting subsystems. Students **develop a model [SEP-2]** 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 [SEP-2]**, including physical, mathematical, conceptual, and pictorial models. One common feature 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 [CCC-5]** 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 [CCC-5]** 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 [SEP-2]** of these boundaries should be detailed enough that they can explain how the physical **structure [CCC-6]** of the boundaries facilitate this important **function [CCC-6]**, though the details of the biochemistry of this process are not required.

Students' **models [SEP-2]** 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 IS5 when inheritance is discussed.

DISCIPLINE SPECIFIC GRADE SEVEN VIGNETTE 6.2: STRUCTURE, FUNCTION, AND INFORMATION PROCESSING

Performance Expectations

Students who demonstrate understanding can do the following:

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*.]

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

Highlighted Science and Engineering Practices	Highlighted Disciplinary Core Ideas	Highlighted Crosscutting Concepts
[SEP-7] Engaging in Argument from Evidence	LS1.A: From Molecules to Organisms: Structures and Processes	[CCC-4] Systems and System Models

CA CCSS for ELA/Literacy Connections: SL.1, SL.4, W.7.8, RST.6–8.1, WHST.6–8.1, 7, 8, 9

CA ELD Connections: ELD.PI.7.1, 2, 5, 6a, 6b, 9, 10

Introduction

This vignette presents an example of how teaching and learning may look in a discipline specific grade seven classroom when the CA NGSS are implemented. The purpose is to illustrate how a teacher can engage 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 the 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 student 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.

DISCIPLINE SPECIFIC GRADE SEVEN VIGNETTE 6.2: STRUCTURE, FUNCTION, AND INFORMATION PROCESSING

Day 1: Organisms: The Sum of Their Subsystems

Students integrate their existing knowledge of how trees grow to identify different systems that help the tree survive and grow.

Day 2: Going on an Interactive Body Tour

Students obtain information about different body systems using an interactive computer program.

Day 3: Exploring the Impact of a Subsystem Break Down

Students organize their knowledge of the body into a model of interacting subsystems. They apply their model to predicting the impact of an injury or disease that disrupts part of the system.

Days 4–5: Synthesizing and Applying Lessons Learned

Students select one organ or tissue and obtain information about the role it plays within its subsystem. They make and support a claim about what will happen if that organ or tissue fails.

Day 1: Organisms: The Sum of Their Subsystems

Anchoring phenomenon: A pine tree struck by lightning on one branch survives and thrives on other branches.

Ms. K began the second part of her instructional segment after she had completed lessons about cells as tiny living systems. She told her students that the focus of the next several lessons would be to **build models [SEP-2]** of how these cells interact and work together to make more complicated organisms involving more complicated interacting subsystems (MS-LS1-3).

Ms. K showed her students a picture of a pine tree with one branch reaching skyward blackened by fire but the rest of the tree green and thriving. After she asked students what they thought had happened, she had them visualize the pine tree as a whole organism then slowly walked 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 discussed the purpose and **function [CCC-6]** of the bark, needles, pinecones, and root system of the tree. Ms. K explained that the tree can be considered a **system [CCC-4]**, made up of several subsystems. She then asked students to consider several questions such as, What would happen if the root system were damaged or fire or a lightning strike compromised the trunk and bark?

Everyday phenomenon: Giant sequoia trees are some of the largest organisms alive.

Ms. K projected several images of the giant sequoia, *Sequoiadendron giganteum*, for the class to view. The images included cross sections of the subsystems discussed in class: trunk,

DISCIPLINE SPECIFIC GRADE SEVEN VIGNETTE 6.2: STRUCTURE, FUNCTION, AND INFORMATION PROCESSING

roots, and bark. To further engage students in this discussion she asked who had ever seen a tree this big. A few students mentioned family trips to some of California's national parks while others described large trees they pass along the way to school. Ms. K then raised the question how something that large can stay alive and prompted students to think about what it must take for this tree to live and grow. Students shared some of their background knowledge about plants from elementary grades, mentioning things about plants needing water, light, nutrients, and air to live. She asked students which parts of the tree are responsible for obtaining each of these resources and framed the problem with the idea that no single part of the tree has access to all these resources in one place. Ms. K then asked students to draw and name the subsystems that might enable a tree this large to obtain **energy [CCC-5]** and matter and move them around so that each part has everything it needs. They wrote about their observations of the subsystems and briefly explained how these systems interact.

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

Day 2: Going on an Interactive Body Tour

Everyday phenomenon: Human bodies have different organs and tissues.

The following day, Ms. K helped her students transition to the concept that the body is a system of multiple interacting subsystems 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 spoke, she wrote these down on the whiteboard, while prompting them to discuss the function of each organ. She then introduced 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 asked students to name as many other tissues as they could think of. Ms. K explained that in these lessons they would make observations about the interactive relationship between subsystems and the body as a system.

Ms. K arranged her class into small groups of two to four students and directed them to the online Interactive Body Tour (Donate Life California http://www.cde.ca.gov/ci/sc/cf/ch6.asp#link37) and one other digital source they selected. She assigned each group to **obtain information [SEP-8]** about one organ and one tissue. She reminded them that as they gathered relevant information from the online digital source, they should **evaluate [SEP-8]** the credibility of each source and take brief notes about the **structure and function [CCC-6]** by quoting or paraphrasing the data and conclusions they were reading. She also asked students to keep track of at least three **questions [SEP-1]** their team had. She emphasized that these questions could be things that they were curious about after exploring the resources. (Other teachers took a slightly different approach: Mr. S, who did not have time for his students to

DISCIPLINE SPECIFIC GRADE SEVEN VIGNETTE 6.2: STRUCTURE, FUNCTION, AND INFORMATION PROCESSING

research in class, assigned this research as homework. Mrs. C, whose students did not have access to computers, reviewed the Interactive Body Tour in a whole group setting and gave her students additional printed materials.)

Day 3: Exploring the Impact of a Subsystem Break Down

Following the students' group research assignments, Ms. K had each small group **communicate [SEP-8]** their findings for the class. One student from each group wrote down the key points on the class whiteboard. Ms. K guided students to focus their comments on the topic of how the **structure [CCC-6]** of the organ or tissue lends itself to its **function [CCC-6]**. She also wrote down the questions they had developed during their group research, and set them aside for later in the lesson.

Following the presentations, Ms. K extended and guided the discussion by asking the students to think of organs and tissues as subsystems, and asked students how subsystems work together in the body to complete a task or regulate body functions, and how the subsystems communicate with each other. She specifically covered some of the systems with which the students were most familiar: circulatory, reproductive, excretory, digestive, respiratory, muscular-skeletal, and nervous systems.

Finally, Ms. K asked her students to think of what might happen to the body if one of the subsystems were compromised. She asked, for example, how lungs that don't work would affect the functioning of our circulatory system and other systems and subsystems in the human body. Ms. K followed with several more specific examples such as how does low blood sugar due to a malfunction of the endocrine system (such as diabetes) affect the nervous system or how an injured ligament might affect other parts of the muscular system.

Ms. K asked 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 asked them how the failure of a particular subsystem of the human body critical to the overall well-being and **functionality [CCC-6]** of the complete **system [CCC-4]** might affect the entire body.

Investigative phenomenon: Humans have two kidneys but can survive with just one. However, they cannot survive when both kidneys fail.

To help her students understand that human health and survival depends on the many different components of the body, body systems, and the interactions among them, Ms. K reminded students that humans have two kidneys, although it is possible to live a healthy life with one. However, she explained to them that if both kidneys fail and cannot clean the blood of toxins and excess fluids, the toxins build up in the blood and the person will not survive. In the case of kidney failure, an individual can have the blood artificially cleansed by a dialysis machine that does the work of the kidneys. In some cases, a person can get a kidney transplant, from a living donor or from someone who died recently, for example, in an automobile accident. Ms. K explained the concept of organ transplant and that one person

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can donate tissue—corneas, skin, bones, ligaments and tendons—and up to eight organs—kidneys, lungs, heart, liver, and intestine—upon death. She asked the students if they knew anybody who had received a transplant, was waiting for a transplant, or was an organ donor. Ms. K asked if any of the students were comfortable sharing their example and suggested that they discuss this important topic with their parents.

Day 4–5: Synthesizing and Applying Lessons Learned

Investigative phenomenon: When one of the body's subsystems in compromised, it can affect other subsystems and the body as a whole (different students investigate different systems).

Ms. K asked the small groups to refer back to the information they collected about organs and tissues. First, she reviewed the class questions from earlier in the lesson, addressing any that had not yet been answered. Then she had students in each small groups choose one of the organs or tissues that interested them so that different groups investigated different systems. She asked the students to discuss how partial or complete failure of the selected organ or tissue might affect the functioning of other subsystems or the human body as a whole. She instructed students to gather **evidence [SEP-7]** from additional research using 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 required each student to write a paper **arguing [SEP-7]** that the body is a system of multiple interacting subsystems (MS-LS1-3). The argument needed to focus on one organ or tissue subsystem, explain its **structure and function [CCC-6]**, and address how a compromised subsystem would affect the human body system. The students' writing drew on several sources to bolster their arguments, including evidence that supports the role of the subsystem's function in survival, growth, and/or behavior. Ms. K told them that they had to draw evidence from informational texts to support analysis, reflection, and research; to include logical reasoning, accurate data and evidence; and to use a formal writing style. Final manuscripts had to also include responses to three questions: (1) how might human activity negatively or positively affect the subsystems? (2) what are some alternatives to support survival, growth, and/or behavior in the body system when a subsystem is compromised? and (3) what are some examples of the impact of disease in our society? Students could quote or paraphrase the data and conclusions from their research, while avoiding plagiarism and providing basic bibliographic information for sources. This activity was designed to 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.

DISCIPLINE SPECIFIC GRADE SEVEN VIGNETTE 6.2: STRUCTURE, FUNCTION, AND INFORMATION PROCESSING

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 gave students multiple opportunities to engage with the core ideas in life sciences related to an organism as a system of interacting subsystems, helping them to move towards mastery of the three components described in the CA NGSS performance expectation.

SEPs. Students **obtained, evaluated and communicated information [SEP-8]** and **engaged in argument from evidence [SEP-7]**. 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 [SEP-8]** to others what they have learned. Students developed their abilities to make oral and written arguments supported by empirical evidence and sound scientific reasoning on days 4–5. Their reasoning was based on a **model [SEP-2]** of the body's interacting subsystems that students developed in prior days using the information they obtained.

DCIs. This vignette helped students understand how multicellular organisms use groups of cells that work together to form tissues and organs (LS1.A Structure and Function).

CCCs. The emphasis within LS1.A was that students think of a multicellular organism as a **system [CCC-4]** composed of interacting subsystems. While students had modeled simple systems in elementary school, the notion of systems being composed of interacting subsystems was a new level of understanding expected in the middle grades (appendix 1). Students also used a giant sequoia as a model of interacting systems and applied it to the human body as **evidence [SEP-7]** of the **structure and function [CCC-6]** of an organism's system and subsystems. During their research on different body systems, they likely saw examples of how certain systems had structures that achieved the needed functions of the systems. The assessment boundary of MS-LS1-3 indicates that the mechanisms that allow a single system to work *in isolation* are not part of the assessment (e.g., students will not be assessed on how the heart's structure enables the body to pump blood, but rather on relationships between systems such as the importance of interactions between the circulatory and respiratory systems).

CA CCSS Connections to English Language Arts and Mathematics. Students used the *Interactive Body Guide* from Donate Life California (day 2) and other resources (days 4–5) to research the different structures and functions of the human body (WHST.6–8.7-8). In their research, students had to determine the validity of a source and quote or paraphrase relevant information (W.7.8). In addition, they participated in a range of collaborative discussions (SL.7.1) and presented their claims and findings about the human body's subsystems in front of the class (SL.7.4). Their arguments focused on disciplinary content (WHST.6–8.1) and drew evidence from their texts (WHST.6–8.9).

Resources:

Donate Life California. 2015. Interactive Body Tour. https://www.cde.ca.gov/ci/sc/cf/ch6.asp#link38

While many of the body systems are essential for regulating **stability [CCC-7]** within an organism, other systems help it interact with the environment around it. In grade four, students created a model of how animals use sense organs to gather, process, and respond to information using their senses and nervous system (4-LS1-2). Now, students focus on the relationship between how sensory stimuli are stored or acted upon. Despite significant advances in medical imaging of the brain, there is still a huge amount of uncertainty about how these processes work. In honor of its 125th anniversary, *Science Magazine* published a list of the 125 biggest unanswered questions in science and many of them related to sensory perception and memory storage (accessed at https://www.cde.ca.gov/ci/sc/cf/ch6.asp#link39). 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 states) 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 [UC Berkeley Cal Alumni Association, *California* magazine https://www.cde.ca.gov/ci/sc/cf/ch6.asp#link40]). Students are fascinated by these topics, and the CA NGSS includes a performance expectation that they will be able to gather and synthesize information about the interaction between human sensory and nervous systems (MS-LS1-8). This provides an excellent opportunity to encourage students to **ask questions [SEP-1]** and **obtain, evaluate, and communicate information [SEP-8]** about possible answers and, more importantly, about more specific questions and subquestions that must be answered in order to answer the big-picture questions that many students likely have.

Students will not be assessed on the mechanisms by which sensory information is conveyed to the brain for MS-LS1-8, but their model of how subsystems interact for MS-LS1-3 should include a survey of these mechanisms. Body systems often communicate chemically through hormones and neurotransmitters. With this **model [SEP-2]** of interactions, students can **ask questions [SEP-1]** about the effects of drugs and alcohol on their body functions (CA Health Education Standard 7–8.1.1.A).

Discipline Specific Grade Seven Snapshot 6.3: What's in the Water?

Anchoring phenomenon: Tiny microscopic organisms live in pond water.

Mrs. N's class took occasional walking field trips to a creek near the school to study the local ecosystem. During the most recent trip, students collected water samples and brought them back to the classroom. Mrs. N asked students if they would want to drink the water in the creek and they all said no because it was too dirty. But what does it mean for water to be dirty? Students took turns looking at drops of water under the classroom microscopes. They noticed all sorts of tiny plants, moving animals, and bits of dirt, even in water samples that appeared clear to the naked eye. Mrs. N gave the students the opportunity to compare water from a local pond with tap water. They compared the pond water to filtered pond water and then to tap water. Students observed that the filtered pond water had fewer particles, than the unfiltered pond water, and that the tap water had almost no particles in it. Mrs. N challenged students to come up with a system to **quantify [CCC-3]** the number of particles in a water sample. Each group constructed a bar graph showing the relative number of particles and then compared their measurement to the other groups. Were the differences related to the measurement technique or the water samples themselves? Student groups decided to switch water droplet microscope slides with another team to test out their ideas.

Everyday phenomenon: Our drinking water is not pure H_2O.

Students then **obtained information [SEP-8]** from their water utility about the different contaminants in their local drinking water (water agencies are required to publish an annual report and most of these are available online). They learned the distinction between organic contaminants (like bacteria) and inorganic ones (like lead and arsenic). They evaluated how their water compared to another city (such as Flint, Michigan, which experienced unacceptable levels of lead contamination in 2015). The effects of non-microbial contaminants such as heavy metals were not as direct and Mrs. N decided to focus on the infectious diseases.

Everyday phenomenon: Outbreaks of disease were common in California during the Gold Rush Era.

While students could see the differences in both the water samples and the reported measurements, they did not yet appreciate why these numbers mattered. Mrs. N set the stage about the prevalence of water borne diseases by having students read an article about life in Gold Rush-era California, including the regular deaths from diseases like

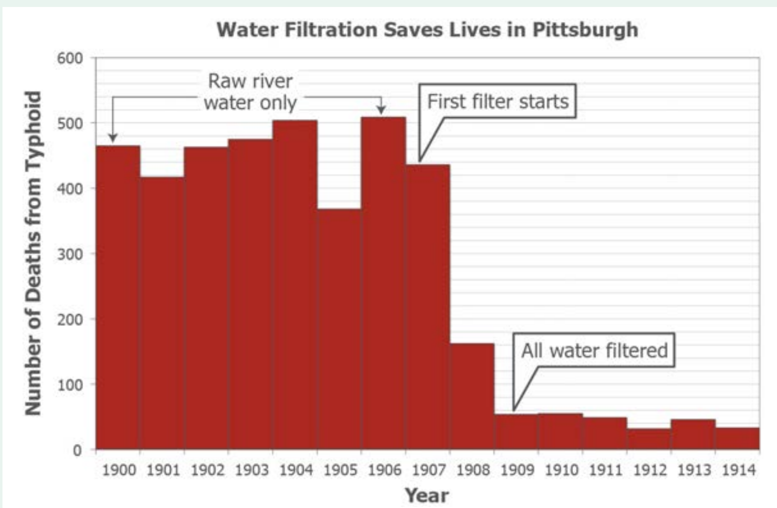
Discipline Specific Grade Seven Snapshot 6.3: What's in the Water?

cholera and typhoid. An outbreak in 1850 may have killed 15 percent of Sacramento residents (Roth 1997).

Investigative phenomenon: When Pittsburgh installed a citywide water filtration system, the number of people dying from disease dropped within a year or two.

Sacramento was not unusual and infectious diseases were a major problem in US cities until midway through twentieth century. Mrs. N was born in Pittsburgh, where the rate of death from diseases in 1900 was the highest of any major US city. Students read an article about how city health officials and engineers changed that by installing a water filtration system in their public water system that cut the death rate from typhoid by almost a factor of 10 within two years (figure 6.25). Mrs. N emphasized ETS2.B (Influence of Engineering, Technology, and Science on Society and the Natural World).

Figure 6.25. Deaths from Typhoid in Pittsburgh Pennsylvania, 1900–1914



Source: Adapted from Pittsburgh City Photographer 1917.
Long description of Figure 6.25.

Mrs. N wanted to make sure that students were able to see the connection between water filtration technology, diseases, and their hands-on experience with the organisms in the pond water. Working in groups, she had students draw a simple pictorial **model [SEP-2]** that illustrated the relationships. Each student then individually wrote a caption with an **explanation [SEP-6]** about how water filters remove organisms that **cause [CCC-2]** disease. Mrs. N told students that next week they would design and test their own water filters.

Discipline Specific Grade Seven Snapshot 6.3: What's in the Water?

Before moving on, Mrs. N led a discussion of one more aspect of the Pittsburgh story. One factor that made the city so vulnerable to disease was that the local drinking water source, the Alleghany River, was also a dumping ground for raw sewage for many upstream communities. Mrs. N told students that when people release materials like sewage into a river, they cause what is called *water pollution*. She asked students if they were aware of any water pollution at the school or in the local community. Students identified several examples of pollution on campus and in the streets by the school, including oil dripping from cars that then flowed down the gutters on the street and into the storm drains. One of the students mentioned that she has seen drains along the street that are labeled, "No Dumping, Leads to Ocean." Mrs. N asked, "Why is this important?" Several students mentioned that on a recent field trip to the coast they learned that oil coming from the storm drain system had been observed along the coast and it had damaged parts of the coastline and some of the wildlife that lives there (EP&Cs II and IV). Mrs. N asked students to reflect on who is affected more by human pollution: natural systems or humans themselves.

Mrs. N asked students if they thought that we still dump our sewage into rivers and water. They then learned more about modern wastewater treatment in preparation for a trip to a local wastewater treatment plant.

Resource

California Education and the Environment Initiative. 2013. *Our Water: Sources and Uses*. Sacramento: Office of Education and the Environment accessed at https://www.cde.ca.gov/ci/sc/cf/ch6.asp#link41.

IS4 Discipline Specific Grade Seven Instructional Segment 4: Evidence of Evolution

Students have documented similarities and differences between organisms since kindergarten and analyzed how fossils record ancient life in grade three (3-LS4-1). Now they use these ideas together to discover evidence that plants and animals have changed over time.

DISCIPLINE SPECIFIC GRADE SEVEN 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?

Performance Expectations

Students who demonstrate understanding can do the following:

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.]

DISCIPLINE SPECIFIC GRADE SEVEN INSTRUCTIONAL SEGMENT 4: EVIDENCE OF EVOLUTION

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

Highlighted Science and Engineering Practices	Highlighted Disciplinary Core Ideas	Highlighted Crosscutting Concepts
[SEP-1] Asking Questions and Defining Problems [SEP-4] Analyzing and Interpreting Data [SEP-6] Constructing Explanations (for science) and Designing Solutions (for engineering)	LS4.A: Evidence of Common Ancestry and Diversity LS4.B: Natural Selection	[CCC-1] Patterns [CCC-2] Cause and Effect: Mechanism and Explanation

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

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

CA CCSS for ELA/Literacy Connections: SL.7.1a–d, 4; RST.6–8.1, 7, 9; WHST.6–8.2a–f, 9

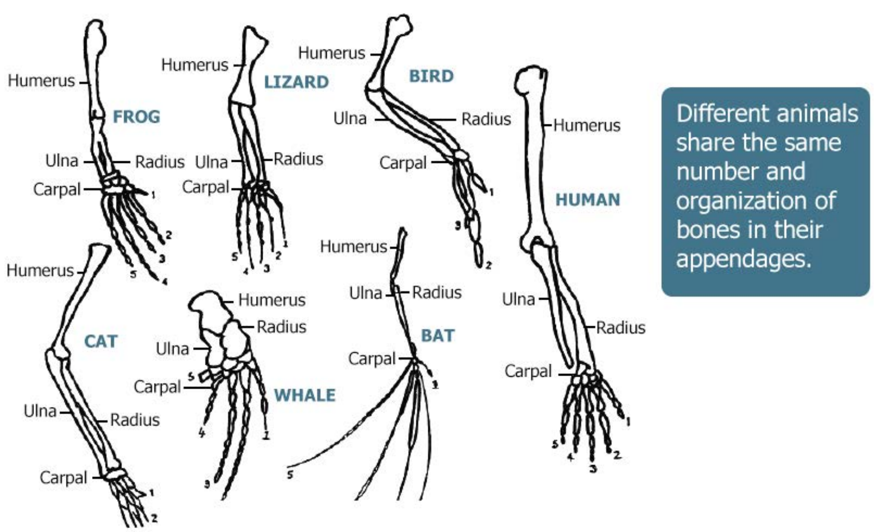
CA ELD Connections: ELD.PI.7.6a–b, 9, 10, 11a

All living organisms have cells that use the same basic **structure [CCC-6]** 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 [CCC-4]** because it works so well, while another 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 [CCC-1]** of **change over time [CCC-7]** and can therefore be **investigated [SEP-3]**. 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 most other species, scientists have sought other lines of **evidence [SEP-7]**. Tracking evolutionary history through chemical markers (such as similarities in DNA) is at the forefront of modern biology, but in the middle grades students should be looking for more tangible expression of evolution. This evidence comes from the fossil record.

In grade six, students developed a **model [SEP-2]** 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 scientists to peer back over a very long **timescale [CCC-3]** and discover transitional life forms as well as indications of organisms that no longer exist, and when the earliest members of each group first appeared.

Even though fossilized dinosaur bones look like bones, fossils are actually made 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 usually decompose too quickly and are rarely preserved in the fossil record). Before looking too far back in time, it helps to start with an **investigation [SEP-3]** comparing the shapes of different skeletons of modern organisms using schematics of the appendages of many creatures, including humans. Students can recognize the **pattern [CCC-1]** 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 [CCC-6]** of the bones relates to the **function [CCC-6]** of the arm. In an organism like a bat that uses its front appendage for flight, 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 6.26).

Figure 6.26. Bone Structures



Bone structure of appendages from many different classes of animals. *Source:* Lawson 2007
Long description of Figure 6.26.

