Chapter 5
Preferred Integrated Course Model for Grades Six Through Eight

2016 Science Framework

FOR CALIFORNIA PUBLIC SCHOOLS
Kindergarten Through Grade Twelve

Adopted by the California State Board of Education
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To view the remaining sections of the 2016 California Science Framework on the CDE website, go to:
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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.

Grades Six Through Eight
Preferred Integrated Course Model

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 (Integrated Model), which interweaves science disciplines in a developmentally appropriate progression; and the Discipline Specific Course 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 grades' performance expectation (PE) by the end of the grade. "Sequence" here refers to in which course (grade six, seven, or eight) 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 example course sequences in this framework describe possible storylines but are not the only way.

Table 5.1 compares **disciplinary core ideas (DCIs)** that 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 all grade levels (although each lesson may focus on only one or two, and each year may emphasize 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 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 specified performance expectations for each year: kindergarten through grade five. However, in the middle grades, the performance expectations were presented for the entire grade span: grade six through grade 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—sixth, seventh, and eighth. Therefore, the State Superintendent of Public Instruction (SSPI) recommended that the State Board of Education (SBE) adopt specific placement of the performance expectations 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 the CA NGSS; the panel subsequently reviewed the national model developed by Achieve (2010), and adapted it to better align with California's needs and recommended only the Integrated Course 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: https://www.cde.ca.gov/ci/sc/cf/ch5.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 (6, 7, and 8) science instruction, and requested that the CDE reconvene the Science Expert Panel to develop as an alternative model 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 the Discipline Specific Model of the CA NGSS.

The board's intent in their November 2013 action was to establish 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 5.1. Comparison of When DCIs are Primarily Addressed in the Two Middle Grades Models

blank	DISCIPLINARY CORE IDEA	SUBTOPIC	Preferred Integrated			Discipline Specific		
			6	7	8	6	7	8
EARTH AND SPACE SCIENCE	**Earth's Place in the Universe**	Universe, Stars, Solar System			x	x		
		History of Planet Earth			x	x		
	Earth's Systems	Water Cycle, Weather, Climate	x			x		
		Rock Cycle, Plate Tectonics		x		x		
	Earth and Human Activity	Global Climate Change Causes	x			x		
		Resources Availability		x		x		
		Natural Hazards		x		x		
		Resource Consumption			x	x		
LIFE SCIENCE	**From Molecules to Organisms: Structures and Processes**	Cells & Body Systems	x				x	
		Photosynthesis and Respiration		x			x	
	Ecosystems: Interactions, Energy, and Dynamics			x			x	
	Heredity: Inheritance and Variation of Traits	Sexual Versus Asexual Reproduction	x				x	
		Mutations			x		x	
	Biological Evolution: Unity and Diversity				x		x	
PHYSICAL SCIENCE	**Matter and its Interactions**	Atoms, Molecules, States of Matter		x				x
		Chemical Reactions		x				x
	Motion and Stability: Forces and Interactions				x			x
	blank	Kinetic Energy and Collisions	x		x			x
	blank	Heat and Heat Flow	x					x
	blank	Potential Energies & Gravity			x			x
	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 from other countries and provinces. Analyzing the science standards of ten countries that produce significant scientific innovations and produce high scores on international benchmark tests, Achieve (2010) found that all ten of these countries use an integrated science model through the middle grades, and seven of the ten countries keep science integrated all the way through grade ten. Summarizing qualitative trends from their analysis, Achieve (2010) concluded, "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. Because these CCCs cannot be explained 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 (e.g., biology, chemistry, physics, geology), so they are expected to have stronger content knowledge in that field. Linda Darling-Hammond 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" (Darling-Hammond 2000). Teachers with a general science certification teaching the middle grades exceed that basic level of competence in all sciences and should be able to teach effectively in both models. Perhaps more important than university learning within a discipline is the pedagogical content knowledge (PCK) learned from years of experience teaching a specific subject area. Some of this PCK is discipline specific (such as awareness of specific preconceptions within one's discipline) (Sadler et. al. 2013), but much of it relates to SEPs and CCCs 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 Integrated and Discipline Specific Models.