Opportunities for Mathematics Connections

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 locomotion 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 [CCC-3]**. Even though each student is different and there is a range of sizes, what causes humans to have such a remarkably similar ratio between the lengths 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 CCSSM 7.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 [SEP-3]**. While some classic experiments are definitely worth conducting, asking **questions [SEP-1]** in which the 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 [CCC-1]** in the measurements. Students use these patterns to **explain [SEP-6]** how animals have a specific ratio of forearm to upper arm length that helps them 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 [CCC-2]** 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 that 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 [CCC-1]** in bone structures in related organisms over time. Students should be able to interpret examples from the fossil record to identify **patterns [CCC-1]** of **change [CCC-7]** (MS-LS4-1). Examples are rear leg bones that get shorter over 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 [CCC-1]** in bone **structure [CCC-6]** and embryo development as **evidence [SEP-7]** for a scientific **explanation [SEP-6]** that these organisms are related through common ancestry and that species have evolved over time (MS-LS4-2). They will revisit this explanation in IS6 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 sense of wonder and a series of **questions [SEP-1]** about how this systematic series of changes could have occurred.

IS5 Discipline Specific Grade Seven Instructional Segment 5: Inheritance and Genetics

In the previous instructional segment, students saw **evidence [SEP-7]** that life has evolved over many generations. The next two instructional segments allow students to construct a **model [SEP-2]** of the mechanism that allows evolution to occur.

DISCIPLINE SPECIFIC GRADE SEVEN 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?

Performance Expectations

Students who demonstrate understanding can do the following:

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

MS-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.]

DISCIPLINE SPECIFIC GRADE SEVEN INSTRUCTIONAL SEGMENT 5: INHERITANCE AND GENETICS

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.

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

Highlighted Science and Engineering Practices	Highlighted Disciplinary Core Ideas	Highlighted Crosscutting Concepts
[SEP-1] Asking Questions and Defining Problems [SEP-2] Developing and Using Models	LS1.B: Growth and Development of Organisms LS3.A: Inheritance of Traits LS3.B: Variation of Traits ETS1.A: Defining and Delimiting Engineering Problems	[CCC-2] Cause and Effect: Mechanism and Explanation [CCC-6] Structure and Function

CA CCSS Math Connections: 6.SP.5a–d, MP.4

CA CCSS for ELA/Literacy Connections: SL.7.5; RST.6–8.1, 4, 7; WHST.6–8.8

CA ELD Connections: ELD.PI.7.6a–b, 9, 10, 11a

Each student in a classroom or a school is unique in appearance and behavior. Organism structures and behaviors are features that generally apply to all members of a species. Examples of human features are eye color, body size, blood type, and personality characteristics such as introversion/extroversion. 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.

Opportunities for Mathematics Connections

Many physical traits can be expressed by a measurable **quantity [CCC-3]** 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. It is important for students to recognize individual differences in appearance and development, and this data-collection activity can engage students in an important discussion that goes beyond scientific facts (Health Education Standards 7–8.1.8.G, 7–8.2.1.G). 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 student in grade seven at their school by sampling students in their 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 tall a person will grow? How does the 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 parents. With this in mind, humans can have some influence on the height of their children by the people they choose as their mates. While students may or may not see much advantage in having an impact on the height of their children, there are many other situations in which 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 [SEP-8]** 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 [SEP-3]** into interesting applications of science to societal issues is not an optional sidetrack, but is 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 that helps them **develop a model [SEP-2]** of 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 [SEP-2]**) to predict or explain the traits in progeny and then conclude based on **evidence [SEP-7]** that some gene alleles are recessive, others are dominant, and some do not fit the dominant/recessive dichotomy.

Discipline Specific Grade Seven Snapshot 6.4: Asexual and Sexual Reproduction

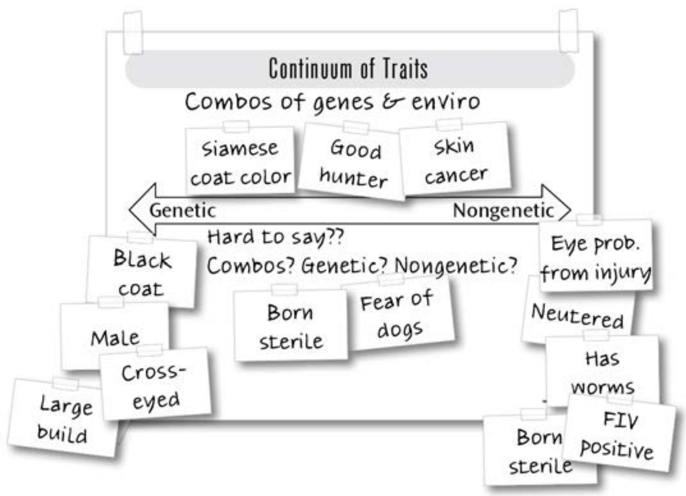
Anchoring phenomenon: Sunflowers, earthworms, strawberries, and whiptail lizards reproduce using different processes.

Ms. Z wanted to use an engaging activity to help students to transition from their analyses of the **causal [CCC-2]** connections between genes and traits into **models [SEP-2]** comparing asexual and sexual reproduction (MS-LS3-2). Basing the activity on an interactive lesson from the University of Utah Learn.Genetics Web site (see "Sexual vs. Asexual Reproduction" at https://www.cde.ca.gov/ci/sc/cf/ch6.asp#link42), 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 [SEP-7]** for their categorizations. Whole-class sharing resulted in common answers and evidence. Small student teams then explored the Web site (in a computer lab, in class with tablets, at home, or in a library) and selected two organisms that have different processes of reproduction.

The following day, student teams made system **models [SEP-2]** 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 posted sticky notes next to the models with any **questions [SEP-1]** 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.

Discussions of traits can get sidetracked by either/or arguments about the roles of genes and the environment in determining traits (the age-old nature–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., being able to play the guitar or having large muscles due to exercise). Most traits are a combination of genetic and environmental influence, and can be placed somewhere along the continuum between the extremes examples (figure 6.27).

Figure 6.27. Genetic and Environmental



Some traits are essentially all genetic, and some are mostly environmental. Most traits are strongly influenced both by genes and the environment. *Source*: From *Making Sense of SCIENCE: Genes and Traits* (WestEd.org/mss) by Daehler and Folsom. Copyright © 2015 WestEd. Reproduced with permission. Long description of Figure 6.27.

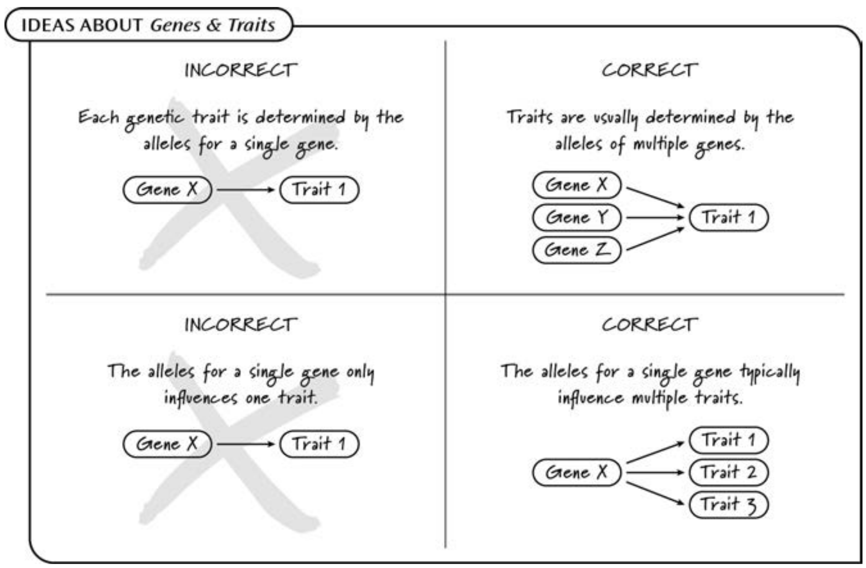
Students should be able to draw connections between their **model [SEP-2]** of the cell **system [CCC-4]** and their model of reproduction. In particular, the genetic code is stored on chromosomes located within the cell nucleus. The chromosomes can be thought of as recipe books that contain the list 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 [CCC-2]** all **changes [CCC-7]** to an organism's **structure [CCC-6]** 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 grade seven (MS-LS3-1). Despite this fundamental role, there are many unanswered **questions [SEP-1]** about the exact mechanisms by which proteins influence traits. For example, specific molecules described in our genes trigger cell growth, but how exactly does the body know when to stop growing? In other words, scientists cannot 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 as the right leg? 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 [SEP-1]**.

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 [CCC-7]** 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 [CCC-6]** 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 [SEP-7]** 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 6.28 contrasts incorrect and correct concepts about the **causal [CCC-2]** linkages between genes and traits. This figure doesn't capture the fact that large sections of DNA appear to do nothing at all and may be relicts left over by evolution. As much as 98 percent 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 used. Many other organisms use a much higher portion of their DNA.

Figure 6.28. Incorrect and Correct Ideas about Genes and Traits



Multiple genes typically determine a specific trait, and an individual gene typically influences multiple traits. *Source:* From *Making Sense of SCIENCE: Genes and Traits* (WestEd.org/mss) by Daehler and Folsom. Copyright © 2015 WestEd. Reproduced with permission.
Long description of Figure 6.28.

Students can now revisit their project **investigating [SEP-3]** how humans can influence traits and **apply their models [SEP-2]** of genetic inheritance and mutations to **evaluating the information [SEP-8]** 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 [CCC-3]** 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 the 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 feline 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 for 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-3 oils using 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 or risks (MS-ETS1-1, EP&C V). As students **evaluate the information [SEP-8]** they find about these genetically modified products, they should search for resources that attempt to **quantify [CCC-3]** the costs or benefits and favor resources that provide this information over resources that make vague or general statements.

Opportunities for ELA/ELD Connections

Students write a letter to a farmer about whether or not they should use seeds that have been genetically modified, determining whether or not the benefits of these modifications outweigh any known or projected costs or benefits. Evidence and examples should be supported by specific research and data. Have students use an organizational writing tool to outline the purpose, audience, and format of the letter.

CA CCSS for ELA/Literacy Standards: WHST.6–8.1

CA ELD Standards: ELD.PI.6–8.10

IS6 Discipline Specific Grade Seven Instructional Segment 6: Natural Selection

Instructional segment six builds from and extends the ideas about inheritance and variation within and across species developed in IS5, which began with students using **graphical and mathematical representations [SEP-5]** of a trait such as height. This instructional segment focuses on how the frequency of different traits **changes [CCC-7]** over time in a population.

DISCIPLINE SPECIFIC GRADE SEVEN 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?

Performance Expectations

Students who demonstrate understanding can do the following:

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.

DISCIPLINE SPECIFIC GRADE SEVEN INSTRUCTIONAL SEGMENT 6: NATURAL SELECTION

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

Highlighted Science and Engineering Practices	Highlighted Disciplinary Core Ideas	Highlighted Crosscutting Concepts
[SEP-1] Asking Questions and Defining Problems [SEP-2] Developing and Using Models [SEP-4] Analyzing and Interpreting Data [SEP-5] Using Mathematics and Computational Thinking [SEP-6] Constructing Explanations (for science) and Designing Solutions (for engineering) [SEP-7] Engaging in Argument from Evidence	LS1.B: Growth and Development of Organisms LS2.A: Interdependent Relationships in Ecosystems LS4.B: Natural Selection LS4.C: Adaptation ETS1.A: Defining and Delimiting Engineering Problems ETS1.B: Developing Possible Solutions ETS1.C: Optimizing the Design Solution	[CCC-2] Cause and Effect: Mechanism and Explanation [CCC-6] Structure and Function

Highlighted California Environmental Principles and Concepts:

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

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

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

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

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

CA CCSS Math Connections: 6.SP.2, 6.RP.1, 7.RP.2a–d, MP.4

CA CCSS for ELA/Literacy Connections: RST.6–8.1, 7, 9; RI.7.8, WHST.6–8.1a–e, 2a–f; SL.7.1a–d, SL.7.4

CA ELD Connections: ELD.PI.1.1, 3, 6a, 6b, 10b, 11a

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 genetic modification. Natural populations follow a similar process in which adaptation of the population occurs through natural selection, which favors those traits that are the best fit to a given environment (i.e., they benefit survival and reproduction). Natural selection exists at the intersection between genetic inheritance (from IS5) and ecosystem **energy flows [CCC-5]** (from IS1). Selection within a population only occurs through breeding over many generations when there are limited **energy, matter [CCC-5]**, 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 [SEP-4]** 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 (California Department of Fish and Wildlife, https://www.cde.ca.gov/ci/sc/cf/ch6.asp#link43). Students can use existing data sets of duck (California Department of Fish and Wildlife, https://www.cde.ca.gov/ci/sc/cf/ch6.asp#link44) or deer (Nevada Department of Wildlife, https://www.cde.ca.gov/ci/sc/cf/ch6.asp#link45) 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 [SEP-1]** about what might happen to these populations as climates change 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 grades curriculum in the CA NGSS, they are a major focus of the high school performance expectations for life and Earth science.

Discipline Specific Grade Seven Snapshot 6.5: Graphing Fish Populations

Anchoring phenomenon: Malnourished sea lion pups have been showing up on Southern California beaches.

Mr. M led an activity in which students **analyzed population data [SEP-4]** (MS-LS2-1) by showing a video clip of a news story about how large numbers of sea lion pups had been showing up malnourished and abandoned by their parents on a beach in Southern California. While this is known to happen, the newscast emphasized that this year had many more abandoned pups than usual. After showing the news story, Mr. M asked students to suggest possible **causes [CCC-2]** for this problem. Students had recently created a food web that included sea lions and they knew that the pups depended on sardines and anchovies as their primary food. Freddy suggested that something caused these populations to drop.

Investigative phenomenon: The number of sardines and anchovies varies across the seasons and from year to year.

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

He assigned different groups of students to plot different subsets of the data. One group plotted the total fish per year while another group plotted the total fish per month over a three-year span. A third group of students calculated the total catch for two different five-year periods and created a graph comparing them. By **analyzing [SEP-4]** their own graphs, the groups plotting anchovies by year noticed a general downward trend while the groups plotting sardines noticed several years when the catch was incredibly high, with most other years having almost no fish at all. The groups plotting the catch by month saw that anchovies appeared each year in early summer while sardines were usually caught in the early autumn. The groups plotting the total over five-year periods found big differences between them; the first five years were dominated by anchovies while the latter five-year period was dominated by sardines.

Mr. M asked the students to provide **evidence [SEP-7]** in favor of or against the **argument [SEP-7]** that "sardine and anchovy populations stay the same over time." All groups strongly disagreed with the statement and cited their own graphs as evidence. Mr. M then had students do a gallery walk and **analyze [SEP-4]** the different graphs created by each team. He then asked students to provide evidence in favor or against the

Discipline Specific Grade Seven Snapshot 6.5: Graphing Fish Populations

argument [SEP-7] that "each graph of anchovy data shows the same thing." Students then discussed how each graph revealed a slightly different pattern, and the conclusions they could draw from these **patterns [CCC-1]** differed.

Investigative phenomenon: Ocean temperature changes from year to year, with cycles correlating in time to sardine and anchovy populations.

Mr. M. then provided 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 recognized that the timing **pattern [CCC-1]** of surface temperatures caused by El Niño corresponded to patterns in the fish populations, which is evidence that it may be the **cause [CCC-2]** of the **changes [CCC-7]** over time. He asked students to speculate about what would happen to the different fish and sea lion populations if global climate change caused El Niño effects to intensify (EP&C III). Students worked over the next few days to create an infographic **communicating [SEP-8]** the complex chain of events that had been causing the sea lion population to change.

Resource

Based on California Academy of Sciences 2015

Since there is natural variation within populations, students should gather **evidence [SEP-7]** to make a scientific **argument [SEP-7]** 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 some traits allow the organisms to access resources more readily while other traits enable the organisms 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 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 [CCC-6]** enables the **function [CCC-6]** to access 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 person-to-person variations in baseline **energy [CCC-5]** 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 snapshot 6.5 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 they did in previous generations. Selection can also occur on a very different **scale [CCC-3]** and can be observed as microbes become increasingly resistant to antibiotics—a fact that has huge impacts on healthcare. Students can **plan an investigation [SEP-3]** to observe how microbe populations **change over time [CCC-7]** in a petri dish exposed to antibacterial soap. For middle grades classrooms that cannot safely conduct this investigation, students can implement their plan in a computer simulator or **analyze data [SEP-4]** from an existing experiment (Achieve 2014).

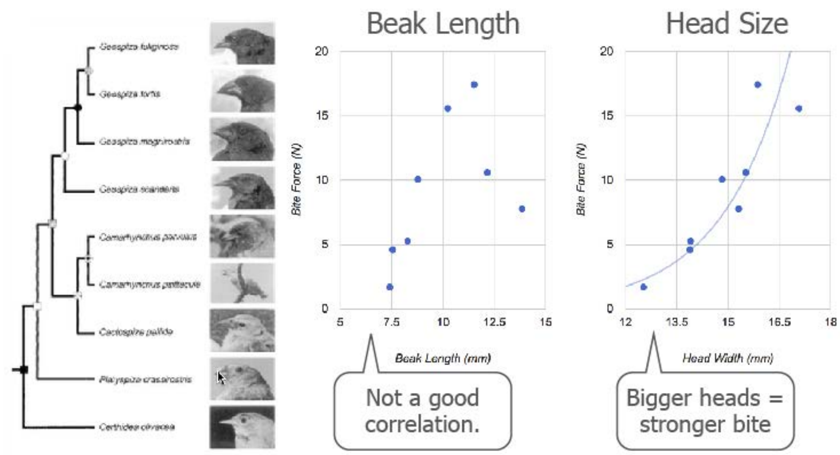
Engineering Connection: Engineer a Bird Beak

In elementary school, students constructed arguments about 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 [CCC-6]** 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 (for example, see Curiosity Machine, Engineer a Bird Beak at https://www.cde.ca.gov/ci/sc/cf/ch6.asp#link46).

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 obtained 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 the 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 [CCC-5]** to survive, the activity can be set up so that the number of points a team receives depends on the ratio of food mass eaten to the beak mass). After testing their design, they make changes 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 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 (Herrel 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 (figure 6.29). They can experiment with different modifications to their bird beaks that mimic these size differences and relate them to levers and forces.

Engineering Connection: Engineer a Bird Beak

Figure 6.29. Analysis of Different Physical Characteristics of Finches



Source: Herrel et al. 2005; charts by M. d'Alessio
Long description of Figure 6.29.

Discipline Specific Grade Seven Snapshot 6.6: Physical Environment Shifts Populations

Anchoring phenomenon: Pygmy people are shorter than many other human 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 asked 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 it survive in a particular environment. The class suggested these items: 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.

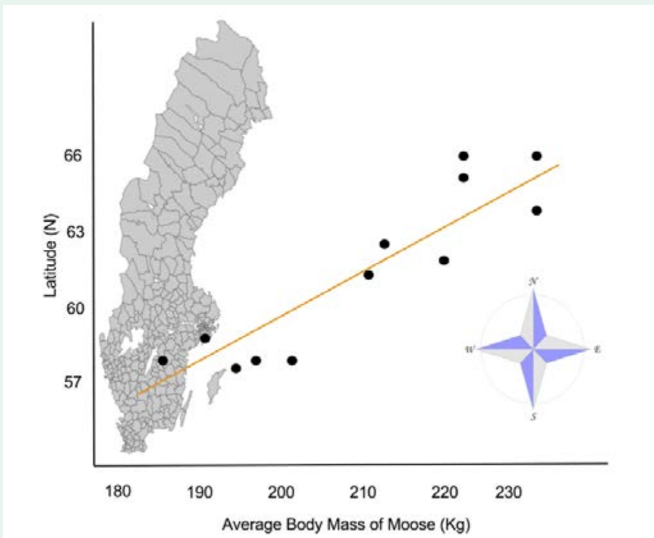
Investigative phenomenon: Moose from Northern Sweden are larger, on average, than those from Southern Sweden.

Ms. H did some Internet research and found a graph of moose weight versus latitude in Sweden (figure 6.30). Students correctly interpreted the axes of the graph to see that

Discipline Specific Grade Seven Snapshot 6.6: Physical Environment Shifts Populations

a moose of average size is larger in the northern part of Sweden compared to the southern part. She showed pictures of Sweden to help students see how cold it gets in the winter and asked them why having more body mass would be an advantage. Students realized that they needed to add heat management to their list of adaptations for size.

Figure 6.30. Average Moose Weight Varies by Latitude in Sweden



Source: Nmccarthy16 2014
Long description of Figure 6.30.

Investigative phenomenon: Populations of pygmy people live in equatorial regions that are hot and moist.

Ms. H asked students to research where different pygmy populations live and plot them on a world map. They found that pygmies live in equatorial regions, which students knew are typically hot (MS-ESS2-6). Upon further investigation, they found that these areas are hot and humid, which means that it is hard for people to lose heat efficiently by sweating (because evaporation occurs slowly in damp, swampy conditions; ties to MS-ESS2-4). Unlike the moose in Sweden, pygmies benefit from generating and retaining as little heat as possible to avoid overheating, and the ineffectiveness of sweating makes heat management even more crucial. Since bodies cool when air touches skin, pygmy's bodies 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

Discipline Specific Grade Seven Snapshot 6.6: Physical Environment Shifts Populations

moves. Very large animals need specific body features to help them stay cool such as African elephants with very large ears. Over time, pygmy populations may have evolved to maximize the ratio of surface area to body mass, which results in a thinner, shorter body. If this body shape and size allows pygmies to be more successful at moving around to obtain food and survive, it gets passed from one generation to the next through their genetic code.

Ms. H assessed whether or not students had mastered these ideas by asking them to write a complete scientific **explanation [SEP-6]** answering the question, Why are pygmies short? including evidence and reasoning. Ms. H could have extended this activity to include an engineering challenge in physical science in which students designed a person or organism that optimized energy transfer for different environmental conditions (MS-PS3-3).

Opportunities for Mathematics Connections: 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 beneficial trait. That 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 CCSSM 7.SP.8). Such problems can be solved by multiplying rational numbers (CA CCSSM 7.NS.2; e.g., half (½) of the population has trait X and one-quarter (¼) of individuals with trait X are expected to survive, so therefore one-eighth (½ x ¼) of 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 [SEP-5]** 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 [SEP-7]** to **explain [SEP-6]** 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 [SEP-6]** 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 [SEP-5]** can be implemented in a game involving a deck of cards (see NOVA Teachers, Dogs and More Dogs classroom activity: https://www.cde.ca.gov/ci/sc/cf/ch6.asp#link47).

Many students hold a common preconception about the **timescale [CCC-3]** of selection. Students incorrectly believe that individuals adapt to the environment as it changes. Students can construct an **argument [SEP-7]** that organisms cannot change their traits such as height, position of their eyes, length of their wings, or **energy [CCC-5]** 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 and whether or not the environment is **stable or changing [CCC-7]**. **Stable [CCC-7]** environments often lead to gradual changes in populations, while sudden environmental changes lead to more dramatic selection. Careful use of language is important to minimize this preconception, such as using the phrase "populations adapt" rather than referring to "organisms adapting."

IS7 Discipline Specific Grade Seven Instructional Segment 7: Ecosystem Interactions, Revisited

This capstone instructional segment for grade seven allows students to revisit the natural systems they investigated all year. This instructional segment can be based on a capstone project in which students explore the effects of humans on natural systems. They can **ask their own questions [SEP-1]**, **obtain and evaluate information [SEP-8]** from outside sources, and use this information to evaluate different design solutions and minimize human impacts on the environment.

DISCIPLINE SPECIFIC GRADE SEVEN 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?

Performance Expectations

Students who demonstrate understanding can do the following:

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.]