Sequencing in a Developmentally Based Learning Progression

The CA NGSS are 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 domain, 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 DCIs appear in grade seven, but core ideas about the nature of matter are not introduced until grade eight. The Integrated 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 Preferred Integrated Course Model for Grades Six through Eight

The Preferred Integrated Course Model (Integrated Model) provides a unique opportunity for teachers to truly address real-world phenomena, ask questions, and seek answers to those questions without regard to disciplinary boundaries. In reality, all objects obey the laws of physics, are made of chemical matter, interact with other parts of the Earth and space system, and are ultimately observed by us as living beings. Many professional scientists do have disciplinary specializations, but more and more of these barriers are being broken by interdisciplinary research.

The Integrated Model also supports the CA NGSS vision of a strong developmental progression where students spiral through the curriculum, revisiting ideas in increasing complexity and detail. Complex scientific problems exist within all the domains of science and engineering, and the Integrated Model places the most complex phenomena at the end of the grade span when students are most ready to face them. Students undergo considerable growth from grades six through eight; it makes the most sense to capitalize on their growth.

Integration was built directly into the architecture of the CA NGSS with the dimension of **crosscutting concepts (CCCs)**. These ideas provide a common thread to all domains. Deep understanding of the CCCs (along with the **science and engineering practices or SEPs**) provides a firm foundation for students to pursue future science in any discipline. This course emphasizes the CCCs, including a strong focus on **systems [CCC-4]** at the beginning of grade six and culminating with **stability and change [CCC-7]** by the end of grade eight (with all the other CCCs embedded along the way). This course is designed to be an integrated course, as opposed to a coordinated science course (table 5.2): “Simply stated, the difference between coordinated and integrated is the type of connections that can be made between and among the various fields of science” (Sherriff 2015). Coordinated science delivers the different domains of science in succession, while a true integration both introduces and teaches related content to answer a single question about a phenomenon within science.

Table 5.2. Integrated Versus Coordinated Science

INTEGRATED	COORDINATED
Every science every year.	Every science every year.
Performance expectations are bundled according to natural connections between them and enable learning about the connections in addition to what is discipline specific.	Performance expectations are bundled according to discipline, resulting in learning that is mostly discipline specific.
Connections between science disciplines are clearly made for and by students.	Connections have to be “remembered” by the student and the teacher.
Examples outside of a particular discipline are given when appropriate.	Examples within a particular discipline are normally given.
A few examples: • Astronomy is taught in conjunction with gravity and forces. The connections and applications of physics are applied to astronomy. • Heat (physics) is taught at the same time, using climate and weather as the applied examples. • Light and the chemistry of photosynthesis are all taught in an interconnected presentation.	A few examples: • Astronomy is taught conceptually with gravity and forces taught in separate units that may not connect to astronomy. • Heat is taught as a separate physics unit. Climate and weather are taught as a separate unit. • Light is taught as a separate unit as strictly physics with no connections to life science needed.

Source: Sherriff 2015

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 (PEs). The phenomena chosen for this statewide document will not be ideal for every classroom in a state as large and diverse as California. Teachers are therefore encouraged to select phenomena that will engage their students and use this chapter's examples as inspiration for designing their own instructional sequence.

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 fields 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 CCCs as tools to make sense of their observations and investigations; the CCCs are recurring themes in all disciplines of science and engineering and help tie these seemingly disparate fields together. The SEPs, DCIs, and CCCs grow in sophistication and complexity throughout the K–12 sequence. While this chapter calls out examples of the three dimensions in the text using color-coding, each element should be interpreted with this grade-appropriate complexity in mind (appendix 1 of this framework clarifies the expectations at each grade span in the developmental progression). Engineering, technology, and application of science (ETS1) 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.

Essential Shifts in the CA NGSS

The 1998 *Science Content Standards for California Public Schools: Kindergarten Through Grade Twelve* (1998 CA 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 SEPs alongside a deep understanding of DCIs and the ability to relate these ideas to CCCs that are common across the domains. As a result, instructional materials and strategies must shift.