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

DISCIPLINE SPECIFIC GRADE SEVEN INSTRUCTIONAL SEGMENT 7: ECOSYSTEM INTERACTIONS, REVISITED

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

Highlighted Science and Engineering Practices	Highlighted Disciplinary Core Ideas	Highlighted Crosscutting Concepts
[SEP-7] Engaging in Argument from Evidence	LS2.C: Ecosystem Dynamics, Functioning, and Resilience LS4.C: Adaptation LS4.D: Biodiversity and Humans ETS1.B: Developing Possible Solutions	[CCC-4] Systems and System Models [CCC-7] Stability and Change

Highlighted California Environmental Principles and Concepts:

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

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

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

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

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

CA CCSS Math Connections: 6.RP.3a–d, MP.4

CA CCSS for ELA/Literacy Connections: RST.6–8.1, 8; RI.7.8; WHST.6–8.1a–e, 9

CA ELD Connections: ELD.PI.1.1, 3, 6a, 6b, 10b, 11a

Once students have **models [SEP-2]** for the interconnectedness of **ecosystem components [CCC-4]** and a sense of how limited resources within ecosystems affect populations (MS-LS2-1), they can construct **arguments [SEP-7]** about how **changes [CCC-7]** 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 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 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 nonjudgmental.

California's Environmental Principles and Concepts (EP&Cs) can provide further guidance. All five of the EP&Cs apply to 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 EP&Cs. For example, the three concepts associated with EP&C III state:

- Natural **systems [CCC-4]** 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 Connection: Using Technology to Enhance an Ecosystem

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, reduction of soil erosion, or recycling of nutrients. Students **investigate [SEP-3]** competing technologies or various design alternatives of a given technology to see which is most beneficial to the ecosystem (MS-LS2-5). One classroom-friendly possibility is to explore different designs of compost **systems [CCC-4]** to optimize nutrient recycling. Students can learn more about the valuable role of decomposers by performing a service for their school by collaborating with the 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 [CCC-4]** thinking and modeling introduced in IS1 provide a scientific framework for evaluating these impacts at a range of **scales [CCC-3]** 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?

Grade Eight Discipline Specific Course Model: Physical Science

From the introduction to the Middle Grades Physical Sciences Standards in the NGSS:

> The performance expectations in physical science blend the core ideas with scientific and engineering practices and crosscutting concepts to support students in developing useable knowledge to explain real-world phenomena in the physical, biological, and earth and space sciences.... The performance expectations in the topic Structure and Properties of Matter help students to formulate an answer to the questions: "How can particles combine to produce a substance with different properties? How does thermal energy affect particles?" by building understanding of what occurs at the atomic and molecular scale.... The performance expectations in the topic Chemical Reactions help students to formulate an answer to the questions: "What happens when new materials are formed? What stays the same and what changes?" by building understanding of what occurs at the atomic and molecular scale during chemical reactions.... The performance expectations in the topic Forces and Interactions focus on helping students understand ideas related to why some objects will keep moving, why objects fall to the ground and why some materials are attracted to each other while others are not. Students answer the question, "How can one describe physical interactions between objects and within systems of objects?".... The performance expectations in the topic Energy help students formulate an answer to the question, "How can energy be transferred from one object or system to another?".... The performance expectations in the topic Waves and Electromagnetic Radiation help students formulate an answer to the question, "What are the characteristic properties of waves and how can they be used?" (NGSS Lead States 2013c)

Just about every change you can think of involves a transfer or conversion of **energy [CCC-5]**. This Physical Science course for grade eight is organized around the crosscutting concept of **Energy Flows, Cycles, and Conservation [CCC-5]**. While the disciplinary core ideas cover physical science, many of the phenomena are drawn from Earth and life sciences so that the course truly serves as a culmination of the middle grades science experience.

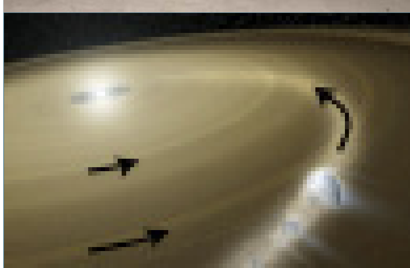
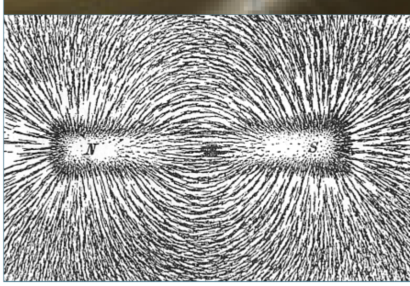
Each instructional segment focuses on one form of **energy [CCC-5]** and they are sequenced such that the most conceptually simple energy form (kinetic) comes first, with an emphasis on colliding objects. Students apply their knowledge of collisions to engineering design challenges in IS1 and then again in IS5 to develop models of thermal energy. The exchange between kinetic energy and gravitational potential energy introduces the concept of potential fields and energy conversion. **Investigations [SEP-3]** in the next instructional segment explore electric and magnetic fields and the role these fields play in the conversion and transfer of various types of energy. An instructional segment addressing waves, another means to transfer energy, is presented after the instructional segment on electricity and magnetism to allow for synergies between the topics since many electrical devices transfer information using waves. The course returns to kinetic energy viewed at a different **scale [CCC-3]** with an instructional segment on thermal energy that emphasizes the view of matter as moving and colliding particles. The final instructional segment culminates with chemical potential energy as these particles interact through chemical bonding, providing the mechanism for organisms to store and use energy, among many other uses.

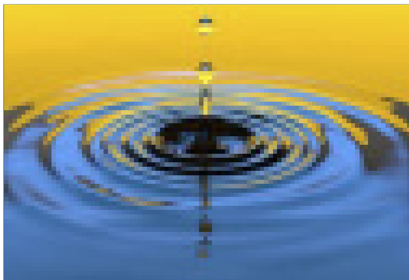
Energy [CCC-5] is a difficult concept to grasp because it is not something tangible (it is not an object that has mass or can be held), yet it appears to come in many different forms. Textbooks often define energy as the ability to do work (with the caveat that the term work has a very specific definition in physical science) or anything that can be converted into heat. An alternative to these technical definitions (that may be less precise but very illustrative) is that energy is the ability to cause damage. For example, there are many different ways a person can get hurt, and each process even has a unique descriptive name just like different forms of energy have unique names.

You can get hurt when something that is moving hits you. We call this a crash in everyday language, and when you describe that you were hurt in a crash, other people instantly know that moving objects were involved (kinetic energy). This manner of getting hurt differs from a burn, a word that communicates that a hot object was involved (thermal energy). Sunburn involves rays of ultraviolet sunshine (a form of light energy). You can be electrocuted only if there is electricity around (electromagnetic energy), or poisoned by exposing yourself to dangerous chemicals (chemical potential energy). There are also some ways of being hurt that only depend on your position, such as having the potential to get hurt by falling when you are high above the ground (gravitational potential energy).

The different terms for the different forms of energy are an example of how language is used in science. Scientists label complex processes with specific terminology so that they can communicate many aspects of a situation in a single word or phrase. While this analogy of different ways of getting hurt corresponding to different energy forms helps communicate ideas about the nature of energy to students, it has limitations like all analogies. All of the examples above involve people being hurt when **energy [CCC-5]** is transferred. Many forms of energy can be associated with objects (but not, for example, light energy), meaning that the objects have energy even when they are not interacting with anything else. Even though it is possible to calculate the energy of an object by itself, it is really only possible to measure this energy by seeing what happens when objects interact and transfer energy. A transfer of energy involves a "force"—an interaction that can change the motion of an object. Thus forces and energy are closely related, and this course discusses forces largely in terms of their relationship to the crosscutting concept of **energy [CCC-5]**. Table 6.8 shows a sequence of six possible phenomenon-based instructional segments in a discipline specific grade eight course.

Table 6.8. Overview of Instructional Segments for Discipline Specific Grade Eight

	**1 Energy of Motion** Students investigate how objects move and collide. They use their observations as evidence that an exchange of energy occurs during these interactions. They refine their model of energy transfer as they develop solutions to minimize damage during collisions.
	**2 Gravity, Energy Related to Position** Students develop a model of the relationship between gravity, force, and energy.
	**3 Electric and Magnetic Interactions and Energy** Students investigate electrical and magnetic interactions to gather evidence that fields exist between the objects. They ask questions about what affects the strength of the forces between objects and develop a model relating the position of the objects to potential energy in the system.



4 Waves Transmitting Energy and Information
Students explore how waves interact with different objects so that they can develop a model of how the energy is reflected, absorbed and transmitted. They then explore how waves can transmit information encoded either as analog or digital signals.

5 Thermal Energy and Heat Flow
Students refine their model of matter at the scale of individual particles and use this model to describe how materials change when heated or cooled. They relate the microscopic behavior to energy changes observed at the macroscopic scale as they design a device to maximize thermal energy transfer.

6 Chemical Energy and Reactions
Students investigate how properties change when substances mix together and react. By analyzing patterns, students refine their model of matter further by representing each particle as a collection of atoms bonded together. They use this model to explain the bulk changes they observe in chemical reactions such as temperature changes.

Sources: National Highway Traffic Safety Administration 2016; adapted from NASA/JPL-Caltech 2006; Black and Davis 1913, 242, fig. 200; Socha 2016; O'Sullivan 2009; Amitchell125 2011

IS1 Discipline Specific Grade Eight Instructional Segment 1: Energy of Motion

Students have addressed the concept of pushes, pulls, and collisions several times in elementary school (K-PS2-1, 3-PS2-1, 4-PS3-3). In this instructional segment, they represent these phenomena in terms of energy transfer.

DISCIPLINE SPECIFIC GRADE EIGHT INSTRUCTIONAL SEGMENT 1: ENERGY OF MOTION

Guiding Questions

- How can understanding energy and forces help make us safer in car crashes?
- What happens to energy when objects collide or otherwise interact?
- Why do objects sometimes appear to slow down on their own?

Performance Expectations

Students who demonstrate understanding can do the following:

MS-PS2-1. Apply Newton's Third Law to design a solution to a problem involving the motion of two colliding objects.* [Clarification Statement: Examples of practical problems could include the impact of collisions between two cars, between a car and stationary objects, and between a meteor and a space vehicle.] [*Assessment Boundary: Assessment is limited to vertical or horizontal interactions in one dimension.*]

MS-PS2-2. Plan an investigation to provide evidence that the change in an object's motion depends on the sum of the forces on the object and the mass of the object. [Clarification Statement: Emphasis is on balanced (Newton's First Law) and unbalanced forces in a system, qualitative comparisons of forces, mass and changes in motion (Newton's Second Law), frame of reference, and specification of units.] [*Assessment Boundary: Assessment is limited to forces and changes in motion in one-dimension in an inertial reference frame and to change in one variable at a time. Assessment does not include the use of trigonometry*.]

MS-PS3-1. Construct and interpret graphical displays of data to describe the relationships of kinetic energy to the mass of an object and to the speed of an object. [Clarification Statement: Emphasis is on descriptive relationships between kinetic energy and mass separately from kinetic energy and speed. Examples could include riding a bicycle at different speeds, rolling different sizes of rocks downhill, and getting hit by a wiffle ball versus a tennis ball.]

MS-PS3-5. Construct, use, and present arguments to support the claim that when the kinetic energy of an object changes, energy is transferred to or from the object. [Clarification Statement: Examples of empirical evidence used in arguments could include an inventory or other representation of the energy before and after the transfer in the form of temperature changes or motion of object.] [*Assessment Boundary: Assessment does not include calculations of energy*.]

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-ETS1-3. Analyze data from tests to determine similarities and differences among several design solutions to identify the best characteristics of each that can be combined into a new solution to better meet the criteria for success.

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.

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

DISCIPLINE SPECIFIC GRADE EIGHT INSTRUCTIONAL SEGMENT 1: ENERGY OF MOTION

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

Highlighted Science and Engineering Practices	Highlighted Disciplinary Core Ideas	Highlighted Crosscutting Concepts
[SEP-1] Asking Questions and Defining Problems [SEP-2] Developing and Using Models [SEP-3] Planning and Carrying Out Investigations [SEP-4] Analyzing and Interpreting Data [SEP-6] Constructing Explanations (for science) and Designing Solutions (for engineering) [SEP-7] Engaging in Argument from Evidence	PS2.A: Forces and Motion PS3.A: Definitions of Energy PS3.B: Conservation of Energy and Energy Transfer ETS1.A: Defining and Delimiting an Engineering Problem ETS1.B: Developing Possible Solutions ETS1.C: Optimizing the Design Solution	[CCC-2] Cause and Effect: Mechanism and Explanation [CCC-3] Scale, Proportion, and Quantity [CCC-4] Systems and System Models [CCC-5] Energy and Matter: Flows, Cycles, and Conservation [CCC-6] Structure and Function [CCC-7] Stability and Change

Highlighted California Environmental Principles and Concepts:
Principle V Decisions affecting resources and natural systems are based on a wide range of considerations and decision-making processes.

CA CCSS Math Connections: 6.NS.5, 6.RP.1, 2, 6.EE.2a–c; 7.EE.3, 4, 7.SP.7a–b, 7.RP.2a–d; 8.EE.1, 2, 8.F.3; MP.2

CA CCSS for ELA/Literacy Connections: RST.6–8.1, 3, 7, 9; WHST.6–8.7, 8, 9

CA ELD Connections: ELD.PI.8.1, 3, 6a, 6b, 10b, 11a

Imagine a boy standing and reading a book and a girl riding a skateboard down the sidewalk toward him. If they collide, which person will gain **energy [CCC-5]** and which person will lose energy? Who will feel a stronger force from the impact? How could this force be minimized so that nobody gets hurt? These are the types of questions that students will be able to answer at the end of this unit.

Engineering Connection: Reducing the Impact of Collisions

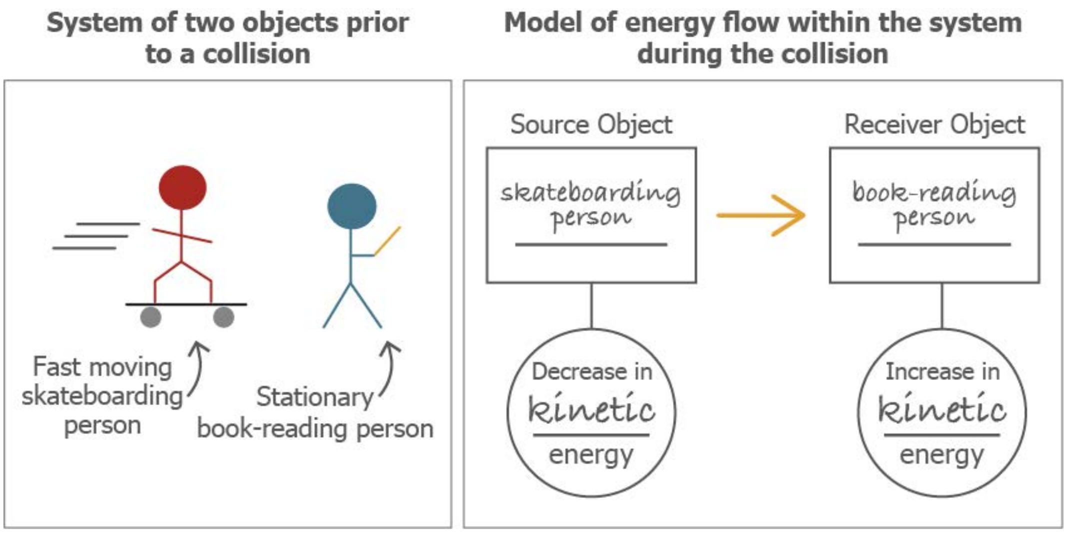
The unit begins with a design challenge in which students use a fixed set of materials to reduce the damage during a collision (MS-PS2-1). The classic egg drop could be used, but many of the solutions to that problem involve slowing the egg down before the collision (via parachute). The emphasis for the performance expectation is on applying Newton's Third Law that objects experience equal and opposite forces during a collision. A variation in which students attach eggs to model cars and design bumpers to protect the eggs, allows for a consistent theme of car crashes throughout the instructional segment and vehicles in general throughout the course. Students will need to identify the constraints that affect their design as well as the criteria for measuring success (MS-ETS1-1). Such a design challenge could be placed at the end of IS1 as a culmination in which students apply what they have learned from **investigations [SEP-3]** throughout the instructional segment. However, here the choice is made to explicitly use an engineering task to draw attention to the variables of interest in the problem. By identifying the common features of successful models (MS-ETS1-3), students can identify the physical processes and variables that govern the process. Students will then investigate these variables more systematically throughout the rest of the instructional segment. At the end of IS1, students return to their design challenge and **explain [SEP-6]** why certain choices they made actually worked (perhaps identifying important **structure/function relationships [CCC-6]** in their designs) and then use their more detailed models of the **system [CCC-4]** to refine their design.

In the design challenge described above, there are objects in motion and interactions between the objects that cause them to change their motion. Different design elements reduce the impact of the collision, despite the fact that all the objects have the same initial motion. Why? Students begin a systematic **investigation [SEP-3]** using objects such as toy cars or marbles on a track. They start by experimenting with what it takes to get the object to move, **asking questions [SEP-1]** about their observations. Does pushing a car work differently than pulling it? The change in motion will be identical if their pushes and pulls are truly identical in strength and direction, but students often pull upward along with forward. Why would that make a difference? If they push the car gently, does it behave differently than if they use a harder push? Does the car behave differently if a human pushes it versus it being pushed by another car?

To talk in detail about the similarities and differences in the motion of an object, students need to be able to make specific measurements of the motion. The word *motion* in the CA NGSS implies both the object's speed and its direction of travel. However, all work in this instructional segment is done in one dimension, and the focus is on speed; the distinction between the technical definitions of velocity and speed is not essential (the assessment boundaries of performance expectations for grade eight clearly state that assessment is restricted to **systems [CCC-4]** of only two objects or more complicated systems where all forces are aligned in one dimension. In high school, students will extend this understanding into two and three dimensions). Speed is the ratio of a distance and a time, allowing students to easily conduct **investigations [SEP-3]** that measure both **quantities [CCC-3]**. Manual measurements of time in tabletop experiments using stopwatches are prone to large error, so there are several alternatives: students can pool multiple measurements using collaborative online spreadsheets and take the average, use an app to calculate speed from video clips (such as “Tracker Video Analysis and Modeling Software” by Douglas Brown found at https://www.cde.ca.gov/ci/sc/cf/ch6.asp#link48), or use a motion-sensor probe.

Students often harbor the preconception that objects will naturally stop when they run out of inertia or when the force given to them runs out. This idea is based on abundant personal experience with moving objects that do indeed stop automatically because of friction, a force that can be reduced or increased by design measures. Understanding why objects slow down requires thinking about motion in terms of **energy [CCC-5]**. Students build on their **explanation [SEP-6]** of the relationship between these ideas from grade four (4-PS3-1) and their model for the **conservation of energy [CCC-5]** from grade five (5-PS3-1). An object retains its kinetic energy until it transfers it to another object or converts the energy to another form, which is the conceptual model that explains Newton’s First Law that an object in motion tends to stay in motion while an object at rest tends to stay at rest unless unbalanced forces act upon it. Students can create a diagrammatic **model [SEP-2]** of the **flow of energy [CCC-5]** within **systems [CCC-4]** as shown in figure 6.31. This simple diagram is a model because it includes components (an energy source and receiver), an understanding of the way these objects will interact based on the laws of physics (energy is conserved, with one object decreasing in energy that will be transferred to the other object), and it can be used to predict the behavior of the **system [CCC-4]** (the object that decreases in kinetic energy slows down while the object that increases in kinetic energy should speed up). Students can use these types of diagrammatic models to illustrate energy transfer throughout an entire physical science course (e.g., Goldberg 2009).

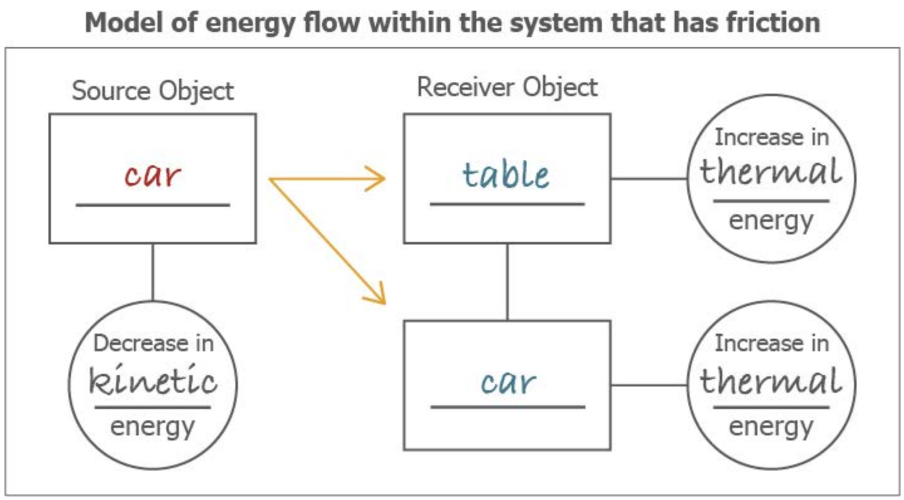
Figure 6.31. Collisions and Energy Flow



Model of energy flow within a system during a collision. Diagram by M. d'Alessio.
Long description of Figure 6.31.

The force of friction is an interaction in which **energy [CCC-5]** is transferred. Students must **plan investigations [SEP-3]** to explore the effects of balanced and unbalanced forces on the motion of objects (MS-PS2-2). One such investigation could involve measuring the speed of model cars with different amounts of friction by attaching sticky notes to the front and sides of the car to vary the amount of friction. Students should notice that when they push the car, they apply a force in one direction while friction is a force working in the opposite direction. The overall change in motion (and therefore change in energy) depends on the total sum of these forces. Using an energy source/receiver diagram to model the situation helps draw attention to the fact that some of the energy must go somewhere because the car clearly decreases in energy. Because energy is conserved, that means another component of the **system [CCC-4]** must increase in energy (figure 6.32). With some simple analogies to the friction of hands rubbing together, students can accept that the energy is likely converted into thermal energy, which will be discussed in more detail in IS5. When a person rubs hands together, both hands warm up even when one hand remains stationary. This observation gives rise to two modifications to the simple energy source/receiver diagram of those depicted in figure 6.32: (1) there can be multiple energy receivers in a **system [CCC-4]** from a single energy source, and (2) an object can be both the source and the receiver of energy if that energy converts from one form to another. Students will revisit this idea in IS2, but the remainder of this instructional segment emphasizes the transfer of energy between two distinct objects.

Figure 6.32. Energy Flow with Friction



Model of energy flow including friction within an experimental system of a tabletop car. Diagram by M. d'Alessio.
Long description of Figure 6.32.

During an interaction when a force acts on an object, that object gains kinetic energy. How much will the object's motion change during this interaction? Students asked similar **questions [SEP-1]** in grade four (4-PS3-3), and now they will begin to answer them. The answer depends strongly on the object's mass. This principle becomes easily apparent in collisions. Students can perform **investigations [SEP-3]** by colliding a given object with objects of different masses that are otherwise identical (for example, glass versus steel marbles of different sizes, cars with or without fishing weights attached, etc.). To measure consistent **patterns [CCC-1]**, students will need to **plan their investigation [SEP-3]** (MS-PS2-2) such that the source object has a consistent speed (for example, by rolling down a ramp of a fixed distance). This will ensure that the initial kinetic energy of the object is the same and leads to a consistent force during the collision interaction, if all other factors remain constant. Students can vary the mass of the target object and see how its speed changes as a result of the impact, plotting the results to look for a consistent pattern. This graphical representation should lead them towards a discovery of Newton's Second Law, which relates the change in an object's motion ("acceleration") to the force applied and the mass of the object. MS-PS2-2 does not require that students have a mathematical understanding of acceleration, it instead focuses on the **proportional [CCC-3]** relationship of motion changes and force.

Opportunities for ELA/ELD Connections

Students create mini-lessons on Newton's laws of motion to present to the class. Each team or group of students research a law of motion, using at least two different sources, for presentation to the class. Encourage students to include multimedia components and visual displays to clarify important findings, explain reasoning, provide evidence, and emphasize salient points. The presentation should include a general description/definition of the law plus an example demonstrating the application of the principle.

CA CCSS for ELA/Literacy Standards: RST. 6–8.2, 7; WHST.6–8.6, 7, 8; SL.6–8.5
CA ELD Standards: ELD.PI.6–8.9

When the objects have equal masses and collisions transfer all of the **energy [CCC-5]** from source to receiver, the speed of the target object after the collision should be similar to the speed of the source object before the collision. This can be seen clearly in billiards when the cue ball comes to a complete stop after hitting another ball. Observations such as these provide evidence to make the **argument [SEP-7]** that as one object loses kinetic energy during the collision, another object must gain energy, and vice-versa (MS-PS3-5). Students should also be able to model this collision in terms of forces; the force exerted by one ball must be equal and opposite to the force exerted on the other ball (Newton's Third Law).

As students investigate collisions, they can frame their thinking using energy source/receiver diagrams (figure 6.31). They can vary the properties of both the source object and receiver object and see how these changes affect the target object's motion. Thus far, they have built up a model in which the effect of a collision depends on the mass of the *target* object. Now they can gather evidence that shows how the speed and mass of the *source* object determine the amount of energy that it transfers during the collision. These observations form the basis for understanding more about kinetic energy. Energy transfers can be thought of as analogous to transfers of money, such as winning the lottery. If a single person buys a lottery ticket alone and wins, they will have big changes in their bank account and lifestyle. If a group of people get together to buy one ticket, the jackpot is split among them and the change in each person's lifestyle will be smaller. To relate the analogy to the collision, the same amount of energy must go into changing the speed of a larger amount of mass. Students can explore this idea further by changing the kinetic energy of the source object. Keeping the target object constant, groups of students can be assigned to vary either the source object's mass or its speed to see how the changes impact the speed of the target.

Opportunities for Mathematics Connections

Each group should graph its findings and report to the class its interpretation of the relationship between kinetic energy and its variable (MS-PS3-1). The graph showing the effect of the source object's mass looks very different than the graph showing the effect of the source object's speed. One is linear while the other has a curved shape that can be described by a square root. Students can be given the challenge of finding different combinations of speed and mass of the source object that all result in the target object going the same speed.

CA CCSSM: 8.EE.2

Engineering Connection: Reducing the Impact of Collisions

Students are now ready to return to their design challenge of reducing the impact of a collision (MS-PS2-1). They should be able to use their models of **energy [CCC-5]** transfer and kinetic energy to **make an argument [SEP-7]** about why their original design solution worked. Two different processes help bumpers reduce damage during collisions: (1) they absorb some of the energy so that less of it gets transferred to kinetic energy in the target object (the absorbed energy gets converted to heat); and (2) they make the collision last longer, so that the transfer of energy occurs over a longer time interval (since speed changes at a slower rate, Newton's laws tell us that a smaller force is exerted on the cars). Students can create energy source/receiver diagrams that are more sophisticated than figure 6.31 to describe the energy flow during a collision that includes a bumper. These diagrams should help students describe how Newton's Third Law helps them design their solution, and begin to **ask questions [SEP-1]** about where the energy actually goes during the interaction. They should also be able to propose improvements to their bumper (MS-ETS1-2, MS-ETS1-4) using the results of a more sophisticated testing regime and their enhanced understanding of the physical processes.

IS2

Discipline Specific Grade Eight Instructional Segment 2: Gravity and Energy Related to Position

Objects appear to start moving spontaneously when we drop them, but their energy of motion must come from somewhere. In this instructional segment, students investigate the force of gravity and understand it in terms of energy conversion.

DISCIPLINE SPECIFIC GRADE EIGHT INSTRUCTIONAL SEGMENT 2: GRAVITY AND ENERGY RELATED TO POSITION

Guiding Questions

- What affects the strength of the force of gravity?
- How do roller coasters get the energy to go so fast?
- Do heavy objects fall faster than lighter ones?

Performance Expectations

Students who demonstrate understanding can do the following:

MS-PS2-2. Plan an investigation to provide evidence that the change in an object's motion depends on the sum of the forces on the object and the mass of the object. [Clarification Statement: Emphasis is on balanced (Newton's First Law) and unbalanced forces in a system, qualitative comparisons of forces, mass and changes in motion (Newton's Second Law), frame of reference, and specification of units.] [*Assessment Boundary: Assessment is limited to forces and changes in motion in one-dimension in an inertial reference frame and to change in one variable at a time. Assessment does not include the use of trigonometry*.]

MS-PS2-4. Construct and present arguments using evidence to support the claim that gravitational interactions are attractive and depend on the masses of interacting objects. [Clarification Statement: Examples of evidence for arguments could include data generated from simulations or digital tools; and charts displaying mass, strength of interaction, distance from the Sun, and orbital periods of objects within the solar system.] [*Assessment Boundary: Assessment does not include Newton's Law of Gravitation or Kepler's Laws*.]

MS-PS2-5. Conduct an investigation and evaluate the experimental design to provide evidence that fields exist between objects exerting forces on each other even though the objects are not in contact. [Clarification Statement: Examples of this phenomenon could include the interactions of magnets, electrically-charged strips of tape, and electrically-charged pith balls. Examples of investigations could include first-hand experiences or simulations.] [*Assessment Boundary: Assessment is limited to electric and magnetic fields, and is limited to qualitative evidence for the existence of fields.*]

MS-PS3-2. Develop a model to describe that when the arrangement of objects interacting at a distance changes, different amounts of potential energy are stored in the system. [Clarification Statement: Emphasis is on relative amounts of potential energy, not on calculations of potential energy. Examples of objects within systems interacting at varying distances could include: the Earth and either a roller coaster cart at varying positions on a hill or objects at varying heights on shelves, changing the direction/orientation of a magnet, and a balloon with static electrical charge being brought closer to a classmate's hair. Examples of models could include representations, diagrams, pictures, and written descriptions of systems.] [*Assessment Boundary: Assessment is limited to two objects and electric, magnetic, and gravitational interactions*.]

DISCIPLINE SPECIFIC GRADE EIGHT INSTRUCTIONAL SEGMENT 2: GRAVITY AND ENERGY RELATED TO POSITION

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

Highlighted Science and Engineering Practices	Highlighted Disciplinary Core Ideas	Highlighted Crosscutting Concepts
[SEP-2] Developing and Using Models [SEP-3] Planning and Carrying Out Investigations [SEP-7] Engaging in Argument from Evidence	PS2.A: Forces and Motion PS2.B: Types of Interactions PS3.A: Definitions of Energy PS3.C: Relationship Between Energy and Force	[CCC-2] Cause and Effect: Mechanism and Explanation [CCC-4] Systems and System Models [CCC-7] Stability and Change Influence of Science, Engineering, and Technology on Society and the Natural World

CA CCSS Math Connections: 6.EE.2a–c; 7.EE.3, 4; MP.2

CA CCSS for ELA/Literacy Connections: RST.6–8.3; RI.7.8; WHST.6–8.1a–e, 7; SL.8.5

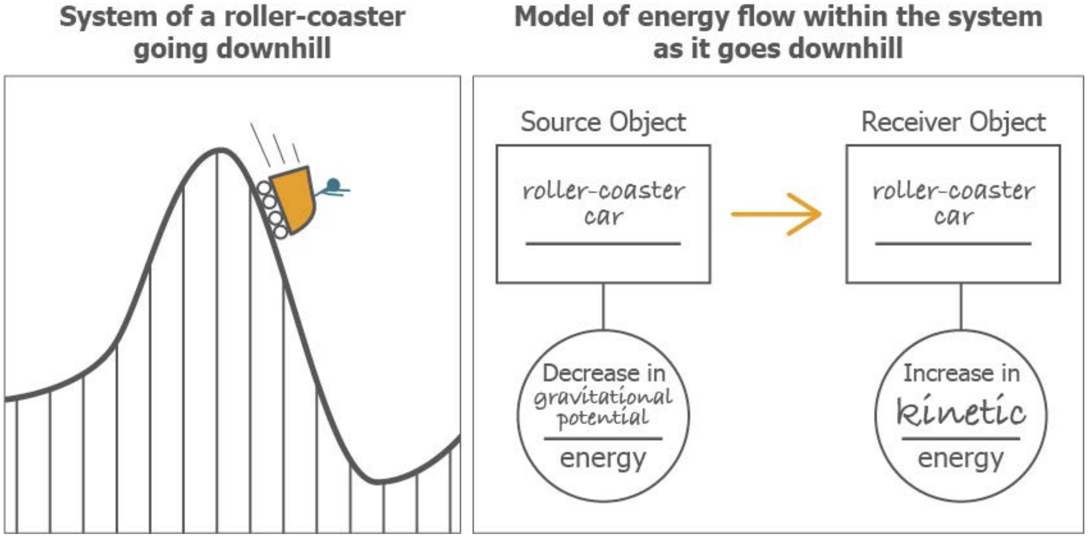
CA ELD Connections: ELD.PI.1.1, 3, 6a, 6b, 10b, 11a; ELD.PII.1

Some interactions happen even when objects are not touching, and the most familiar of these involves gravity. Gravity is one of only four fundamental forces in the universe, and it causes literally all objects with mass in the universe to be mutually attracted. The Golden Gate Bridge pulls on the Hollywood sign (and every student in the state) just like the Moon pulls on the Earth. The reason we do not notice this pull is that it is so weak compared to the attraction toward Earth itself. That is because the planet has so much more mass than the Hollywood sign or even the Golden Gate Bridge. Since all mass is attracted to all other mass in the universe, it is also true that the Sun itself pulls on every student in the class. The star Alpha Centauri is many times more massive than the Earth, so why don't students fly up in the sky towards that star or any of the others? The answer is that the strength of the gravitational force also depends on the relative position of the two objects (i.e., the distance between them). Gravity on Earth is usually thought of as pulling objects towards the center of the planet, but there is nothing particularly special about the mass at the center of the planet or the downward direction. A person gets pulled by every piece of the entire planet, with the rock directly beneath his or her feet exerting the strongest pull and the rock on the opposite side of the planet having the weakest because of its distance away. Just like students investigated the sum of forces when objects are touching in IS1

(MS-PS2-2), the overall change in motion is **caused [CCC-2]** by the sum of all the forces. The Earth is a sphere, so there is approximately the same amount of rock to the north, south, east, and west of a person and the overall effect is a downward pull towards the center of the planet. With very careful measurements, however, scientists can measure slight differences in the direction and strength of the pull of gravity at different locations on Earth. For example, if an underground aquifer is full of water or a volcano magma chamber fills with magma, the extra mass will pull slightly harder on objects than if the aquifer were dry or the magma chamber empty. This pull can even be measured by satellites orbiting the planet, which provide valuable data for monitoring global water supplies and volcanic hazards (see American Museum of National History, GRACE Watches Earth's Water at https://www.cde.ca.gov/ci/sc/cf/ch6.asp#link49).

Students conduct **investigations [SEP-3]** into gravitational interactions on Earth to create a mental **model [SEP-2]** of the relationship between the concepts of gravity, force, and energy. Their investigation could include letting cars roll down ramps or dropping balls and recording their speed at different points in time with a sensor probe or frame-by-frame video analysis app. For this particular investigation, students should explicitly **evaluate [SEP-8]** the experimental design, which might include the teacher providing students with a cookbook-style procedure with an intentional flaw in it that students must correct before they are able to collect useful data. They notice a change in motion, which must be caused by a force that exists even though the objects are not touching (MS-PS2-5; even though assessment on this performance expectation is restricted to electric and magnetic fields, the same principle applies to gravitational fields). By noticing that the speed of the object changes, they infer that the kinetic energy of the object is increasing (assuming that its mass does not change). If an object increases in **energy [CCC-5]**, that energy must come from some sort of interaction. The inevitable conclusion is that there must be some sort of energy associated with gravity, and scientists refer to it as gravitational potential energy. The everyday language use of the word *potential* applies fairly well in this situation in that there is energy ready to be unleashed with the capability to do work because the force of gravity is always acting on the object. The moment that this force acts in an unbalanced way on an object, there will be a net transfer of energy and the potential energy will convert to motion or vice versa (MS-PS2-2; figure 6.33). Other forces for which the energy change depends only on the final position of the object (as opposed to the path it took to reach that position) are also said to be associated with potential energies (such as electric forces discussed in IS3 and the elastic forces in springs and other materials).

Figure 6.33. Roller Coaster Energy Flow



Schematic diagram and model of energy flow within a system of a roller coaster going downhill. Note that the source and receiver objects are the same but the type of energy has changed. Diagram by M. d'Alessio

Long description of Figure 6.33.

Students can extend their **investigation [SEP-3]** to include the interplay between gravitational potential and kinetic energy by predicting an object's speed as it moves between different heights (by creating a roller coaster, marble track, or simply throwing a ball upwards and recording its speed at points moving upward and downward). They can use their roller coaster to **develop a model [SEP-2]**: changes in the position of the object affect the amount of gravitational potential **energy [CCC-5]** it has (MS-PS3-2). This model should allow them to predict how high a car will go on a ramp when released at different heights or how its speed will change as it moves from one height to another. Their model can be refined by interacting with a computer simulator of a roller coaster or skate park (see PhET, Energy Skate Park at https://www.cde.ca.gov/ci/sc/cf/ch6.asp#link50).

Opportunities for Mathematics Connections

One of the things students may notice in either physical or computer simulations is that the mass of the object does not affect its speed as an object's **energy [CCC-5]** converts back and forth between gravitational potential and kinetic energies. This observation will likely surprise many students who harbor the common preconception that heavier objects fall faster. Students' mental model of forces should include the idea that objects with more mass require a stronger force to speed up and slow down. The force of gravity pulls harder on heavier objects. This stronger gravitational pull is exactly balanced by the greater inertia of massive objects such that all objects end up falling at the same speed on planet Earth. Students should use evidence (likely from computer simulations) to **construct an argument [SEP-7]** that gravitational interactions attract objects together and depend on the mass of the object (MS-PS2-4). To **communicate [SEP-8]** their argument, students may construct fact sheets that include charts showing the relative strength of different interactions (such as Earth–Moon, Earth–Sun, Jupiter–Sun, Earth–student, or even student–student interactions). The CA NGSS explicitly states that students will not be assessed on using the formula for Newton's Law of Gravitation, but students can use the equation to apply scientific notation to a real-world problem (CA CCSSM 8.EE.4). Regardless of their ability to do the calculations themselves, they should be able to represent the relative magnitudes (i.e., **scale and proportion [CCC-3]**) of these forces using scientific notation (CA CCSSM 8.EE.3). Students can also use this sort of **mathematical thinking [SEP-5]** to **evaluate the claims [SEP-8]** of astrologers (who argue that our actions are affected by the position of distant planets) by examining the relative strength of the force of gravity between themselves and each of the planets. How do these magnitudes compare to the scale of other gravitational forces such as the force between the students and the desks in which they are sitting or the textbooks they are reading? Are they large enough to **cause [CCC-2]** major changes to interactions on Earth?

CA CCSSM: 8.EE.3, 4

IS3 Discipline Specific Grade Eight Instructional Segment 3: Electric and Magnetic Interactions and Energy

Students investigated the forces of magnetism in grade three (3-PS2-3), and electric currents in grade four (4-PS3-2). In grade eight, students explore electromagnetism collecting more rigorous quantitative data and modeling these interactions in terms of energy transfer and conversion.

DISCIPLINE SPECIFIC GRADE EIGHT INSTRUCTIONAL SEGMENT 3: ELECTRIC AND MAGNETIC INTERACTIONS AND ENERGY

Guiding Questions

- How do electric motors work to convert electricity into motion?
- How does a compass needle move?

Performance Expectations

Students who demonstrate understanding can do the following:

MS-PS2-3. Ask questions about data to determine the factors that affect the strength of electric and magnetic forces. [Clarification Statement: Examples of devices that use electric and magnetic forces could include electromagnets, electric motors, or generators. Examples of data could include the effect of the number of turns of wire on the strength of an electromagnet, or the effect of increasing the number or strength of magnets on the speed of an electric motor.] [*Assessment Boundary: Assessment about questions that require quantitative answers is limited to proportional reasoning and algebraic thinking.*]

MS-PS2-5. Conduct an investigation and evaluate the experimental design to provide evidence that fields exist between objects exerting forces on each other even though the objects are not in contact. [Clarification Statement: Examples of this phenomenon could include the interactions of magnets, electrically-charged strips of tape, and electrically-charged pith balls. Examples of investigations could include first-hand experiences or simulations.] [*Assessment Boundary: Assessment is limited to electric and magnetic fields, and is limited to qualitative evidence for the existence of fields.*]

MS-PS3-2. Develop a model to describe that when the arrangement of objects interacting at a distance changes, different amounts of potential energy are stored in the system. [Clarification Statement: Emphasis is on relative amounts of potential energy, not on calculations of potential energy. Examples of objects within systems interacting at varying distances could include: the Earth and either a roller coaster cart at varying positions on a hill or objects at varying heights on shelves, changing the direction/orientation of a magnet, and a balloon with static electrical charge being brought closer to a classmate's hair. Examples of models could include representations, diagrams, pictures, and written descriptions of systems.] [*Assessment Boundary: Assessment is limited to two objects and electric, magnetic, and gravitational interactions.*]

MS-ETS1-3. Analyze data from tests to determine similarities and differences among several design solutions to identify the best characteristics of each that can be combined into a new solution to better meet the criteria for success.

DISCIPLINE SPECIFIC GRADE EIGHT INSTRUCTIONAL SEGMENT 3: ELECTRIC AND MAGNETIC INTERACTIONS AND ENERGY

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

Highlighted Science and Engineering Practices	Highlighted Disciplinary Core Ideas	Highlighted Crosscutting Concepts
[SEP-1] Asking Questions and Defining Problems [SEP-2] Developing and Using Models [SEP-3] Planning and Carrying Out Investigations [SEP-4] Analyzing and Interpreting Data	PS2.B: Types of Interactions PS3.A: Definitions of Energy PS3.C: Relationship Between Energy and Force ETS1.B: Developing Possible Solutions ETS1.C: Optimizing the Design Solution	[CCC-2] Cause and Effect: Mechanism and Explanation [CCC-4] Systems and System Models [CCC-5] Energy and Matter: Flows, Cycles, and Conservation

CA CCSS Math Connections: MP.2

CA CCSS for ELA/Literacy Connections: RST.6–8.1, 3; WHST.6–8.1a–e, 7

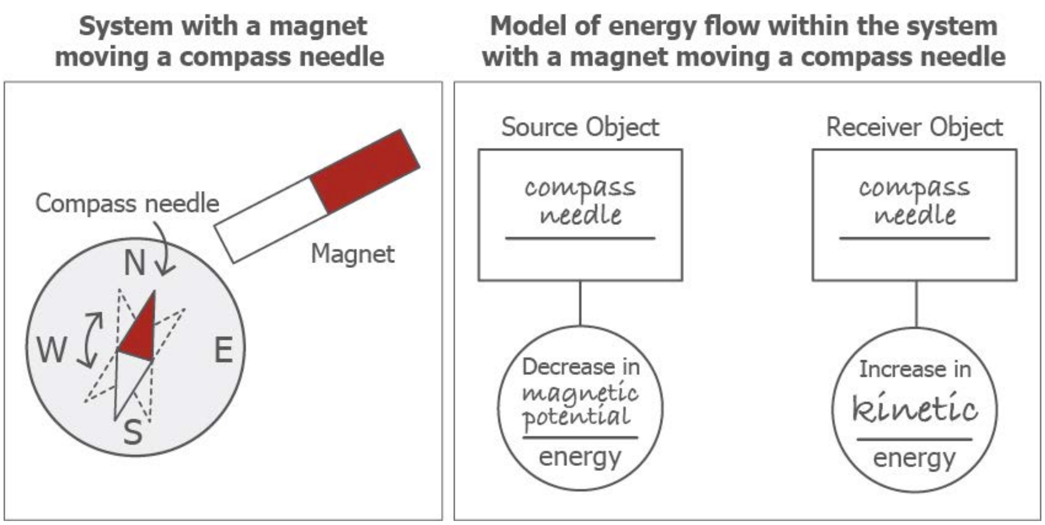
CA ELD Connections: ELD.PI.8.1, 3, 6a, 6b, 10b, 11a

Electric cars drive quickly and efficiently thanks to innovations in electric motor design. The motors for full-size passenger cars are big and expensive, but students can disassemble smaller electric motors from old fans or other electronics (donated by parents or purchased cheaply at local thrift stores) to look inside. As they open them up, they will encounter magnets and wires carrying electricity (see Arizona Science Lab, All About Electric Motors at https://www.cde.ca.gov/ci/sc/cf/ch6.asp#link51 and https://www.cde.ca.gov/ci/sc/cf/ch6asp#link52). How do these interact with one another to push a car?

Electricity and magnetism are grouped together in physics courses because the same fundamental force ultimately drives them, and they can interact with one another. Both are, like gravity, examples of forces that act on objects even when the objects are not touching, and both are associated with a potential **energy [CCC-5]**. Unlike gravitational fields around stars and planets that are hard to visualize, students can easily investigate magnetic fields with simple bar magnets and iron filings (MS-PS2-5). Placing the iron filings on top of a thin, flat piece of clear plastic, students can place various magnets and magnetic objects beneath the screen. They should begin to **ask questions [SEP-1]** about the spatial **patterns [CCC-1]** they see (MS-PS2-3). What happens if two magnets are placed end-to-end versus side-by-side? Does the pattern change as a magnetic object is held in between? The iron filings also tend to concentrate in areas where the magnetic force is strongest. Does the location of a strong magnetic field change in any situations? Can they arrange the magnets so that they create a stronger force?

While many teachers are familiar with thinking about magnetic forces, what is the relationship between magnets and **energy [CCC-5]**? Magnetic fields are a way to visualize the potential energy of magnets. Magnetic potential energy has some similarities with gravitational potential energy because the relative position of the objects determines the strength of the force. Magnets have two poles; therefore, orientation also becomes important. Changing the relative position and orientation of magnets can store potential energy that can be converted into kinetic energy (figure 6.34). This is the basic principle behind electric motors. By **analyzing data [SEP-4]** from frame-by-frame video of a compass needle, students can determine the conditions that cause the needle to gain the most kinetic energy. They use these observations to support their **model [SEP-2]** that the arrangement of objects determines the amount of potential energy stored in the **system [CCC-4]** (MS-PS3-2).

Figure 6.34. Energy Flow and Magnets

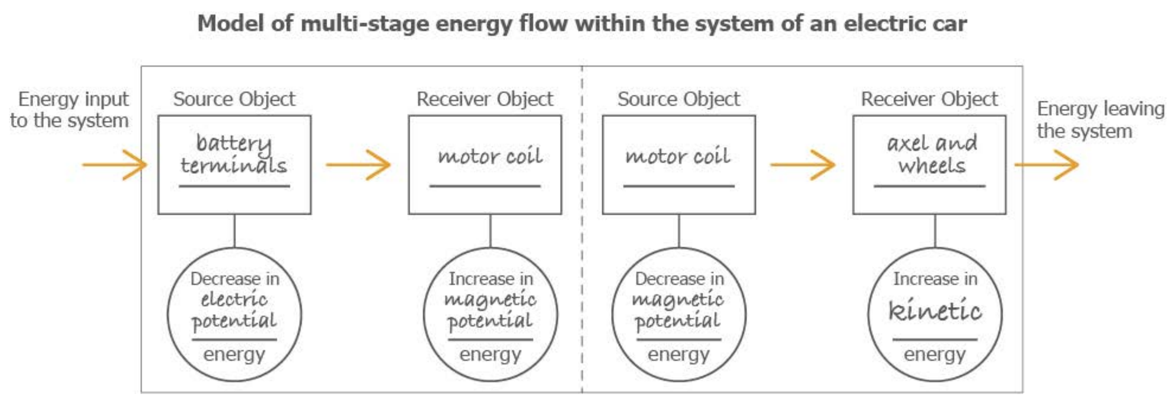


Schematic diagram and model of energy flow within a system of a magnet moving a compass needle. Note that the energy source/receiver model is very similar to the roller coaster being pulled by gravity in figure 6.33. Diagram by M. d'Alessio.
Long description of Figure 6.34.