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, students may be expected to know *fewer* details about phenomena than they did in the 1998 CA Science Standards, with the focus shifted to richer reasoning and more opportunities to apply knowledge. These details are not missing from the CA NGSS, but they have been moved from the middle grades to high school, where they are more developmentally appropriate. The level of detail builds slowly. Teachers often complain that students do not remember concepts from year to year, but perhaps this forgetting is a consequence of teachers' 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 interweaved storylines that develop over years. In order to accomplish this slow build up, teachers likely will 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," situations in which students 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 learning to help teachers make these modifications in supportive, collaborative environments.

Grade Six Preferred Integrated Course Model

This section is meant to be a guide for educators on how to approach the teaching of the California Next Generation Science Standards (CA NGSS) in grade six according to the Integrated Model (see the introduction to this chapter for further details regarding different models for grades six, seven, and eight). It 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 into integrated groups that can effectively guide instruction in four sequential instructional segments. There is no prescription regarding the relative amount of time to be spent on each instructional segment. As shown in figure 5.1, the overarching guiding concept for the entire year is "Systems within organisms and between them are adapted to Earth's climate systems."

Figure 5.1. Integrated Grade Six Storyline

Guiding Concept: Systems within organisms and between them are adapted to Earth's climate systems.

Instructional Segment	**1** A cell, a person, and planet Earth are each a system made up of subsystems.	**2** Weather conditions result from the interactions among different Earth subsystems.	**3** Regional climates strongly influence regional plant and animal structures and behaviors.	**4** Human activities can change the amount of global warming, which impacts plants and animals.
Life Science (LS)	All living things are made of cells. The body is a system made of interacting subsystems.	Blank	Variations of inherited strains arise from genetic differences. Genetic traits and local conditions affect the growth of organisms. Organisms rely on their body structures and behavior to survive long enough to reproduce.	Local conditions affect the growth of organisms. Organisms rely on their body structures and behavior to survive, but these adaptations may not be enough to survive as the climate changes.
Earth and Space Sciences (ESS)	Water cycles among the land, ocean, and atmosphere. Weather and climate involve interactions among Earth's subsystems.	The movement of water and interacting air masses helps determine local weather patterns and conditions. The ocean has a strong influence on weather and climate.	Energy input from the Sun varies with latitude, creating patterns in climate. Energy flow through the atmosphere, hydrosphere, geosphere, and biosphere affects local climate. Density variations drive global patterns of air and ocean currents.	Human changes to Earth's environment can have dramatic impacts on different organisms. Burning fossil fuels is a major cause of global warming. Strategic choices can reduce the amounts and impacts of climate change.
Physical Science (PS)	Blank	Temperature measures the average kinetic energy of the particles that make up matter. Energy transfers from hot materials to cold materials. The type and amount of matter affects how much an object's temperature will change.	The type and amount of matter affects how much an object's temperature will change.	Blank
Engineering, Technology, and Applications to Science (ETS)	Design criteria. Evaluate solutions.	Design criteria. Evaluate solutions. Analyze data. Iteratively test and modify.	Blank	Design criteria. Evaluate solutions. Analyze data.

In IS1, students define **systems and system models [CCC-4]** and apply these ideas to different Earth science and life science contexts. A key understanding from IS1 is that **systems [CCC-4]** are made of component parts that interconnect with each other. Moreover each of the component parts is itself a system that is made of component parts. This notion of *systems within systems within systems* (also called nested systems) is particularly apparent in analyzing a "human being system" that is made of components called body systems (e.g., the circulatory system) that are made of organs (e.g., the heart) that are made of tissues that consist of different kinds of cells.

In IS2, students explore California weather from the perspective of the **flow of energy and cycling of matter [CCC-5]** within a **system [CCC-4]**. In grade five, students **developed models [SEP-2]** of how Earth's systems interact (IS1 reviews the systems). They also explored the reservoirs of the water cycle. In IS2 students deepen their understanding by analyzing the processes of the water cycle and the physical science underlying these processes. These Earth science and physical science concepts are then applied to understanding weather in different California regions. **Patterns [CCC-1]** of temperature and precipitation are **causally related [CCC-2]** to geographical features such as proximity to the ocean, latitude, altitude, and proximity to mountains. The water cycle is also important conceptually because of its central role in weather phenomena and because it provides an example of a property of a whole **system [CCC-4]** that is different than the properties of its parts.