Students then **investigate [SEP-3]** electromagnets using iron filings to see that the electromagnets create magnetic fields with similar spatial **patterns [CCC-1]** to permanent magnets. Students can be given a challenge to create the strongest electromagnet, allowing different groups to **ask questions [SEP-1]** about the factors that affect magnetic strength such as the number or arrangement of batteries, number of turns of the coil, or material inside the coil (MS-PS2-3). They can compare their results from this investigation to a computer simulator that also visualizes the magnetic fields (see PhET, Magnets and Electromagnets, https://www.cde.ca.gov/ci/sc/cf/ch6.asp#link53).

They can then apply their knowledge to electric cars by creating a small electric motor using simple items including a battery, a magnet, and magnet wire (see the Exploratorium Web site at https://www.cde.ca.gov/ci/sc/cf/ch6.asp#link54). What approach will create the motor that spins fastest? (MS-PS2-3). Students present their designs and each group should refine its motor, potentially integrating successful design elements from other groups (MS-ETS1-3). Like all engineering design, they will need to figure out a way to measure and compare the performance of different designs. For example, they could play a video recording of their real motor in slow motion to count the number of turns their motor completes in 5 seconds. Students can create a graph comparing this **quantification [CCC-3]** of motor speed to the initial length of wire used in the motor coil, the number of loops of wire in the coil, or other factors. Two students might have used identical wires for the coil, but their motors perform differently. Students can focus on what differences there might be between the two designs or how carefully they were constructed. Students then return to the motor that they dissected at the beginning of the instructional segment and compare it to their simple motor (figure 6.35). Why are electric car motors designed the way they are?

Figure 6.35. Multi-Stage Energy Flow



Model of multi-stage energy flow within the system of an electric car. Note that the energy chain continues on both sides of the chosen system (energy must come from somewhere outside the system and will eventually leave the system). Diagram by M. d'Alessio.
Long description of Figure 6.35.

As written, this instructional segment focuses almost entirely on a storyline that deals primarily with magnetic fields. Even though students can meet the expectations of

MS-PS2-3, MS-PS2-5, and MS-PS3-2 with the magnetic phenomena only, these performance expectations explicitly mention both magnetic and electric fields. Teachers will have to decide how to partition their time between static electricity phenomena and magnetic phenomena, but students should be prepared to confront either on assessments. One approach would be to have students learn about magnetic fields and then provide a rich performance task as an assessment where they apply the same principles to a situation involving an electric field.

IS4

Discipline Specific Grade Eight Instructional Segment 4: Waves Transmitting Energy and Information

Electricity and magnetism work together to transmit another type of **energy [CCC-5]**, electromagnetic radiation that manifests itself as light, radio waves, microwaves, and x-rays, among others. In this instructional segment, students explore both the nature of waves themselves and how people use waves to transmit information.

DISCIPLINE SPECIFIC GRADE EIGHT INSTRUCTIONAL SEGMENT 4: WAVES TRANSMITTING ENERGY AND INFORMATION

Guiding Questions

- How do waves interact with different objects?
- How are waves used to move energy and information from place to place?

Performance Expectations

Students who demonstrate understanding can do the following:

MS-PS4-1. Use mathematical representations to describe a simple model for waves that includes how the amplitude of a wave is related to the energy in a wave. [Clarification Statement: Emphasis is on describing waves with both qualitative and quantitative thinking.] [*Assessment Boundary: Assessment does not include electromagnetic waves and is limited to standard repeating waves.*]

MS-PS4-2. Develop and use a model to describe that waves are reflected, absorbed, or transmitted through various materials. [Clarification Statement: Emphasis is on both light and mechanical waves. Examples of models could include drawings, simulations, and written descriptions.] [*Assessment Boundary: Assessment is limited to qualitative applications pertaining to light and mechanical waves.*]

MS-PS4-3. Integrate qualitative scientific and technical information to support the claim that digitized signals are a more reliable way to encode and transmit information than analog signals. [Clarification Statement: Emphasis is on a basic understanding that waves can be used for communication purposes. Examples could include using fiber optic cable to transmit light pulses, radio wave pulses in Wi-Fi devices, and conversion of stored binary patterns to make sound or text on a computer screen.] [*Assessment Boundary: Assessment does not include binary counting. Assessment does not include the specific mechanism of any given device.*]

DISCIPLINE SPECIFIC GRADE EIGHT INSTRUCTIONAL SEGMENT 4: WAVES TRANSMITTING ENERGY AND INFORMATION		
The bundle of performance expectations above focuses on the following elements from the NRC document *A Framework for K–12 Science Education*:		
Highlighted Science and Engineering Practices	**Highlighted Disciplinary Core Ideas**	**Highlighted Crosscutting Concepts**
[SEP-2] Developing and Using Models [SEP-5] Using Mathematics and Computational Thinking [SEP-7] Engaging in Argument from Evidence [SEP-8] Obtaining, Evaluating, and Communicating Information	PS4.A: Wave Properties PS4.B: Electromagnetic Radiation PS4.C: Information Technologies and Instrumentation	[CCC-1] Patterns [CCC-6] Structure and Function

CA CCSS Math Connections: 6.RP.1, 3a–d; 7.RP.2a–d; 8.F.3; MP.2, MP.4

CA CCSS for ELA/Literacy Connections: RST.6–8.1, 2, 9; WHST.6–8.9; SL.8.5

CA ELD Connections: ELD.PI.1.1, 3, 6a, 6b, 10b, 11a; ELD.PII.1

Learning how to convert electricity to electromagnetic radiation has allowed engineers to design an array of technology, especially technology to help communicate voices, images, and data. In this instructional segment, students make simple models of how waves travel and how they can be used to transmit information.

Opportunities for ELA/ELD Connections

During the instructional segment, have students develop a sequenced set of illustrations with accompanying content vocabulary to convey their understanding of waves. Students can use concept maps, word webs, or graphic organizers (e.g., Frayer Model) to identify corresponding types, examples and nonexamples, definitions, illustrations of a concept, or essential (or nonessential) characteristics. These strategies help all learners acquire effective vocabulary-development strategies as they acquire content knowledge.

CA CCSS for ELA/Literacy Standards: RST. 6–8.4; L.6–8.4

CA ELD Standards: ELD.PI.6–8.6

Even though radio waves used for communication are invisible oscillations of electromagnetic fields, they share a lot in common with waves in the ocean and other examples of *mechanical waves*. Mechanical waves involve the back-and-forth motion of physical materials instead of the oscillations of invisible fields, but the idea of repeated oscillatory movement is common between them. In fact, waves share several common features: (1) they are repeating quantities; (2) they interact with materials as they are transmitted, absorbed, or reflected; (3) they can transfer **energy [CCC-5]** over long distances without long-distance movement of matter; and (4) they can be used to encode information.

Over the course of this instructional segment, modeling activities should begin with mechanical waves propagating in a medium that is visible (such as water waves), then waves that propagate through a medium that is invisible (such as sound waves moving through air), and finally wave models of light. **Investigations [SEP-3]** with real-world objects can be complemented with technology. Computer or smartphone apps provide interactive simulations of simple waves (https://www.cde.ca.gov/ci/sc/cf/ch6.asp#link55), ripple tanks (see Falstad, P. Virtual Ripple tank at https://www.cde.ca.gov/ci/sc/cf/ch6.asp#link56) or even display the waveforms of sound recorded by microphones so that students can use their personal technology as an oscilloscope to visualize waveforms of noises in the room.

Students begin IS4 by **investigating [SEP-3]** a variety of waves they can generate and observe in a flat-bottomed water container (ripple tank). Students observe and discuss general properties of waves as observed including (1) reflection and reflections from a barrier, (2) transmission of one wave through another, (3) transmission of a wave past a row of posts, and even 4) the addition of multiple waves to make complex waveforms. Placing floating objects at the surface and drops of colored dye below the surface allow students to track the motion of particles within the tank. All of these observations of phenomena should provoke students to **ask questions [SEP-1]** about some unique wave behaviors. Each group of students could use a digital camera to create a short video clip of a surprising or exciting observation that they would like to understand further. These questions can form the organizing **structure [CCC-6]** for the instructional segment, and teachers can revisit them often.

Waves are part of many different physical processes, all of which share some common aspects related to the shape, direction of their motion, and how this motion changes over time. To clarify these common elements, scientists often use a diagrammatic representation of a “typical” wave shape as a regularly spaced series of peaks and valleys (figure 6.36) and they have developed a common set of vocabulary to describe key aspects of this shape and its change over time. By illustrating simple waves on a stretched rope or spring, students should be able to describe a wave’s *amplitude*, *wavelength*, *frequency*, and *wave speed*. They can also apply these terms to describe things they saw in their ripple tank investigation. Students described waves by their wavelength and amplitude in grade four.

Figure 6.36. Diagrammatic Representation of a Wave

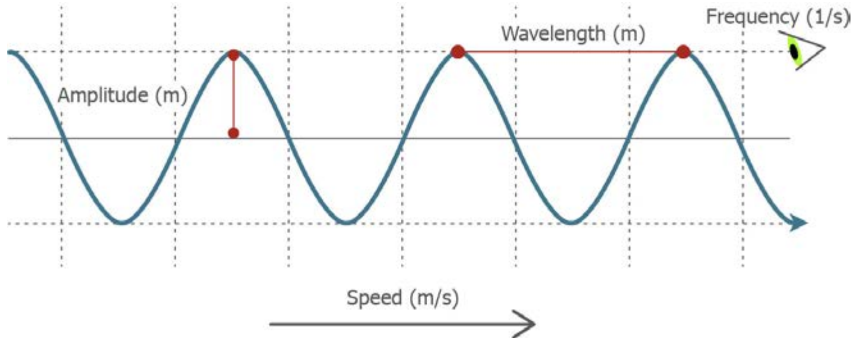


Diagram by M. d'Alessio.
Long description of Figure 6.36.

Having become familiar with the properties of waves and developed ways to represent and describe travelling waves, students are ready to think about and model waves and/or wave pulses as carriers of **energy [CCC-5]** and of information. They can readily recognize that a wave or wave pulse of water in the open ocean transmits energy (in the form of motion of the medium): they can see the motion of the water up and down by observing a boat bobbing at the surface (motion = kinetic energy) and they know that the wave will eventually crash into the shore and transfer this energy. They can also see that more of this up-and-down motion results in a higher amplitude, thus qualitatively connecting the growth in amplitude of the wave to an increase in the energy it transmits (MS-PS4-1). Students can make this representation quantitative by dropping objects of different sizes into a tank and measuring the height of waves generated (perhaps with the aid of digital photography to allow more precise measurements of the fast-moving waves).

A car with its radio blasting may actually cause the windows of a neighboring car to rattle because of the transmission of **energy [CCC-5]** by sound waves. To **explain [SEP-6]** how the glass moves, students will **model [SEP-2]** the transformation of energy and its propagation as a wave through the air to the glass. First, they will include the vibration of the car speaker and how that vibration is transferred to the molecules of air. Then, they will model how that vibration travels through space by compression and expansion of air molecules finally reaching the window. Finally, students' models will represent the transfer of energy from the vibrating air molecules to the molecules in the glass.

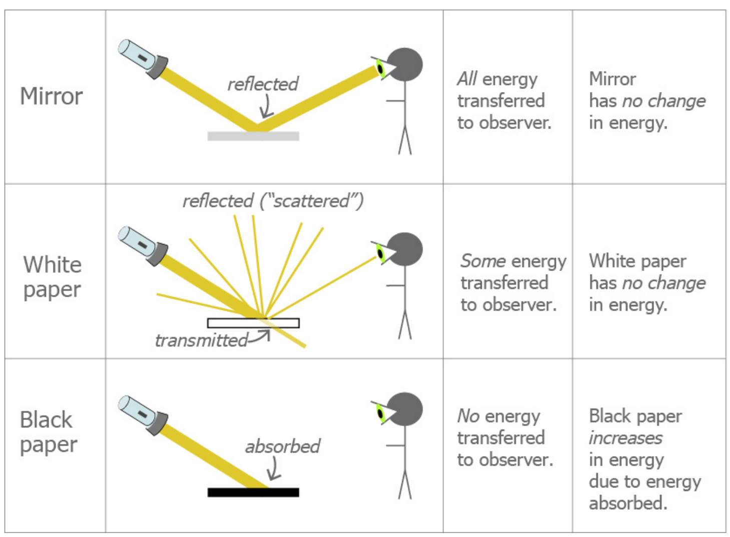
Using their own **models [SEP-2]** of wave motion, amplitude, and **energy [CCC-5]** allows students to come up with an **explanation [SEP-6]** for why waves break at the beach (allowing for California's famous surfing and other beach play). Surfers know that water in a breaking wave is moving toward the beach (which pushes their surfboard forward), but out beyond the breakers, it is not! They wait beyond the breakers and bob up and down until a good wave arrives and then they paddle forward into the location where waves begin to break. When the water gets shallow enough, there is not enough room for the wave to move up and down over its full amplitude without pushing against the sand below. At that point, the wave can no longer maintain all its kinetic energy as up-and-down motion, and some of the energy is transferred into forward motion that causes the wave to tip over and break. Students can explore this phenomenon in a ripple tank by introducing a sloping bottom spanning about a third of the tank length and driving waves by moving a flat object up and down at the other end of the tank. They can observe the relationship between the location where the sloped bottom begins and where waves begin to break, and vary the slope angle to measure its effect on the waves.

While water waves are easily recognizable as waves, students need evidence to believe that light and sound are waves. Because students' models of waves include motion, they may wonder what is moving in the sound wave or the light wave. For sound, students can readily feel the movement as sound passes through a solid and **develop a model [SEP-2]** of back-and-forth motion of the solid material. This model is then readily generalized to a model for sound travelling through a gas, where this motion cannot be directly observed. Eventually this work must link to particulate models of solids and gases developed later in IS5 and the way the particles in the medium move as sound travels through it to develop a model of a sound wave. Students can observe the driving energy of sound by observing the vibrations of speakers using slow motion video clips or by simply placing paper scraps on top of a large speaker. Students should be able to draw diagrams relating the driving motion from the speaker to the driving motion in the ripple tank in order to **communicate [SEP-8]** their **model [SEP-2]** of waves. Sound exhibits other key aspects of waves: sound can be described by frequencies (pitch) and amplitudes (volume), sound waves reflect or are absorbed at various surfaces or interfaces, and two sounds from different sources can pass through one another and emerge undisturbed.

Middle grades students should realize that light is also a wave phenomenon by recognizing that it shows all the behaviors of waves (reflection, absorption, transmission through a medium such as glass, carrying **energy [CCC-5]** and information from place to place, MS-PS4-2). Eyes perceive waves with different frequencies as different colors, and each wave's amplitude is observed as light's brightness. The obvious question—What is the moving medium in a wave pattern for light?—is difficult to answer at this grade level. In light, the movement is actually the changing pattern of electric and magnetic fields travelling across space or through some forms of matter. Students will continue to explore the nature of light in high school physics.

Light is an ideal platform for investigating the reflection, absorption, and transmission of waves because students can literally see these processes in action. Students can perform **investigations [SEP-3]** to compare the different effects of mirrors and different color paper on the path of light. Students can draw diagrams to **model [SEP-2]** each situation, tracing the path of light and how **energy [CCC-5]** is transferred to different objects based upon the interaction between the light and the materials (MS-PS4-2; figure 6.37). As early as grade four, students began developing a model of how light allows objects to be seen (4-PS4-2), and teachers should connect to that learning experience to emphasize that reflection is crucial because we only see objects after they reflect light back to our eyes. White paper reflects light and most reams of paper have a label that the paper industry calls the paper's brightness, but this is really related to percentage of light reflected by the paper (measured in a specific frequency range). A "96 bright" paper reflects about 96 percent of the incident light, which is actually more efficient than many mirrors. How can paper reflect more than mirrors because light reflected off mirrors seems so much brighter? The answer is that paper is rough at the microscopic level, so the light is reflected in all directions instead of concentrated in one place like it is when light bounces off a smooth mirror. So the total reflection of white paper and mirrors are often comparable, but people only observe a small portion of the paper's reflection from one location.[1]

Figure 6.37. Light Waves and Different Materials



A pictorial model of the interactions between light waves and different ideal materials. Diagram by M. d'Alessio.
Long description of Figure 6.37.

1. Shining a light on some shockingly bright fluorescent colored paper appears to reflect more than 100 percent of the visible light energy, in apparent violation of **conservation of energy [CCC-5]**. What is the source of this extra energy? In fact, these papers contain dyes that absorb invisible ultraviolet energy and re-emit that energy as visible light that gets added to the total visible light reflected off the paper. Some white papers as well as many laundry detergents also include these dyes that increase the apparent brightness of surfaces. Unfortunately, these dyes can decrease the recyclability of paper and are another chemical going down the drain for laundry detergents (EP&C Principle IV).

In earlier grades, students developed an understanding of how humans and other animals use light and sound to gain information about the world around them and transmit information to others. In this instructional segment the emphasis shifts to the use of technology to greatly expand our ability to transmit information encoded as waveforms or wave pulses over large distances. For example, converting sound to electromagnetic signals that are transmitted over a distance and converted back to sound at a receiver (telephone, radio). Historical examples of encoded information in wave pulses, such as drum or smoke signals and the invention of Morse code and early telegraph systems, can be helpful in developing both the idea of information in a waveform and the idea of encoding information. More modern examples include the difference between AM and FM radio signals, fiber optics that allow us to use light to transmit information around the world and around corners, and Wi-Fi signals that use low-level radiation spread across a range of frequencies in what is called spread-spectrum communication. In all of these techniques, there is the risk that signals will be distorted along their journey. Students can model this problem with a game of telephone (a whispered message passed from student to student rarely emerges unchanged). Another model, an analogy, is trying to whisper outside on a windy day. The random noise of the wind interferes with the successful reception of a person's words. Similar effects occur in long distance communication when spurious noise from another source arrives at the receiver along with the intended signal. Students can **develop solutions [SEP-6]** to overcome or minimize this problem and ensure that the signal is encoded in a way that the information is less readily destroyed or corrupted when some low level of noise is added to the signal. Students should **obtain information [SEP-8]** that allows them to **support claims [SEP-7]** about the benefits of digital encoding over analog encoding of information (MS-PS4-3).

The purpose of this last part of the instructional segment is not to develop detailed understanding of the functioning of all the relevant technology, but simply to begin to recognize that engineers use an understanding of how sound and electromagnetic waves are produced or absorbed to design modern communication and computation technologies.

IS5

Discipline Specific Grade Eight Instructional Segment 5: Thermal Energy and Heat Flow

What is heat? Is it something you can hold? Does it have mass? While the word heat is a noun, it may be better to think of the adjective form as a description of matter: hot stuff. Even as far back as ancient Greece, Democritus stated that "opinion says hot and cold, but the reality is just atoms and empty space." The goal of this instructional segment is to help students understand what that statement means and how it relates to car crashes and **conservation of energy [CCC-5]**.

DISCIPLINE SPECIFIC GRADE EIGHT INSTRUCTIONAL SEGMENT 5: THERMAL ENERGY AND HEAT FLOW

Guiding Questions

- How can we represent matter at the microscopic level?
- When an object is hot, how is it different from when it is cold?
- What happens when hot objects and cold objects interact?
- What happens to the kinetic energy of an object when it crashes or collides with the ground and stops?

Performance Expectations

Students who demonstrate understanding can do the following:

MS-PS1-4. Develop a model that predicts and describes changes in particle motion, temperature, and state of a pure substance when thermal energy is added or removed. [Clarification Statement: Emphasis is on qualitative molecular-level models of solids, liquids, and gases to show that adding or removing thermal energy increases or decreases kinetic energy of the particles until a change of state occurs. Examples of models could include drawings and diagrams. Examples of particles could include molecules or inert atoms. Examples of pure substances could include water, carbon dioxide, and helium.]

MS-PS3-3. Apply scientific principles to design, construct, and test a device that either minimizes or maximizes thermal energy transfer.* [Clarification Statement: Examples of devices could include an insulated box, a solar cooker, and a Styrofoam cup.] [*Assessment Boundary: Assessment does not include calculating the total amount of thermal energy transferred*.]

MS-PS3-4. Plan an investigation to determine the relationships among the energy transferred, the type of matter, the mass, and the change in the average kinetic energy of the particles as measured by the temperature of the sample. [Clarification Statement: Examples of experiments could include comparing final water temperatures after different masses of ice melted in the same volume of water with the same initial temperature, the temperature change of samples of different materials with the same mass as they cool or heat in the environment, or the same material with different masses when a specific amount of energy is added.] [*Assessment Boundary: Assessment does not include calculating the total amount of thermal energy transferred.]*

DISCIPLINE SPECIFIC GRADE EIGHT INSTRUCTIONAL SEGMENT 5: THERMAL ENERGY AND HEAT FLOW

MS-PS3-5. Construct, use, and present arguments to support the claim that when the kinetic energy of an object changes, energy is transferred to or from the object. [Clarification Statement: Examples of empirical evidence used in arguments could include an inventory or other representation of the energy before and after the transfer in the form of temperature changes or motion of object.] [*Assessment Boundary: Assessment does not include calculations of energy.*] (Revisited from IS1.)

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

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

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

Highlighted Science and Engineering Practices	Highlighted Disciplinary Core Ideas	Highlighted Crosscutting Concepts
[SEP-2] Developing and Using Models [SEP-3] Planning and Carrying Out Investigations [SEP-4] Analyzing and Interpreting Data [SEP-6] Constructing Explanations (for science) and Designing Solutions (for engineering) [SEP-7] Engaging in Argument from Evidence	PS1.A: Structure and Properties of Matter PS3.A: Definitions of Energy PS3.B: Conservation of Energy and Energy Transfer ETS1.A: Defining and Delimiting an Engineering Problem ETS1.B: Developing Possible Solutions	[CCC-2] Cause and Effect: Mechanism and Explanation [CCC-3] Scale, Proportion, and Quantity [CCC-5] Energy and Matter: Flows, Cycles, and Conservation

Highlighted California Environmental Principles and Concepts:
Principle IV The exchange of matter between natural systems and human societies affects the long-term functioning of both.

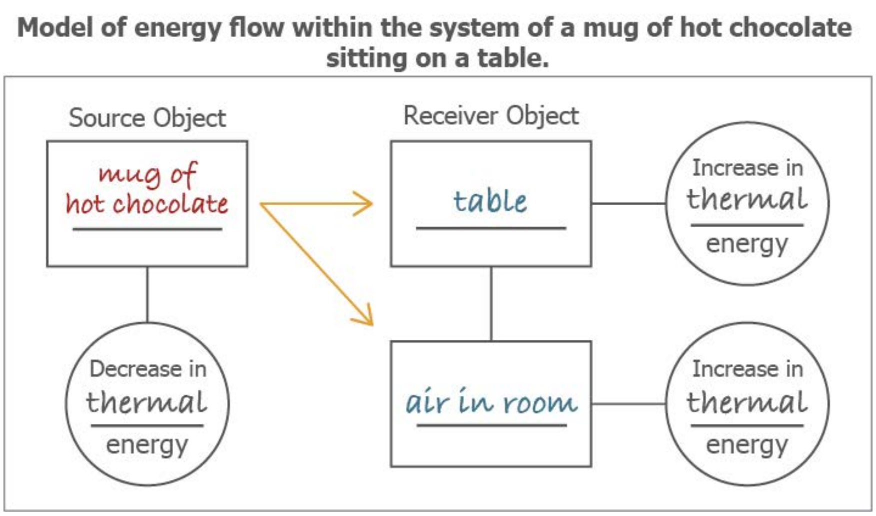
CA CCSS Math Connections: 6.RP.1, 6.SP.5a–d; 7.EE.3; MP.2

CA CCSS for ELA/Literacy Connections: RST.6–8.1, 3, 9; RI.7.8; WHST.6–8.1a–e, 7, 9

CA ELD Connections: ELD.PI.8.1, 3, 6a, 6b, 10b, 11a

In grade four, students observed that heat flow is a mechanism to transfer **energy [CCC-5]**, but they did not make any quantitative measurements or come up with a model to **explain [SEP-6]** what heat is or how it can be transferred. To set the stage, students should be given a challenge question for formative assessment (Keeley, Eberle, and Farrin 2005, 103–108). A person has two identical thermometers and places one inside a mitten and the other on the table just beside the mitten. After a few hours, what will happen to the temperature shown on the two thermometers? Many students will incorrectly say that the thermometer inside the mitten will heat up, but there is no energy source such as a human body to cause this increase. As long as one object is hotter than other objects or its surroundings, it will serve as an energy source that transfers energy to its surroundings (figure 6.38). A mitten serves as an insulator that reduces some of this energy transfer between the hand and the cold air. By thinking about how their own bodies are hotter than their surroundings, students are ready to **conduct a detailed investigation [SEP-3]** into the factors that affect heat transfer between objects at different temperatures (MS-PS3-4). Their goal is to determine how factors such as the amount of material they use, the temperature difference at the start of the investigation, and the type of material affect the transfer of **energy [CCC-5]** between two objects (PS3.B). There is a lot of flexibility in the experiment students choose and it is difficult to investigate all the factors in a single, simple experiment. MS-PS3-4 assesses whether or not students can identify a specific subquestion related to heat transfer and design an experiment that collects evidence that will help answer that question. To ensure that students see the role of each factor, student groups **communicate [SEP-8]** the results of their experiments to the entire class.

Figure 6.38. Energy Flow and Hot Chocolate



Model of energy flow within a system of a mug of hot chocolate sitting on a table. Diagram by M. d’Alessio.
Long description of Figure 6.38.

Students began to develop a **model [SEP-2]** of matter as a collection of tiny particles in grade five (5-PS-1) that is useful in understanding heat transfer. Teachers can activate student thinking about this model by asking students to draw the air inside a syringe and describe how they would represent it. Then, to elicit the importance of the space between particles, students can be prompted to draw how the **system [CCC-4]** changes when the syringe is sealed and compressed without air being allowed to escape. Students should be introduced to evidence that these particles are in constant motion. Video clips of soot or dust particles settling show that these big, macroscopic particles seem to be pushed randomly left, right, and even upward as they drift slowly downward (see FranklyChemistry, A Smoke Cell demonstrating Brownian Motion in Air, at https://www.cde.ca.gov/ci/sc/cf/ch6.asp#link57). The best **explanation [SEP-6]** is that gases consist of tiny particles that are moving around and crashing into one another randomly. Since these particles have mass and a speed, they must have kinetic energy that is transferred as they collide. The models that students constructed to describe the transfer of kinetic energy in car crashes can help students **explain [SEP-6]** heat flow and thermal energy. It allows them to explain why objects eventually reach the same temperature as they thermally interact until they reach a **stable configuration [CCC-7]** (both objects have the same average kinetic energy, so neither of them has any additional energy to give to the other). This model is also the first stage in understanding how atoms combine into molecules during chemical reaction (MS-PS1-1). The vignette below illustrates how this model can be developed further within a classroom.

DISCIPLINE SPECIFIC GRADE EIGHT VIGNETTE 6.3: DEVELOPING AND USING MODELS TO UNDERSTAND PROPERTIES OF GASES

Performance Expectations

Students who demonstrate understanding can do the following:

MS-PS1-4. Develop a model that predicts and describes changes in particle motion, temperature, and state of a pure substance when thermal energy is added or removed. [Clarification Statement: Emphasis is on qualitative molecular-level models of solids, liquids, and gases to show that adding or removing thermal energy increases or decreases kinetic energy of the particles until a change of state occurs. Examples of models could include drawings and diagrams. Examples of particles could include molecules or inert atoms. Examples of pure substances could include water, carbon dioxide, and helium.]

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

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

Highlighted Science and Engineering Practices	Highlighted Disciplinary Core Ideas	Highlighted Crosscutting Concepts
[SEP-2] Developing and Using Models [SEP-3] Planning and Carrying Out Investigations [SEP-6] Constructing Explanations (for science) and Designing Solutions (for engineering) [SEP-7] Engaging in Argument from Evidence	PS1.A: Structure and Properties of Matter PS3.A: Definitions of Energy ETS1.B: Developing Possible Solutions	[CCC-2] Cause and Effect: Mechanism and Explanation

CA CCSS Math Connections: MP. 2, MP.3; S.IC.5 (Introduced in preparation for higher mathematics)

CA CCSS for ELA/Literacy Connections: SL.8.1, 2; RST.6–8.3, 9; WHST.6–8.9, 10

CA ELD Connections: ELD.PI.8.1, 3, 6a, 11a

DISCIPLINE SPECIFIC GRADE EIGHT VIGNETTE 6.3: DEVELOPING AND USING MODELS TO UNDERSTAND PROPERTIES OF GASES

Introduction

The students in Ms. S's grade eight classroom are **investigating [SEP-3]** **structure [CCC-6]** and properties of **matter [CCC-5]**. They are challenged to be precise with their scientific language and revise their conceptual **models [SEP-2]** as new evidence is produced through the classroom's **investigations [SEP-3]** or the teacher's presentations. The students have gained experience with some of the practices and core ideas of the CA NGSS during the previous 14 days of science instruction. Therefore, the students in Ms. S's class are building on their prior knowledge of the particle nature of matter to further explore the behavior of atoms and molecules. The learning outcomes of the instructional segment include the concept that matter, specifically a gas, is composed of particles called *molecules* that move more quickly or more slowly, depending on the temperature of the gas. In addition, the students are extending their learning to incorporate a relationship between the relative speed of the particles in a **system [CCC-4]** and the pressure exerted on the sides of the container.

Ms. S promotes student learning through real-world examples and student-constructed models. She enables the students to develop their own conceptual models, to use the models in predicting relationships between the model components, and to evaluate the models for their explanatory power (**developing and using models [SEP-2]**). As the students gain understanding of the core ideas through use of the additional CA NGSS practices of **planning and carrying out investigations [SEP-3]** and **obtaining, evaluating, and communicating information [SEP-8]**, they address the limitations presented in the different **models [SEP-2]** and work together to revise the models as new evidence comes to light.

Day 1: Developing an Initial Conceptual Model

The teacher probes students' prior knowledge of states of matter and then presents them with the phenomenon of an imploding tanker truck. Students propose possible models.

Day 2: Gathering New Evidence to Evaluate and Revise Conceptual Models

Students use a soda can as a physical model of the imploding tanker truck. Students begin to verbalize an explanation about the role of air pressure in the implosion.

Day 3: Using Literacy, Discourse, and Argumentation to Develop a Shared Understanding

Students perform five short investigations that illustrated the behavior of air pressure and share the results.

Day 4: Using Revised Models to Explain Phenomena

Students use a computer simulation to model air pressure and then revise their initial models of the tanker implosion based on the new understanding.

Days 5–8: Application of Scientific Knowledge to an Engineering Problem

Students propose possible solutions to prevent tankers from imploding in the future. They present and compare the solutions by different groups.

DISCIPLINE SPECIFIC GRADE EIGHT VIGNETTE 6.3: DEVELOPING AND USING MODELS TO UNDERSTAND PROPERTIES OF GASES

Day 1: Developing an Initial Conceptual Model

Ms. S started an instructional segment on matter and its interactions that involved analysis of the forces between atoms and molecules, but first wanted to find out if her students had an understanding of the molecular nature of matter. She used a whole-class discussion to bring out students' prior knowledge. She asked some challenging conceptual questions (see ConcepTests in the chapter on assessment) to review state changes and molecular movement in relation to temperature. Based on this informal assessment, she learned that some of the class remembered previous experiences with state changes that occur with water.

The teacher began by asking the class to describe what they already knew about how gases behave. This allowed her to build new learning onto their prior knowledge and choose questioning and **investigations [SEP-3]** more appropriate for her students. "We looked at air, carbon dioxide, and water vapor. What do you know about the molecules of a gas? How do they move? What affects their movement? What is a gas?" As students volunteered, she wrote down several students' responses on chart paper, for example, "Gases expand when heated." "As a liquid evaporates, it becomes a gas and the molecules move rapidly." "There is a difference in density." "Gas is a state."

"Molecules are small for gas and large for solid," Canyon offered. Ms. S asked Canyon if he had any examples of his idea and he replied, "No examples." She stated, "That's a question," and wrote Canyon's words on the question side of the chart paper. She added, "Does anyone want to comment on Canyon's remark?" Lorenzo contributed that he thought molecules stayed the same size and that as the molecules heated up, they moved faster. After listing many student responses, Ms. S asked the driving question, "How do gases and their behavior affect matter?"

Anchoring phenomenon: A railroad tank car dramatically imploded after being cleaned.

The students then **evaluated information [SEP-8]** about a real-world scenario, using photographs and video. In the video, a railroad tank car (tanker) was washed out with steam and then all the outlet valves were closed. The video revealed the tanker dramatically imploding the next day. After watching the video twice, the students began to speculate why the tanker was crushed. They thought that the car froze, exploded, or compressed, and the steam caused the tanker to collapse inward. An understanding of the **cause and effect [CCC-2]** concept helped students make sense of this phenomenon.

Rick called out, "Okay, that's crazy!" Ms. S asked the class to write in their journals their descriptions of why the tanker was crushed. "Do you want to guess?" she asked. "I have no idea," one student replied. The teacher encouraged the class by asking them to continue to think and work in their regular discussion groups. Each group's task was to decide on one **model [SEP-2]** to **explain [SEP-6]** why the tanker imploded, making sure the drawings included molecules and arrows indicating the direction of the overall forces they applied to

DISCIPLINE SPECIFIC GRADE EIGHT VIGNETTE 6.3: DEVELOPING AND USING MODELS TO UNDERSTAND PROPERTIES OF GASES

the tanker. Ms. S circulated among the students and asked guiding questions, such as, “What happens when water vapor turns into liquid?” She directed students to include their ideas in the models they were creating. The students drew and discussed the models in their groups. “Steam inside is moving fast.” “Maybe it was cold.” “Didn’t explode; it imploded,” clarified a student. Another said, “It was sealed. Nothing in there but air and steam.” Lorenzo decided that there was a tornado inside. Ms. S directed the group to review what happens when steam turns into a liquid. She reminded students of a previous balloon experiment when they had identified a pressure difference and asked what would **cause [CCC-2]** the pressure to change. She also encouraged students to incorporate the observation that heating a gas in a container increases the pressure. Circulating among the four groups, she asked students about their drawings, “Why did the tanker crush the next day? How do temperature changes affect molecules? Is there pressure against the walls? Why?” Cristiano answered, “Pressure in air is more than inside,” and his partner Jasmine offered, “The steam inside turned to liquid.” Ms. S redirected their conversation with a new question, “Why would it implode?” Jasmine answered immediately, “Heat expands molecules!” “The molecules were getting smaller,” contradicted Cristiano. After thinking a moment, he said, “They *don’t* do that, do they?”

Ms. S asked the group about the air pressure arrows at the top of the tanker, “Why only at the top of the tanker?” Cristiano ventured, “There’s more air on top, not at the bottom.” Al added, “Molecules combine to take up less space.” Ms. S emphasized that when molecules combine, they make new substances. Jasmine reminded the group that temperature had to do something. Ms. S moved over to another group that had just broken into laughter and asked what was so funny. Rick related, “I see smashed cans all the time. I think an airfoot stomped the tanker down. And the molecules transformed into a molecule foot.” Ms. S asked, “What is this imaginary foot?” Latasia answered, “Air.” Ms. S guided the students, suggesting that they add that idea to the model.

As the discussions continued, several students began making connections between the steam turning to liquid overnight and the resulting changes in collisions of molecules with the walls inside and outside of the tanker. Through further questioning and reminders of previous learning that contradicted students’ claims, Ms. S pressed the students to prioritize evidence while, at the same time, allowed them to generate their own incomplete conceptual model. Ms. S was well aware that she needed to allow her students to construct an understanding of phenomena by putting their ideas together. She also knew that through guided experiences and meaningful dialogue, students would adapt their model and demonstrate authentic learning.

Day 2: Gathering New Evidence to Evaluate and Revise Conceptual Models

The following day Ms. S encouraged students to reflect on how their ideas had evolved from the beginning of the instructional segment. She wondered whether changes in students’ ideas would be apparent in their developing models: air molecules slowed down; water changed state to liquid; pressure arrows showed the collisions of molecules against the edge of the tanker; and when the gas molecules turned to liquid, there was less pressure on the

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inside causing the tanker to crumple. Reviewing the driving question from the day before, "What would **cause [CCC-2]** pressure or a pressure difference?" the class identified two key factors: temperature and pressure. The molecules that made up the steam were also hitting the inside of the tanker, balancing the air molecules hitting the tanker on the outside. Students were thus able to use their **model [SEP-2]** of particles to **explain [SEP-6]** a macroscopic phenomenon.

Ms. S asked the class a new question, "What caused the pressure inside the tanker to change?" The students did not respond at first. Then Lorenzo concluded that outside air pressure presses on the tanker to crush it. Ms. S asked why it would do that. This question led Ms. S to introduce the soda can investigation. She asked the class to make predictions about what would happen to the soda can if water inside the can were heated, and the soda can rapidly cooled. Students called out their predictions, "It's going to do what the tanker did." "Crush!" "Implode." Jasmine asked, "Are we going to seal the container?" showing her understanding of the variables involved.

Investigative phenomenon: An aluminum can with a small amount of water inside is heated on a hot plate and then submerged upside down in ice water. It implodes instantly.

Working in their groups, the class prepared for a simulation of the crushed tanker using an aluminum soda can. A small amount of water was put in the can and heated to boiling on a hot plate; the can was then submerged upside down in an ice bath using tongs. The can was immediately crushed. The enthusiastic reactions from the students included "Oh!" "That's cool!" "Awesome, it sucked it in!" (Some comments were based on incomplete understanding.) The teacher asked the students to draw new models showing the molecules of gas in the can and writing down their ideas in their science journals.

The following day, Ms. S provided students with a list of questions to guide their review of the can implosion investigation from the day before. The list included movement of molecules (speed), state of matter, and causes of pressure inside and outside of the can. Ms. S asked the students to write answers in their science journals. Then they discussed their ideas in groups. As she met with each group, Ms. S pressed students to verbalize core ideas about the behavior of molecules and left the group with questions to consider. Finally, she directed the students to write about their ideas as far as they had gotten. Ms. S provided a scaffold for writing complete ideas by giving the class this sentence: *When _____, the can crushed more because _____.*

As their understanding grew, students refined their **models [SEP-2]** and **planned further investigations [SEP-3]** to explore changes in the variables. Calling the class back together, Ms. S summarized the variables suggested by the groups: amount of water in the can, temperature of the water bath, amount of time on the hot plate, size of the can, and amount of seal when the can is flipped into the bath. Ms. S also reminded the students of the

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connection between the tanker implosion and their can implosion: the molecules of air hitting on the outside were not balanced with the molecules of steam hitting the inside.

Day 3: Using Literacy, Discourse, and Argumentation to Develop a Shared Understanding

Investigative phenomenon: Students test out different variables that might affect whether or not the aluminum can will implode.

The following day the **investigations [SEP-3]** continued, using students' ideas. Ms. S asked questions about why more steam caused more pressure. The class regrouped to perform five investigations with each group taking one idea: amount of water, temperature of bath, time on hot plate, volume of can, and amount of seal. Each group identified three variables to test as a way to develop a more causal explanation. As the groups worked, the teacher questioned the students on their predictions and probed to elicit evidence to support their **explanations [SEP-6]**. Lorenzo offered, "Steam vapor cools inside the can when the can is placed in the ice bath and turns into water." "Water liquid molecules move slower than water gas molecules and the water liquid molecules take up less space because the gas condensed into water," added Jaylynn.

One group submerged the can with the opening upward and was surprised that the can did not crush. Latasia thought there was too much space, so the can did not crush. Mia thought that with more air there was more space because of the ratio between the air and space. Mia's response revealed a gap in students' understanding of pressure differences. Ms. S assigned a reading assignment on air pressure to help students **obtain information [SEP-8]**.

Day 4: Using Revised Models to Explain Phenomena

When students returned the next day, they drew a model of air pressure on people in their science journals. Alicia described her picture of pressure on Earth and pointed out that higher up there was less pressure because there were fewer steam molecules. The class reviewed the meaning of forces and how force arrows explained pressure in the model they were refining for the tanker question.

Investigative phenomenon: In a computer simulation of gases, changing the temperature of gas inside a sealed container also changes the pressure.

Student responses became more confident as the lessons continued. Students used a computer simulation of pressure versus temperature and Ms. S asked them to predict what would happen; the class buzzed with conversation. Next, the students improved their models. Again, Ms. S gave her students incomplete sentences to finish and reflect on what happened with their soda can **investigations [SEP-3]**. Ms. S reminded students to provide **evidence [SEP-7]** for

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their **explanations [SEP-6]**, "What are the molecules doing? Let's say the molecules are at a popular hip-hop concert trying to see the band. What would the molecules be doing?" Jaylynn conjectured that the quantity of molecules influences the pressure in the can: "The kids would be pushing each other to get a better view of the band. Therefore, in the can more molecules would mean less space in the can." Alicia offered, "And molecules hitting the can from the outside would not be able to push the can in." Canyon added, "When the steam cools in the can, it means less steam and less pressure. Because fewer molecules are hitting the inside of the can, the can collapses." The students' responses show they understood the concept that as the temperature decreased, the molecules moved more slowly and had fewer collisions.

The students compared the results of the soda can **investigations [SEP-3]** with the implosion of the tanker. As they **constructed explanations [SEP-6]**, their understanding of gas behavior concepts was evident and their models were more complete: "The tanker imploded and the can got crushed because the number of air molecules hitting the outside far exceed the number of air molecules or water molecules hitting the inside." "The molecules hitting the side cause pressure." The students concluded that under normal conditions, the tanker would not implode because the force of the molecules hitting the outside would equal the force hitting the inside.

Days 5–8: Application of Scientific Knowledge to an Engineering Problem

Investigative phenomenon: How can we prevent railroad tanker cars from imploding in the future?

At the end of the two-week instructional segment, Ms. S challenged the teams to apply their knowledge of thermal energy and pressure to design a tanker that would not implode after cleaning. The design constraints include the use of local materials and a feature that would ensure even poorly trained technicians would not accidentally **cause [CCC-2]** the tanker to implode. Ms. S led a discussion about how to evaluate the competing designs, and the class agreed upon two criteria: cost effectiveness and no implosion.

The students were given additional aluminum soda cans to allow them to test their ideas. After about 30 minutes of small-group brainstorming, designing, and building, each group had a model to test. Cristiano, Jasmine, and Al proposed keeping the tanker in a warm room after cleaning so that it would cool very gradually. To test their idea, they immerse it in warm water, not ice water. It implodes very slightly. Al suggested, "Let's use hot water instead of warm. Then it would cool off very slowly." The group agreed to try that.

Lorenzo's group punched a small hole at the opposite end of the can and when they immersed the can in the ice bath (with the punched hole just above the waterline), the can did not collapse at all. Lorenzo and Latasia whooped for joy! Mia reacted, "Wait! What happens to the liquid inside if there's a hole in the tanker?" "What do you mean?" asks Lorenzo. "Well, if the tanker has something like oil in it, the oil will evaporate out of the hole!" The others agreed, but liked their design anyway, and thought that the problem was not that important.

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Canyon, Alicia, and Jaylynn whispered together for a long time before asking Ms. S for materials. Jaylynn argued successfully to immerse a room-temperature can (not heated) in ice water. When the group tried that, the can did not implode. Alicia is worried, "Do you think we're cheating?" Ms. S pointed out that it was a design worth considering and asked the group if they could think of any problems with this design. Canyon offers, "This design is great! But what if the tanker had a liquid inside that would not clean well with cold water?"

Rick's group made a sign that they said they would paint on the tank, so it would never come off. The sign said, "After cleaning, open all doors." They demonstrated how it would work by immersing the can right side up so that cool air could flow into the tank.

Ms. S concluded the class by pointing out that engineering problems often have many solutions, with some better than others. The next day, the groups presented their design solutions. Based on the two criteria that they established earlier, the class discussed which of the solutions was best.

Vignette Debrief

The CA NGSS vision of blending disciplinary core ideas, science and engineering practices, and crosscutting concepts was exemplified in this vignette. The learning progressions of the CA NGSS disciplinary core ideas allowed teachers to assess whether students had the needed foundation for the new concepts. The teacher presented engineering practices when she introduced the tanker design engineering problem. Students were asked to apply the evidence from the soda can experiment to the real-world problem of preventing a tanker from crushing if maintained properly.

The vignette also highlighted that learning science has important implications in the real world. In the vignette, the workers who cleaned the tanks had no conceptual understanding—or at least no accurate mental model—of what would happen if they closed all the valves after steam cleaning the tank. That was an expensive mistake for the company, and the workers might have lost their jobs over it. This was a lesson about the importance of science in using and maintaining equipment and illustrated the interdependence of science, technology, and engineering.

SEPs. The students in the vignette engaged in many science and engineering practices, thereby building a comprehensive understanding of what it means to do science. The scientific practice of **developing and using models [SEP-2]** was highlighted throughout the vignette. Students constructed two conceptual models: the first for the tanker's implosion and the second for the implosion or lack of implosion of the soda can. The second model was more sophisticated and built on the first model, as new evidence was presented. A third model was based on the concepts from the other two and illustrated a design solution. Throughout the vignette, the students were challenged to modify and revise their models as they gained an understanding of the disciplinary core ideas of the pressure and temperature variables. In addition, the students were engaged in the scientific practices of **planning and carrying out investigations [SEP-3]** and **engaging in argument from evidence [SEP-7]**. In small-group and whole-group discussions, the students **constructed scientific explanations [SEP-6]**

DISCIPLINE SPECIFIC GRADE EIGHT VIGNETTE 6.3: DEVELOPING AND USING MODELS TO UNDERSTAND PROPERTIES OF GASES

for the tanker implosion, revised their explanations as they synthesized the tanker information, used their understanding of core ideas to construct a design solution, and supported or refuted claims. Students completed assignments by **obtaining, evaluation, and communication information [SEP-8]** about pressure differences and design explanations.

DCIs. Students built on their understanding of the nature of matter (PS1.A: Structure and Properties of Matter) by developing their model of solids, liquids, and gases. This model is significantly richer than it was in elementary school where they simply determined that matter was made of tiny particles. In the middle grades, students describe how temperature and state of matter affect the motion and interaction of particles. In high school, they will extend their model to so that it includes how the mechanism of electrical forces between particles causes these behaviors, but this vignette demonstrates how middle grades students can explain sophisticated phenomena even without referencing electrical charges or the internal structure of atoms and molecules.

CCCs. **Cause and effect [CCC-2]** was highlighted in the vignette as students described the effect of the forces applied on the tanker and soda can, and made comparisons. The students' observations guided them to provide evidence for the causality of the tanker and soda can collapse. They made predictions about scientific phenomena based on their developing understandings of effects of molecular movement and causes for state changes. Later, students applied **structure and function [CCC-6]** to an engineering a solution to prevent the implosion of a tanker.

CA CCSS Connections to English Language Arts and Mathematics. The CA NGSS support an interdisciplinary approach to science learning to provide experiences across disciplines. It is for this reason that each performance expectation has an associated connection to the CA CCSS for ELA and mathematics. The students in the vignette grappled with core ideas in physical science while meeting the CA CCSS for ELA/Literacy by holding whole-class and small-group discussions (SL.8.1) and evaluating the scientific **argument [SEP-7]** presented by others (SL.8.3). With the help of the teacher, the students wrote **arguments [SEP-7]** about their **models [SEP-2]** and their learning in their science journals (WHST.6–8.10).

The vignette also addressed grade-appropriate CA CCSSM throughout the exploration with core ideas in physical science. In the vignette, the students strove to successfully combine math and science practices to present valid explanations. In the vignette, student models reflected abstract reasoning, using a symbol system including comparisons of relative pressure (MP.2). Students drew the conclusion that as one variable (temperature) increased, the other variable (pressure) increased. Students inferred the properties of matter from their observations and experiments and justified their conclusions using the models they created (laying the foundation for S.IC.5, a higher mathematics standard).