Instructional segment 3 extends the students' investigations to the more general level of regional climate in different parts of the planet. At the level of climate, students can correlate the **cause and effect [CCC-2]** relationships that determine regional climate patterns and the circulation of **matter and energy [CCC-5]** by the atmosphere and ocean. Students also correlate **cause and effect [CCC-2]** relationships between the climate of a region and the structures and behaviors of plants and animals that live in that region. Regional climate provides another compelling example of a property of a whole **system [CCC-4]**.

Instructional segment 4 concludes the year by **scaling [CCC-3]** from the regional climate level to the level of global warming. In previous instructional segments, students had several opportunities to design solutions to problems primarily from engineering and technology perspectives. During IS4, they have opportunities to work on projects related to monitoring an environmental issue and **designing solutions [SEP-6]** to reduce the impacts related to that issue. Global climate change provides many opportunities to further develop and apply skills relating to the technological and scientific aspects of solving societal problems. Global climate change also provides a real-world context where some of the criteria and constraints can involve social motivations and patterns of behavior that must be considered as part of the design in solving a problem.

IS1

Integrated Grade Six Instructional Segment 1: Systems and Subsystems in Earth and Life Science

The CCC of **Systems and System Models [CCC-4]** is a useful tool that can help learners to connect ideas both within a topic and across science disciplines. Chapter 1, the overview of this framework, provides a detailed definition of **systems [CCC-4]** in the CA NGSS. In brief, systems are a just a way of thinking about a small section of the world and the objects and processes that occur within that section. In this instructional segment, students practice defining systems, recognizing their components, and describing how they interact using examples at a range of scales from cells to organisms to the entire planet Earth.

INTEGRATED GRADE SIX INSTRUCTIONAL SEGMENT 1: SYSTEMS AND SUBSYSTEMS IN EARTH AND LIFE SCIENCE

Guiding Questions

- How are living systems and Earth systems similar and different?
- What is the value of creating a systems model?

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) 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.*]

INTEGRATED GRADE SIX INSTRUCTIONAL SEGMENT 1: SYSTEMS AND SUBSYSTEMS IN EARTH AND LIFE SCIENCE

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.*]

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-ESS2-6. 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.*]

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.

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-7] Engaging in Argument from Evidence [SEP-8] Obtaining, Evaluating, and Communicating Information	LS1.A: Structure and Function LS1.D: Information Processing ESS2.C: The Role of Water in Earth's Surface Processes ESS2.D: Weather and Climate ETS1.A: Defining and Delimiting Engineering Problems ETS1.B: Developing Possible Solutions	[CCC-2] Cause and Effect [CCC-3] Scale, Proportion, and Quantity [CCC-4] System and System Models [CCC-5] Energy and Matter: Flows, Cycles and Conservation [CCC-6] Structure and Function

INTEGRATED GRADE SIX INSTRUCTIONAL SEGMENT 1: SYSTEMS AND SUBSYSTEMS IN EARTH AND LIFE SCIENCE

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

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

CA CCSS Math Connections: 6.EE.9

CA CCSS for ELA/Literacy Connections: RST.6–8.1, R.I.6.8, WHST.6–8.1, 7, 8, 9, SL.6.

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

The scientific definition of a system differs from the everyday language definition. Students often equate systems with cycles such as a life cycle or a collection of orbits like the solar system. Rather than learning terminology and definitions first, students begin this instructional segment by exploring a situation that exemplifies the key features of systems. Students **obtained information [SEP-8]** about the massive experiment called *Biosphere 2,* where scientists placed plants, animals, and people in an airtight glass building to see what challenges they faced as they tried to survive together as a system. As an anchoring phenomenon for this unit, students learn about how the project failed when oxygen levels were unsafe and some animals died. After watching a short video that describes some of the events that occurred in the Biosphere experiment, students consider the question, What did the scientists in the Biosphere need to survive and where did they get it? For food, the people ate fish, But what did the fish need to survive and where did they get it? As students draw a system **model [SEP-2]** that traces out the exchange of energy and matter, they grapple with the key features of **systems [CCC-4]**: boundaries, components, interactions, inputs/outputs, and one or more system properties.