Resource

Adapted from NGSS Lead States. 2013a. Appendix D Case Studies, Case Study 1. https://www.cde.ca.gov/ci/sc/cf/ch6.asp#link58

To relate their experiments of heat transfer to their microscopic **model [SEP-2]** of molecular movement, students use interactive computer simulations. These simulations help them visualize the accepted scientific model of molecular motion and extend their own model so that they can **explain [SEP-6]** state changes between solids, liquids, and gases, and the transfer of **energy [CCC-5]** in terms of colliding molecules. In IS1, students **argued [SEP-7]** that a change in kinetic energy is **evidence [SEP-7]** of energy transfer. In this instructional segment, they look at the argument from the opposite direction and argue that energy is transferred by changes in the kinetic energy of molecules (MS-PS3-5). The simulations also help visualize how thermal energy includes both kinetic energy from the translational movement of particles from place to place and kinetic energy from vibrations within molecules and between atoms in a solid. Using this model, students should be able to define temperature as being a measure of the average kinetic energy of the atoms in an object.

With this **model [SEP-2]** of thermal energy, students can start to **explain [SEP-6]** the **flow of energy [CCC-5]** in various situations. In IS1, students saw that some of an object's kinetic energy is converted to thermal energy by friction as it slides against another object (see PhET, Friction at https://www.cde.ca.gov/ci/sc/cf/ch6.asp#link59). Sliding along rough surfaces essentially re-orients the motion of individual particles so that their systematic motion (from which we calculate their kinetic energy) is converted to randomly oriented movements (from which we calculate their thermal energy). The particles continue moving the same speed, on average, as they were originally so that no energy is actually lost. The major change is in the average orientation of the motion (along with the fact that some of the energy is also transferred to the stationary object as the molecules of the two objects collide). The dissipation of sound waves with distance works the same way: systematic vibrations devolve into random movement. Even though a person's whisper cannot be heard on the other side of a room, the energy of their voice is used to warm the room up very slightly. Car crashes in real life undergo the same process: both cars appear to be moving quickly in one direction at the beginning of the crash but are stopped at the end. Where does the energy go? Again, the systematic motion of the car overall decays into random vibrations and movements of the individual molecules in the car. When a car collides with another object, whatever energy that is not transferred to the kinetic energy of that object is converted primarily into thermal energy and sound energy by the end of the crash (with a small amount of the energy going into permanent changes to the relative position of the molecules within the deformed materials, but this turns out to be less than 10 percent of the original kinetic energy for many metals). Engineers design the crumple zones so that all of this deformation and energy conversion into heat is concentrated in areas away from the passenger compartment, which is intended to remain a rigid protective cage. The crumpling also ensures that the passenger compartment slows down gradually, thereby reducing the force on the occupants. There is significant effort by engineers today to select materials and structures that "absorb energy" even more efficiently, which means converting it to heat.

Engineering Connection: Engineering Challenge: Design a Vehicle Radiator

Many **systems [CCC-4]** from human bodies to spacecraft operate best when they are neither too hot nor too cold. Living organisms have evolved so that they have mechanisms to avoid overheating (dogs pant, people sweat, rabbits have large ears, etc.) or becoming too cold (birds have inner down feathers, mammals have layers of fur, penguins huddle in groups, etc.). Many of these adaptations illustrate how the heat transfer **function [CCC-6]** is supported by the specific shape or **structure [CCC-6]** of the organism. Thermal regulation is also important in many different technologies. Obvious examples include keeping the inside of refrigerators cool and the inside of ovens warm, but engineers also include thermal regulation in the designs of a variety of technology. Computer chips that are present in just about every electronic object become damaged when they overheat, so almost all of these everyday objects also include design elements to keep them cool. Students engage in a design challenge in which they plan, build, and improve a **system [CCC-4]** to maximize or minimize thermal **energy [CCC-5]** transfer (MS-PS3-3). Ideas for the challenge include designing well-insulated homes (Concord Consortium, Build and Test a Model Solar House at https://www.cde.ca.gov/ci/sc/cf/ch6.asp#link60), a beverage or food container (NASA, Design Challenge: How to keep gelatin from melting at https://www.cde.ca.gov/ci/sc/cf/ch6.asp#link61), a solar oven (Teach Engineering, Hands-on Activity: Cooking with the Sun at https://www.cde.ca.gov/ci/sc/cf/ch6.asp#link62), or even a cooling system for a nuclear powered submarine (Lisa Allen, Historic Ship Nautilus: Submarine Heat Exchange Lesson Plan at https://www.cde.ca.gov/ci/sc/cf/ch6.asp#link63). This design challenge could also be integrated into the course theme of vehicles by having students design an effective radiator for a car. Their design could take advantage of liquids with different heat capacities flowing through tubes and/or fin-shaped metal heat exchangers, just like the radiators in the cars and buses that might take them to and from school. Students can consider the environmental impact of different materials as one of the many factors constraining their design (MS-ETS1-1). Because the performance of thermal regulation systems is easy to measure with a thermometer, students **plan [SEP-3]** a rigorous testing process (MS-ETS1-4), **analyze the data [SEP-4]** from the tests (MS-ETS1-3), and **evaluate [SEP-8]** different potential solutions (MS-ETS1-2) to iteratively improve their final design. Heat flow is also easily simulated on a computer using software that is available for free (Concord Consortium, Energy2D:

Engineering Connection: Engineering Challenge: Design a Vehicle Radiator

Interactive Heat Transfer Simulations for Everyone at https://www.cde.ca.gov/ci/sc/cf/ch6.asp#link64), allowing students to perform some of their planning and initial testing and revision in a simulator before actually building any physical objects. During the design process, students will likely need to become familiar with different mechanisms of heat transport (conduction, convection/advection, and radiation).

While these processes are not explicitly mentioned in the performance expectations for grade eight, students should be applying scientific principles to guide their design; for example, different methods of heat flow require different design strategies to exploit or minimize overall **energy [CCC-5]** transfer. Such information could have been introduced during the **investigations [SEP-3]** of MS-PS3-4, but the emphasis there was on the **quantity [CCC-3]** of overall energy transfer and different mechanisms were not essential. The distinction becomes more important for this design challenge because effective insulation designs often need to reduce all three mechanisms and effective heat exchange designs typically exploit them all. Students should already have applied models of convection to understanding **energy flow [CCC-5]** in Earth's atmosphere and interior during grade six (MS-ESS2-1 and MS-ESS2-6). Students can now relate their macroscopic understanding of heat transport processes to their models of the movement of individual particles. Conduction involves the transfer of energy directly by collision between particles. Energy moves in convection when particles with large amounts of thermal energy move to a different location and take their energy along with them. Hot particles can also radiate energy as electromagnetic waves, which can be absorbed by other particles during the energy transport process called radiation. Students finish the activity by creating a product information sheet in which they **argue [SEP-7]** that people should buy their product. They will **communicate [SEP-8]** the features of their product that allow it to perform better than their imaginary competitors as well as **evidence [SEP-7]** from their **investigations [SEP-3]** and testing showing that it actually does.

IS6 Discipline Specific Grade Eight Instructional Segment 6: Chemical Energy and Reactions

In IS5, students represented matter as moving particles. In this instructional segment, they modify that understanding to show that the particles can consist of smaller pieces called *atoms* and that particles come in different sizes and shapes called *molecules*, each with a unique set of properties that differ from the properties of the individual atoms. These molecules break apart and recombine through chemical reactions.

DISCIPLINE SPECIFIC GRADE EIGHT INSTRUCTIONAL SEGMENT 6: CHEMICAL ENERGY AND REACTIONS

Guiding Questions

- How do car engines turn gasoline into motion?
- How do people use technology to change natural materials into synthetic ones?

Performance Expectations

Students who demonstrate understanding can do the following:

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-PS1-2. Analyze and interpret data on the properties of substances before and after the substances interact to determine if a chemical reaction has occurred. [Clarification Statement: Examples of reactions could include burning sugar or steel wool, fat reacting with sodium hydroxide, and mixing zinc with hydrogen chloride.] [*Assessment Boundary: Assessment is limited to analysis of the following properties: density, melting point, boiling point, solubility, flammability, and odor.*]

MS-PS1-3. Gather and make sense of information to describe that synthetic materials come from natural resources and impact society. [Clarification Statement: Emphasis is on natural resources that undergo a chemical process to form the synthetic material. Examples of new materials could include new medicine, foods, and alternative fuels.] [*Assessment Boundary: Assessment is limited to qualitative information*.]

MS-PS1-4. Develop a model that predicts and describes changes in particle motion, temperature, and state of a pure substance when thermal energy is added or removed. [Clarification Statement: Emphasis is on qualitative molecular-level models of solids, liquids, and gases to show that adding or removing thermal energy increases or decreases kinetic energy of the particles until a change of state occurs. Examples of models could include drawings and diagrams. Examples of particles could include molecules or inert atoms. Examples of pure substances could include water, carbon dioxide, and helium.]

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*.]

DISCIPLINE SPECIFIC GRADE EIGHT INSTRUCTIONAL SEGMENT 6: CHEMICAL ENERGY AND REACTIONS

MS-PS1-6. Undertake a design project to construct, test, and modify a device that either releases or absorbs thermal energy by chemical processes.* [Clarification Statement: Emphasis is on the design, controlling the transfer of energy to the environment, and modification of a device using factors such as type and concentration of a substance. Examples of designs could involve chemical reactions such as dissolving ammonium chloride or calcium chloride.] [*Assessment Boundary: Assessment is limited to the criteria of amount, time, and temperature of substance in testing the device.*]

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-ETS1-3. Analyze data from tests to determine similarities and differences among several design solutions to identify the best characteristics of each that can be combined into a new solution to better meet the criteria for success.

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.

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

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

Highlighted Science and Engineering Practices	Highlighted Disciplinary Core Ideas	Highlighted Crosscutting Concepts
[SEP-2] Developing and Using Models [SEP-4] Analyzing and Interpreting Data [SEP-6] Constructing Explanations (for science) and Designing Solutions (for engineering) [SEP-8] Obtaining, Evaluating, and Communicating Information	PS1.A: Structure and Properties of Matter PS1.B: Chemical Reactions PS3.B: Conservation of Energy and Energy Transfer ETS1.A: Defining and Delimiting an Engineering Problem ETS1.B: Developing Possible Solutions ETS1.C: Optimizing the Design Solution	[CCC-1] Patterns [CCC-2] Cause and Effect: Mechanism and Explanation [CCC-3] Scale, Proportion, and Quantity [CCC-5] Energy and Matter: Flows, Cycles, and Conservation [CCC-6] Structure and Function

DISCIPLINE SPECIFIC GRADE EIGHT INSTRUCTIONAL SEGMENT 6: CHEMICAL ENERGY AND REACTIONS

Highlighted California Environmental Principles and Concepts:

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

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

CA CCSS Math Connections: 6.NS.5, 6.SP.4,5a–d, 6.RP.3, 7; 7.EE.3, 7.SP7a–b; MP.2, MP.4

CA CCSS for ELA/Literacy Connections: RST.6–8.1, 3, 7, 9; WHST.6–8.7, 8, 9

CA ELD Connections: ELD.PI.8.1, 3, 6a, 6b, 10b, 11a

The CA NGSS performance expectations for grade eight do not require students to probe the interior structure of atoms nor to **investigate [SEP-3]** the mechanisms by which chemical reactions are accomplished. The focus is instead on bulk properties of materials and how changes to them can be explained by reorganizing atoms into different molecules. The performance expectations ensure that students build a robust **model [SEP-2]** of the relationship between chemical reactions and the particulate model of matter, **conservation of matter [CCC-5]**, and the macroscopic effects of chemical reactions. The **structure [CCC-6]** of atoms, the periodic table, and the details of bonding are all addressed in detail when it is developmentally appropriate during high school (HS-PS1-1 through HS-PS1-8). This focus contrasts with the California 1998 Science Content Standards (1998 Standards) where the periodic table was introduced in grade five and the interior **structure [CCC-6]** of atoms was introduced in grade eight.

Students begin the instructional segment by bringing in one of their favorite objects from home. What is it made out of? Most objects in our everyday life are made out of synthetic materials, meaning that natural materials were taken from the natural environment and then transformed by chemical processes into materials with new properties. These materials are often stronger, more durable, or weigh less than the original natural material. Students **obtain information [SEP-8]** about the materials that make up their objects (MS-PS1-3). What natural materials were the raw ingredients to their own objects of interest? How do the properties of the final products differ from the raw ingredients?

Opportunities for ELA/ELD Connections

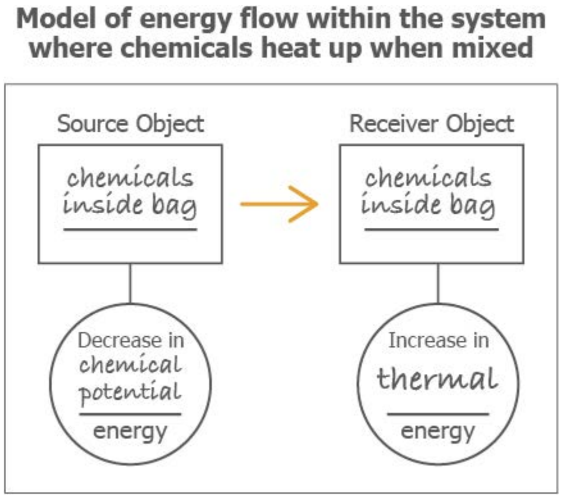
If a student has brought in an object (as noted above), have the student ask questions to help gather information about whether their object is from all natural ingredients. Example questions are: What natural materials were the raw ingredients to the object of interest? How do the properties of the final products differ from the raw ingredients? What processes did the materials have to undergo in order to change? Students can use Internet resources to find answers to these questions. Students should then **communicate [SEP-8]** some of their findings with presentations to small groups. Each group then compares the products and identifies commonalities in both raw materials and manufacturing processes. These **patterns [CCC-1]** help **explain [SEP-6]** what is actually happening during these processes. Another goal of this activity is to help students make the connection between natural resources and the built environment. Based on their research about the source materials for their objects, students present **arguments [SEP-7]** about whether or not they agree or disagree with the statement about each object: Should this object be labeled "all natural."

CA CCSS for ELA/Literacy Standards: WHST.6–8.7; SL.6–8.1, 2
CA ELD Standards: ELD.PI. 6–8.2, 5

What happens when materials are mixed together? Sometimes nothing, but sometimes materials change in exciting ways. These transformations are at the heart of the chemical processes that convert natural materials to synthetic ones and occur every instant in living organisms and in the nonliving environment. This instructional segment begins with an **investigation [SEP-3]** into a series of mystery powders and liquids, most available at the local supermarket (powders include flour, Epsom salts, powdered lemonade, calcium chloride, washing soda, and corn starch. Liquids include water, vinegar, lemon juice, and iodine tincture. Purple cabbage juice can be added as a colorful pH indicator). The materials are not identified by name, which is done to emphasize the observation component of the activity without devoting time to naming chemical compounds (see Minnesota Science Teachers Education Project, Chemical Reactions: Investigating Exothermic and Endothermic Reactions at https://www.cde.ca.gov/ci/sc/cf/ch6.asp#link65). Students first observe the different properties of individual liquids and powders, including their color and texture, and density (students have been conducting such **investigations [SEP-3]** since grade two, 2-PS1-1, 5-PS1-3). Next, students combine different combinations of two unknown powders with one unknown liquid in a plastic zip top bag. They conducted a similar **investigation [SEP-3]** in grade five (5-PS1-4), but this time the emphasis will be on observing properties to determine whether or not a chemical reaction has occurred (MS-PS1-2). In this inquiry approach, students are not given any criteria for identifying chemical reactions, but record careful notes about which powders and liquids were used in each combination using a collaborative online spreadsheet. Because they are pooling observations, they are able to collect a large number of different combinations that allow them to recognize **patterns [CCC-1]** in the events. Changes in state, density, odor, and unusual color changes are all indicators that a chemical change has occurred. In many cases, however, students will observe no unusual changes (e.g., red-colored liquids might turn into a pink squishy gel when combined with a white powder) because no chemical change resulted from the combination. They should be able to **analyze the data [SEP-4]** and use the patterns to predict what will happen with a previously untested combination of powders and liquids. Their prediction should be specific, including describing changes in properties such as density, melting or boiling point, solubility, effervescence, or odor.

One of the most obvious changes students observe is a temperature change inside the bag when certain combinations of the powders and liquids are chosen. In some cases, the bag heats up. Students define the **system [CCC-4]** of interest as the ingredients inside the zip-top bag and try to model the **flow of energy [CCC-5]** using the same energy source/receiver diagrams they have used in previous instructional segments (figure 6.39). Knowing that the energy to warm up the materials has to come from somewhere, students can use their observations and this model to support the **argument [SEP-7]** that there must be a chemical potential energy in which energy can be stored, and that this energy can convert into thermal energy. They should also be able to model the opposite situation where the bag cools down. At this point, students should have many **questions [SEP-1]** about what chemical energy is or how it is stored, but most of these questions remain unanswered until high school. They can infer that the relative position of the ingredients plays a role because potential energies are related to the relative position of objects. At this point, students' model should simply consist of the relationship that chemical reactions **cause [CCC-2]** energy to be converted through a change in the position of the particles relative to one another. They will refine this **model [SEP-2]** later in the instructional segment.

Figure 6.39. Energy Flow and Heated Chemicals



Model of energy flow within a system where chemicals heat up when mixed. Diagram by M. d'Alessio. Long description of Figure 6.39.

Engineering Connection: Designing a Hand Warmer Powered by Chemical Reactions

Students now imagine that they will travel to a very cold place to explore and play and that they will want a way to keep their hands warm for as long as possible. Their goal is to **analyze data [SEP-4]** from the previous experiment to help design a hand-warming pad powered by chemical reactions (MS-PS1-6). Students will need to **define the criteria [SEP-1]** for judging hand warmer performance (MS-ETS1-1). Is it best to have the hand warmer reach its peak temperature quickly and cool back down quickly, or to warm slowly to a lower peak temperature? The engineering challenge works best when the whole class records its findings from the mixtures with two powders and a liquid in a collaborative spreadsheet so that a large number of unique combinations can be tested. Students should discover **patterns [CCC-1]** in the class observations to identify which two materials consistently react before they select their materials and begin to test them. They then perform iterative tests to determine the relative concentration of the two ingredients that lead to optimal hand warmer performance (MS-ETS1-2, MS-ETS1-4). By **communicating [SEP-8]** their findings to the class, teams with different solutions can compare the relative performance of their hand warmers to decide the relative merits of each one (MS-ETS1-3).

Earlier in the instructional segment, students applied their understanding of potential energies to infer that chemical reactions must **cause [CCC-2]** particles to change their position relative to one another. This relates to students' work in grade seven when they developed a model of how food molecules are rearranged through chemical reactions (MS-LS1-7). They focused on the simple chemical equations of photosynthesis and respiration. Now they can revisit those reactions. In what way are the particles rearranged? Using the familiar molecules involved such as water and carbon dioxide, teachers can illustrate how atoms combine to form simple molecules with very simple shapes. Students can then make physical models of these combinations (MS-PS1-1) using interconnecting plastic toy bricks, sticky notes, or digital representations. Not only do these models depict atoms that are chemically bonded together, but they also introduce students to the concept of molecular shape. Molecular **structure [CCC-6]** is crucial in determining the behavior and function of these molecules in living **systems [CCC-4]**, but also in determining the properties of water and other inorganic compounds. It should be emphasized that explaining these applications is outside the scope of middle grades (for example, water's polarity cannot be explained without a detailed understanding of the internal **structure [CCC-6]** of the atom and chemical bonding), but this performance expectation lays the foundation for more advanced study.

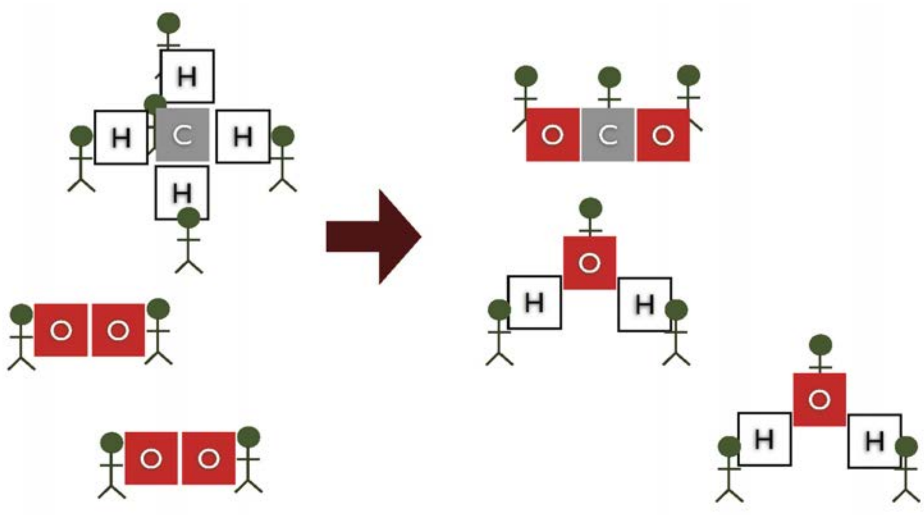
Thermal energy plays an important role in chemical reactions, as the challenge of the hand warmer at the beginning of this instructional segment illustrates. Students can apply the kinesthetic **model [SEP-2]**, using their bodies to represent atoms in a reaction in which chemical potential energy is converted to thermal energy (MS-PS1-4). The products of the chemical reaction in a hand warmer are noticeably hotter than the original unreacted material, which means that they must speed up after the chemical reaction. The same is true in a number of other important chemical reactions such as combustion and respiration. Natural gas in the burner on a gas stove reacts with oxygen and produces a very hot combination of water and carbon dioxide. These gases are hot enough to cook food, transferring some of their thermal energy to warm it up. The new molecules created by combustion, water and carbon dioxide, both float away harmlessly into the room so that there is no smoke or soot on the pot. A similar reaction occurs in a vehicle engine. Gasoline also combusts with oxygen, and the carbon dioxide and water produced are moving fast enough that they collide with the walls of the engine and push on cylinders that ultimately cause the wheels of a car to turn. These molecules retain enough heat to remain gases until they eventually exit the exhaust pipe. Sometimes exhaust pipes drip water, which just means that the water produced during the combustion reaction cooled enough to condense before getting to the end of the exhaust pipe. The speed of molecules also plays an important role leading up to the chemical reaction. When particles are moving faster in a material, they are more likely to collide with one another. Since many chemical reactions begin when particles collide, particles that are moving faster are more likely to participate in certain chemical reactions.

Students should be able to use their models of particles interacting during chemical reactions to depict the difference between pure substances (made of a single type of atom or a single type of molecule) and mixtures. For example, a jar containing a mixture of hydrogen and oxygen atoms is extremely flammable and will easily ignite, but a jar containing the exact same number of hydrogen and oxygen atoms bonded together to form the pure substance of water is not flammable at all. Once simple structures have been mastered, students should also be able to represent larger combinations of multiple atoms using different shapes.

While physical models often depict individual molecules, it is important to remind students that these molecules typically exist as a sea of an uncountable number of similar molecules that interact with one another and different atoms and molecules. Whether the material behaves as a solid, a liquid, or a gas depends on the relationship and interaction between these molecules. When molecules are close enough to strongly interact, they behave as a solid. Some solid materials form extended crystal structures where the same pattern of atoms repeats and it is not necessarily clear where one "molecule" begins and another ends. The clarification statement for MS-PS1-1 mentions diamonds and salt as examples of extended structures, but the vast majority of inorganic solids are crystalline, including pure metals and all minerals. Glass, wax, plastics, thin films, and gels are all examples of solids without a crystal structure that are common in synthetic products but rarer in nature.

Interactions between molecules of different types sometimes result in collisions in which atoms change partners completely. Students should be able to use their models of simple molecular structures to illustrate chemical reactions as atoms changing partners. Physical manipulatives can be useful to illustrate the conservation of mass, which requires that the number of atoms at the beginning of a chemical reaction must equal the number of atoms at the end. If students have actual objects left over, it means that they haven't recombined the atoms correctly (MS-PS1-5). Students can also use their own bodies as a physical model to represent individual atoms that change partners (figure 6.40). Chemical equations are also models of chemical reactions, but the assessment boundary for MS-PS1-5 states that students will not be responsible for balancing symbolic chemical equations. Nonetheless, students should be able to balance a chemical equation using physical manipulatives (by making sure that all starting atoms are included) and also support the claim that the mass of the **system [CCC-4]** does not change during the chemical reaction because the number of atoms has not changed.

Figure 6.40. Student Physical Model



Students using their bodies as a physical model of the combustion of methane.
Diagram by M. d'Alessio.
Long description of Figure 6.40.

Students now return to their research into synthetic and natural objects from the beginning of the instructional segment. What atoms were in the natural materials and how were they rearranged? Often during manufacturing, "impurities" are removed. These atoms do not go away, and so these processes often generate waste. Rearranging atoms can sometimes release **energy [CCC-5]** when it happens spontaneously, but many manufacturing processes rearrange atoms in ways that do not occur naturally. These processes require energy input, which means that manufacturing requires energy resources. The source for this energy can be chemical reactions, as it is for fossil fuels. But accumulating the source materials such as coal, oil, and natural gas comes at significant cost. Students **obtain information [SEP-8]** about energy sources and waste products and **communicate [SEP-8]** how the technology of their synthetic material influences society and the natural world (EP&C II).

Science Literacy and English Learners

This section presents a vignette with an example of how teaching and learning may look in a grade seven classroom when the California Next Generation Science Standards (CA NGSS) are implemented in tandem with the California Common Core State Standards (CA CCSS) for English Language Arts (ELA)/Literacy and the California English Language Development (CA ELD) Standards. 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 (SEPs) and the crosscutting concepts (CCCs) to understand the disciplinary core ideas (DCIs) associated with the topic in the vignette. An additional purpose is to provide examples of how language and literacy development are cultivated through interactive and engaging science literacy learning tasks. The vignette includes scaffolding approaches for English learner (EL) students. Many of the strategies employed in the vignette are inspired by the document *Integrating the CA ELD Standards into K–12 Mathematics and Science Teaching and Learning* (Lagunoff et al. 2015), which provides illustrative examples of the tandem implementation of the CA ELD Standards with the CA NGSS and California Common Core State Standards for Mathematics (CA CCSSM).

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 CA NGSS performance expectations or complete the instructional segment. Neither does it indicate that the performance expectations should be taught one at a time. This vignette is based on similar CA NGSS performance expectations presented in this chapter's Discipline Specific Middle Grades Vignette 6.2: Structure, Function, and Information Processing.

The vignette uses specific classroom contexts and themes, but it is not meant to imply that this is the only way in which students are able to achieve the indicated performance expectations and learning target. Rather, the vignette highlights examples of teaching practices, lesson organization, and possible student responses. Science instruction should take into account that student understanding builds over time and is extended by revisiting topics and concepts throughout the course of the year. In addition, some topics or concepts require different pedagogical and scaffolding approaches, depending on individual student needs. Finally, while the vignette provides several illustrations of pedagogical practices, it does not include everything that educators need to consider when designing and facilitating learning tasks. All learning environments should follow research-based guidelines.

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Performance Expectations

Students who demonstrate understanding can do the following:

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*.]

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

Highlighted Science and Engineering Practices	Highlighted Disciplinary Core Ideas	Highlighted Crosscutting Concepts
[SEP-7] Engaging in Argument from Evidence [SEP-8] Obtaining, Evaluating, and Communicating Information	LS1.A: From Molecules to Organisms: Structures and Processes	[CCC-4] Systems and System Models [CCC-6] Structure and Function

CA CCSS for ELA/Literacy Connections: SL.7.1; WHST.6–8.1a–e, 4, 5, 7

CA ELD Connections: ELD.PI.7.1, 2, 4, 7, 10; ELD.PII.7.1, 2

Introduction

Ms. K's grade seven students are learning about interacting systems. To provide her students with rich and varied learning experiences that meet the needs of all of her diverse learners, Ms. K designs her lessons so students have opportunities to make scientific discoveries, understand science concepts, and learn to read and write like scientists—all in a supportive environment that include ample discussion and collaboration. In this lesson sequence, she wants her students to make connections about the relationships between and among **systems [CCC-4]**, so they more fully understand both their own bodies and the natural world. The big idea that guides her lesson planning is that ***systems [CCC-4]*** *affect one another, so that* ***changes [CCC-7]*** *in one system or subsystem may affect other systems or subsystems within an organism or ecosystem.*

The 32 students in Ms. K's fifth-period grade seven class have a wide variety of backgrounds and bring a rich diversity of experiences and knowledge into the classroom. About one-third of her students speak a nonstandard dialect of English at home. In addition, 10 of her students are reclassified as fully English proficient within the last three years, while

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another five are at the late Expanding or early Bridging level of English proficiency. These students have a strong grasp of conversational English but need support understanding and using some academic language. Two of her students are newcomers at the early Emerging level of English language proficiency, and they regularly need substantial support to participate in all classroom activities. Ms. K's goal is to provide an appropriate level of support for all of her students so all can not only learn science content deeply but also increase their ability to read and write complex scientific texts.

Lesson Context

Ms. K's current lesson sequence has two parts, and the class is mid-way through the second part. In the first part, the class focused on cells as tiny living systems. They are currently studying how these cells interact and work together to make more complicated organisms involving more complicated interacting subsystems, including those within the human body.

Anchoring phenomenon: Pine trees have different visible parts.

To help students build their understanding of more complex systems, Ms. K's class studied pine trees, examining, discussing, and writing about the tree as a **system [CCC-4]** consisting of several subsystems. The class had co-created a large multi-media composition of a pine tree on butcher paper that covered the wall in the back of the classroom. The pine tree had been painted, but real pine needles had been glued onto the butcher paper, as had small twigs and pieces of bark. The pine tree's parts were labeled in the home languages of the students in the classroom: English, Spanish, and Filipino. Other academic and domain-specific language related to the content was also included on the mural, including short, student-friendly definitions.

Investigative phenomenon: A pine tree struck by lightning on one branch survives and thrives on other branches.

Ms. K explained that the tree can be considered a **system [CCC-4]** made up of several sub-systems. Ms. K posed a set of questions that the students had to answer together, co-writing their responses on the mural:

- What would happen if the root system were damaged?
- What if the trunk and bark were compromised due to fire or a lightning strike?
- How does the tree obtain energy and matter and move them around?
- How does each subsystem contribute to the tree's survival?

In their written responses, Ms. K supported students in using the academic and domain specific vocabulary from the instructional segment.

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Everyday phenomenon: Human bodies have different organs and tissues.

After her students had studied the subsystems within a pine tree in depth, Ms. K facilitated a series of lessons in which students began to transfer their understanding of systems and subsystems from trees to the human body.

Students first examined organs and tissue within the human body. Students worked in collaborative groups to explore an online interactive body tour, choose and research an organ and a tissue, and then give a group presentation on the group's chosen organ and tissue. For these group projects, Ms. K strategically created linguistically heterogeneous groups; the students in each group represented a range of English language proficiency. Whenever possible, each newcomer was placed in a group in which at least one student spoke his or her home language. As a component of the presentation, each group created a labeled graphic that was then posted on the classroom walls. The class also co-created a word wall that included the words necessary to understand the content, as well as student-friendly definitions.

As students continued to build both their science conceptual understandings and language and literacy skills, they used what they had learned to write a scientific **argument [SEP-7]** about how complete or partial failure of the whole organ or tissue chosen would affect other subsystem(s) or the functioning of the human body as a whole. The following learning target and CA NGSS performance expectation guide teaching and learning for the lesson.

Learning Target: Students will write an [redacted] demonstrating understanding of the relationship of body systems to survival. (MS-LS1-3)

Lesson Excerpts

Building Models

Investigative phenomenon: Humans have two kidneys but can survive with just one. However, they cannot survive when both kidneys fail.

Following the students' group research assignments and presentations, Ms. K began the next phase of the lesson sequence in which the objective was to help her students understand how the organs and tissues of the body work together as subsystems to complete tasks and regulate body **functions [CCC-6]** necessary for survival. She began by introducing students to the role of kidneys.

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As a first step, Ms. K asked her students to build models of body **systems [CCC-4]** in small groups, as this format promotes interdependence and is conducive to peers providing support. She divided the students into eight groups of four, again ensuring that the groups incorporated students representing a range of English language proficiencies. Four of the groups each built a model of the heart that showed its function; the other four groups each built a model of the kidneys that showed their **function [CCC-6]**. Ms. K had a set procedure for models and experiments in which she organized the materials and placed them in bins before class, and each group immediately assigned a materials manager to collect the materials. For the heart, students were provided a water bottle, different sizes of surgical tubing, duct tape, red food coloring, balloons, and a foam core board. For the kidneys, students worked with a larger water bottle, a smaller water bottle, a plastic cup, cotton balls, and a tea bag. Ms. K wanted her students to be inventive and demonstrate independence. Because she also wanted to support them, she had written instructions for building each of the models and provided YouTube videos ready to view on the classroom computers that showed each of the models in action. Ms. K let students know that if they felt stuck or overwhelmed, they could request written instructions, watch a video of the model in action, request to observe what another group was doing, or ask Ms. K for assistance. Ms. K circulated during the modeling activity to ensure her students understood and to judiciously provide appropriate levels of support.

Ms. K stopped by one of the groups working on the heart model to see how its model was progressing. The group consisted of four students: Yesenia, Patricia, Dominic, and Carlos. In particular, Ms. K monitored how Patricia, at the early Emerging level of English proficiency, was understanding the group task.

Yesenia: (Holding the water bottle.) This should be the heart, 'cause we could make it beat. (She squeezes the water bottle a few times.)

Dominic: Yeah, it could push the blood out and around.

Yesenia: Pump the blood.

Ms. K: It sounds like you're already thinking through your approach. From our recent work, do you remember what word we used to discuss blood moving around the body?

Carlos: Umm … circulate?

Yesenia: (Still holding and pumping the water bottle.) This heart could circulate the blood all around the body.

Dominic: Throughout the whole body in the veins

Ms. K: I see you are using academic vocabulary. Can you create a sentence to describe what you're planning that uses academic vocabulary?

Dominic: We can use the bottle to create …

Yesenia: We can use the bottle as the heart to circulate the blood …

Carlos: Circulate the blood throughout the body in the veins.

Dominic: We can use the bottle as the heart to circulate the blood throughout the body in the veins.

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Ms. K: ¿*Entiendes*, Patricia?

Patricia: (Making a "so-so" motion with her hand.) *Tipo de* …

Ms. K: Yesenia, can you help Patricia understand your approach?

Yesenia: (Holding up the bottle.) *Podemos utilizar la botella como un corazón …* (She squeezes the bottle) *… para mover la sangre por todo cuerpo*.

Patricia: *El corazón es* the bottle*. Circula la sangre. Si*. (She turns to Ms. K.) I understand.

Yesenia: (Prompting Patricia.) The blood circulates.

Patricia: The blood circulates.

Ms. K: (Smiles and makes eye contact with all the students in the group.) Thank you. Please continue your work.

Ms. K moved on to different groups, continuing to circulate, encouraging, and supporting her students in building viable models and using appropriate domain-specific vocabulary to discuss their approaches to building the models. After the students completed their models, each group discussed answers to the questions below before sharing out to the class. Ms. K also provided sentence stems to support students in answering the questions and sharing answers with the class.

- What about our approach was successful? (The aspects of our approach that were successful were …)
- How does our model accurately reflect the circulatory system? (Our model accurately reflects the circulatory system because …)
- How does our model not accurately reflect the circulatory system? (Some aspects of our model do not inaccurately reflect the circulatory system because …)

Ms. K used the numbered heads together routine for sharing out. In this routine, Ms. K assigned each student a number. The students were familiar with this routine and understood that they would not know who would share out until after the discussion. As such, the group's responsibility was to help all students feel prepared to share out. The students also knew that during share-out time helping the reporter was encouraged, but no reporter was allowed to pass.

Preparing to write:

Investigative phenomenon: When one of the body's subsystems is compromised, it can affect other subsystems and the body as a whole (different students investigate different systems).

The day following the building of the heart and kidney models, Ms. K began to prepare her students to write their argument essays. To successfully write this essay, students had to be able to answer the question, What might happen to the body if one of the body's organs were

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compromised? Because understanding this issue was so important, Ms. K had planned a series of scaffolds to support her students.

First, she partnered her students strategically, ensuring that each student at the Emerging level of English language proficiency (ELP) was partnered with at least one English-proficient student who spoke the same primary language. She also partnered her other students based on their individual needs and language ability. For example, she tried to partner her students who were recently reclassified as fully English proficient with either a native speaker of English or with a student at the Expanding or Bridging level of English proficiency. Ms. K made sure to keep her partner pairings flexible over the course of each day, week, and month so that each student sometimes had the opportunity to be the more knowledgeable or able peer and sometimes had the opportunity to work with a partner who had more advanced linguistic and/or content understanding. She also sometimes created groups or pairs, depending upon the purpose of the task. For her newcomer students, though, she ensured they were with a partner who would effectively support them with the language demands of all the learning activities.

Using the Think-Write-Pair-Share routine, Ms. K asked her students to jot down in pairs the organs and tissues (along with their respective purposes) they had researched and reported on earlier in the week. She encouraged them to refer to the posters on the walls and the heart- and kidney-based circulatory system models they had completed. She asked each student to first think about what they had learned during the week about organs, tissues, and body systems. She then gave them a minute of think time followed by two minutes of writing time. While the students were thinking and writing, she checked in with each of her ELs at the Emerging level of proficiency to make sure they understood the task.

She then put a piece of paper under her document camera and drew four vertical lines down the paper, creating five vertical columns. She explained that each student would record his or her own response and use this chart in preparation for writing his or her science argument essays (see example below). She labeled the first column “Organ or Tissue,” the second column “Body System,” the third column “Function,” the fourth column “What happens if it is compromised?” and the fifth column “How might its compromise affect other subsystems or the whole-body system?” She explained to her students that she would like them to complete their own tables in their pairs, using their collective knowledge. Ms. K then modeled the first row for the students. She deliberately chose neither the heart nor the kidneys as her example. Since the students had studied these organs in more detail, she wanted students to use their own knowledge of them independently. Instead, she chose the skin; it was not an entirely new concept for the students because one of the groups presented on the skin earlier in the week. Ms. K thought aloud as she completed the chart:

Ms. K: One of the organs I remember is the skin. The skin is part of the integumentary system. Let’s all say that together.

The class: (Chorally) Integumentary.

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Ms. K: I know that this particular organ is made of two layers of tissue called the dermis and the epidermis. I remember from the presentation earlier this week that the function of the skin is to protect the body from external damage, to absorb nutrients, and to regulate temperature. Since we're just making notes here, I think it's okay to use bullet points. So, if the skin protects us and something damages it, bacteria and chemicals may more easily get inside the body and harm it. For example, if the bacteria caused an infection, the whole system of the body might be at risk. In extreme cases, a person's survival might even be at risk.

As Ms. K thought aloud, she paused periodically to complete an anchor chart students may refer to during an upcoming writing task.

Organ or tissue	Body System	Function	What happens if it is compromised?	How might its compromise affect other subsystems or the whole body system?
The skin, including the dermis and the epidermis	Integumentary system	• To regulate temperature • To protect the body from external damage • To absorb nutrients	It is easier for chemicals or bacteria to get inside the body.	The body might get an infection, which could affect the body's whole system. In extreme cases, it might put a person's survival at risk.

Ms. K asked which organ the class wanted to try next. She instructed students to quickly turn and talk to a partner. Students shared with one another, and most students said that they would like to try the heart or the kidney. But some students wanted to try other organs they had worked with earlier in the week. Ms. K told her students they could continue adding two to three rows to the chart using the organs or tissues of their choice, but that they had to negotiate and agree with their partners. She reminded students of the resources they were regularly encouraged to use to get more **information [SEP-8]** if they needed it: anchor charts, word walls, and student-created material on the classroom walls; the four classroom computers with Internet access and encyclopedia software loaded; each other; and herself, Ms. K. As students worked on their charts, Ms. K circulated to support students with both their content understanding and their use of academic and domain-specific vocabulary.

After the students had completed their charts, Ms. K brought the class back together and asked a series of questions, gradually working toward jointly constructing a statement about the interconnected relationship of the subsystems of the body.

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Ms. K said, "Think about what you know about organs…What might happen if an organ is compromised? Please think for a minute, and when you answer I'd like you to use the sentence frame: If the (organ/tissue) ______ is/are damaged, then _______ might __________. Let me give you an example. If the skin is damaged, then bacteria might get inside the body and create an infection." (Ms. K had prepared this sentence stem on a chart paper so students would have a visual reminder of how she would like them to respond.) "Please turn and talk with your partner, take turns thinking of several sentences, and make sure one of you is comfortable sharing out one sentence." After about one minute of students taking turns speaking, Ms. K asked Lakisha to share with the class what she and Jose Luis had discussed.

Lakisha: So, if the heart is damaged, then someone might have a heart attack.

Ms. K: Absolutely, that is one result of damage to the heart. When a person has a heart attack, the heart might become damaged. Can you say more about what happens to the body if the heart is damaged?

Lakisha: The heart pumps blood through the body and …

Jose Luis: If it gets damaged it might not be able to …

Lakisha: It might not be able to pump the blood it needs to.

Ms. K: That sounds reasonable to me. Would another group like to add on to what Lakisha and Jose Luis have shared?

Maria: If the heart can't pump the blood throughout the body …

Yesenia: Circulate!

Maria: Yeah, if the heart can't circulate the blood throughout the body, cells don't get the stuff they need.

Ms. K: Thank you, Yesenia and Maria for using the term "circulate." I agree, Maria, the cells don't get what they need. Let's try to be more specific about that. What do cells need? Let's all think for a moment.

Joseph: (After a moment …) I think they need oxygen?

Ms. K: They do indeed need oxygen. Maria, can you repeat your idea using the word "oxygen"?

Maria: Sure. Um, if the heart can't pump … circulate blood in the body, cells don't get the oxygen they need.

Ms. K: This is an important piece of information. Let's write this down together. I'll write it under the document camera, and I'd like every one of you to write in your science notebook. (Writes "If the heart becomes damaged and cannot … ") What word should I put here?

Several students: Circulate!

Ms. K: (Writes " …circulate the blood in the body, then …") What do you think goes next? Please turn and talk with your partner. (She gives students a moment to turn and talk.) Miguel, what do you think?

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Miguel: Then cells don't get what they need.

Ms. K: (Writes "cells don't get what they need.") That is certainly true. Is there a way we can say this that incorporates more specific terminology?

Gloria: Cells don't get the oxygen they need.

Ms. K: That is more specific, and it includes one of the academic terms we've been using. (Crosses out "what" and adds "the oxygen.")

Ms. K continued to support her students in understanding and expressing ideas using both academic and domain-specific language. She guided her students through questioning and prompting, moving from the heart to the kidneys, to co-construct statements about the interdependent nature of the subsystems of the body:

- If the heart is damaged and cannot circulate blood throughout the body, cells do not get the oxygen they require to survive. If cells do not get oxygen, they die. If cells die, especially cells in important places like the brain, the body can also die.
- If the kidneys are damaged and cannot filter toxins and water from the blood, those toxins are circulated throughout the body and can damage or kill the cells in our body. Without oxygen-rich clean blood, our cells cannot survive.
- Each of our organs is made of cells that need to be healthy for the organ to be healthy. If one of our organs, such as the heart or kidneys, is damaged, it can affect the health of other organs by damaging their cells. Therefore, the subsystems of the body affect the body as a whole.

Ms. K led her students through an analysis of the language they used to make this scientific **argument [SEP-7]**. She drew her students' attention to the causal "if…then" statements and terminology such as "therefore."

To extend the discussion about how damage to one organ can affect the interacting subsystems (organs) in the body, Ms. K asked students to consider situations when the body can heal itself, as is the case with the flu or a broken bone. Ms. K then asked her students to think about times when medical technology or another strategy may be helpful to a person who is deaf or has diabetes. In this example, she prompted her students to think about sign language to help a person who is deaf to communicate or how insulin can do the job of the pancreas. To help her students transition into the concepts of systems being made of subsystems that can, at times, be replaced, Ms. K prompted her students to think of other systems they know of where one part can be replaced to make the system functional again. If necessary, she guided students to think about replacing a car battery, a bicycle tire, or computer keyboard or mouse.

Investigative phenomenon: Humans have two kidneys but can survive with just one. However, they cannot survive when both kidneys fail. (revisited from earlier)

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Ms. K took her students back to the earlier conversation about the kidneys as one of the subsystems of the body. She reminded students that humans have two kidneys, but it is possible to live a healthy life with only one. In the case of kidney failure, an individual can have the 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 explained the concept of organ transplant and explained that one person can also donate tissues, such as corneas, skin, bones, ligaments and tendons, and up to eight organs—kidneys, lungs, heart, liver, and intestine—upon their death. In this way, she explained, each donated organ can replace the organ that was compromised and the body as a **system [CCC-4]** can again function properly.

She asked the students if they know anybody who has received a transplant, is waiting for a transplant, or was an organ donor. Ms. K asked if any of the students were comfortable sharing their example and suggested that they discuss this important topic with their parents.

The following day, it was time for students to begin their individual scientific arguments. With a disproportionate number of people of Hispanic/Latino background on the kidney transplant waiting list, this topic it important to cover. Researchers are discovering that a person on the waiting list is more likely to be a "match" with and receive an organ from someone with a similar ethnic make-up.

After careful observation during each of the phases of the lesson sequence, Ms. K considered that most of her students were ready to tackle writing an **argument [SEP-7]** on their own. She reminded students that they would follow the writing process and would each have the opportunity to receive feedback from two peers as well as from Ms. K herself, or another adult, before submitting a final argument. She assigned her students a writing prompt.

If an organ or tissue partially or completely failed, which other subsystem(s) would it affect, and how might it affect the functioning of the human body as a whole? Choose a human organ or tissue. Write an essay that explains the effects of the failure of the organ or tissue that you chose. Be sure to support your discussion with evidence from classroom discussions, notes, and other appropriate resources.

Ms. K reminded the students who would be writing independently that they had many resources available: anchor charts and other materials on the walls, the computer, each other, and her. She encouraged them to use the ideas the class generated together, but emphasized that they would need to include more details and specificity in their writing. Alternatively, they could opt to challenge themselves by selecting an organ or tissue that had not been discussed in class.

Ms. K wanted to provide additional support to the three ELs at an Emerging level of English proficiency, as well as four of her students who struggle with writing, two of whom are ELs at the late Expanding level of English proficiency. She pulled these seven students to the

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back of the room and led them through the process of planning their arguments, including creating a controlling idea and supporting it with **evidence [SEP-7]** using a causal structure and vocabulary typical of science **arguments [SEP-7]** (e.g., because, since, consequently, as a result, may be due to, this led to, so that, in order to, if … then, for this reason).

Teacher Reflection and Next Steps

Ms. K evaluated the first drafts of her students' writing so that she could make strategic decisions about her next steps. She noticed that most of her students seem to understand the concept of the interactivity of subsystems, but they were a little less clear in their writing about how damage to an organ can cause cell death. She noted this as an area for further discussion and inquiry.

She also noticed that some of her ELs were doing well using domain-specific vocabulary but were having trouble using some general academic terminology. During designated ELD time, she decided to set up several days of targeted instruction using a seven-step vocabulary routine on high-leverage Tier 2 words (e.g., indicate, require, react, apply, clarify, etc.).

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