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 that has them write the reasons they consider it 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 that either confirm or refute it as a system, have them discuss the connections they gathered between their classroom example and textual evidence, including a definition. Ask students in their groups to revisit their classroom examples and reach consensus on whether or not each meets the criteria of a **system [CCC-4]** based on the five important features: boundaries, components, interactions, inputs/outputs, and one or more system properties.

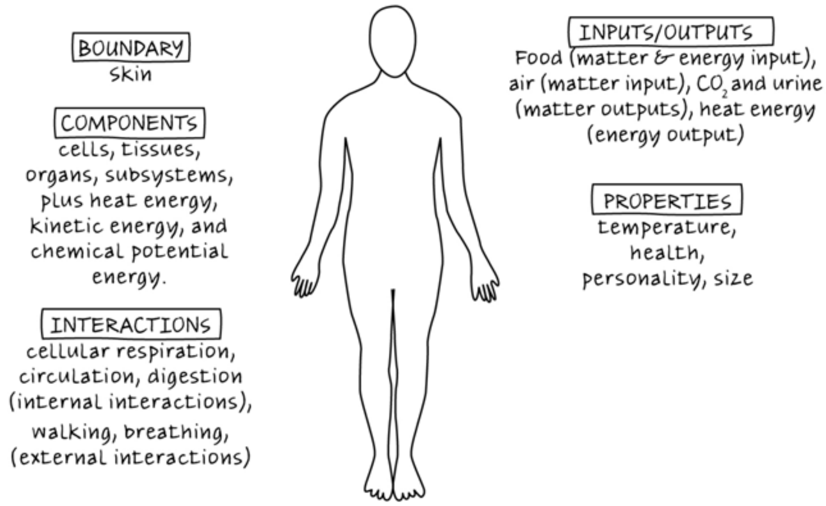
CA CCSS for ELA/Literacy Standards: RST.6–8.1, 2, 4; SL.6–8.1

CA ELD Standards: ELD.PI.6–8.1, 2

Human Body Systems

Next, students focus on their own body system (figure 5.2). Explicitly discussing the features of a **system [CCC-4]** is just the first step in creating a system **model [SEP-2]** that can explain different phenomena in a human body. For example, answering the question, Why does my heart race when I get scared? requires that students **obtain information [SEP-8]** about how different components of the body interact. Students trace the chain of interactions from the energy input to their system (via sense receptors) to low-level interactions in the nervous system to the endocrine system (transfer of energy as electrical impulses). The endocrine system then transfers matter into the circulatory system (adrenaline and other hormones) that stimulates the muscular system to react, enabling a body as a whole to run away from a dangerous situation. The brain also encodes these perceptions as memories to anticipate future problems (MS-LS1-8).

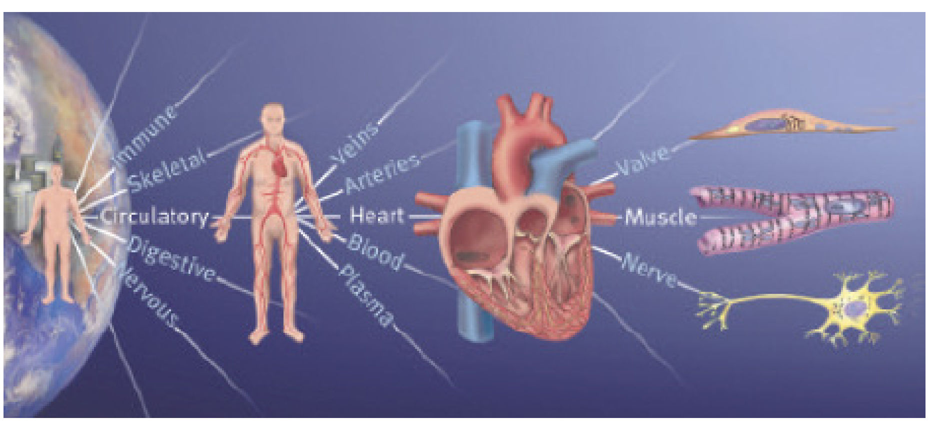
Figure 5.2. Features of a Human Person System



Source: From Making Sense of SCIENCE: Land and Water (WestEd.org/mss) by Folsom and Daehler. Copyright © 2012 WestEd. Adapted with permission.
Long description of Figure 5.2.

When tracing out these interactions within the body system, students uncover the middle school understanding: "Systems may interact with other systems; they may have subsystems and be a part of larger more complex systems" (NGSS Lead States 2013). In other words, the components of a system are generally themselves systems that are made of smaller components (figure 5.3). Students must be able to use examples of body phenomena to **support an argument [SEP-7]** that the human body has interacting subsystems (MS-LS3-1).

Figure 5.3. Systems Within Systems Within Systems



Body systems, such as the circulatory system, are examples of systems within systems within systems. *Source:* Sussman 2000
Long description of Figure 5.3.

Engineering Connection: Designing a Better Swing

Teaching about organ and tissue donation provides opportunities to connect learning about body **systems [CCC-4]** with a socially beneficial topic that also has strong connections with engineering and technology. Donate Life California has an informative Web site that includes educator resources, notably an Interactive Body Tour (see Donate Life California at https://www.cde.ca.gov/ci/sc/cf/ch5.asp#link2.)

Students can work in groups to research and learn about organ and tissue donation related to different body systems and diseases. They can create system diagrams related to the different diseases and transplantation remedies as well as representing the system for soliciting donors, identifying recipients, and getting the organs/tissues to the patients in excellent condition and within the necessary criteria and time constraints.

Students can also **evaluate [SEP-8]** how well the Web page motivates people to become donors. Without a large pool of potential donors, doctors won't be able to provide transplants to people that need them. Sharing these issues to policy makers and the public are important aspects of **communicating science [SEP-8]**. Students can also analyze donor recruitment as a system for which they can identify **constraints [SEP-1]** and propose **solutions [SEP-6]** to increase the number of people who volunteer to become donors. This kind of **system modeling [CCC-4]** extends the crosscutting concept beyond physical science and engineering into applications of science to social issues.

Components of subsystems can even be considered systems themselves when viewed at a smaller **scale [CCC-3]**. Students can focus in on a phenomenon that requires them to understand interactions at the level of an individual cell. For example, What happens to the body when someone gets cancer? Doctors have figured out that cancer occurs when a cell "malfunctions," so students will need to know what a cell is and how it normally functions. Students begin by **performing an investigation [SEP-3]** to gather evidence that living things are made of cells and nonliving things are not (MS LS1-1). Comparing microscope images of nonliving objects and different types of cells, students can identify similarities and differences between each of the cells. Then they **ask questions [SEP-1]** about the role of the parts they see: Why do red blood cells have no large circle in the center? Why is a sperm cell so small and an egg so big? Why do all plant cells have a thick wall around them but animal cells do not? Why do all plant cells have green circles in them but animal cells do not? With scaffolding from the teacher and other resources, they use their observations to **develop a model [SEP-2]** of what several parts of the cell do: the nucleus, mitochondria, chloroplasts, cell wall, and cell membrane. The clarification statement of MS-LS1-2 specifies this limited set of parts so that students can focus on the key structures that facilitate energy and reproduction, and the details of other organelles will not be assessed in the middle grades (students will expand their model in high school as part of the developmental progression of the CA NGSS). Students **obtain information [SEP-8]** from books or media about how **energy and matter [CCC-5]** flow into, out of, and within the cell system. Rather than the traditional assessment of having students label parts of the cell, students could use a cell diagram as a template for making a system **model [SEP-2]** with arrows and labels indicating **energy and matter flows [CCC-5]**. Students can return to the original phenomena of cancer in the context of their model of the cell, identifying the location where the cell malfunctions (the nucleus).

Students should not only be able to represent the system model of the cell, they should be able to use it to explain more complicated phenomena such as why people get thirsty when they eat salty foods. As with all systems, student can identify salt as the input of matter and then trace the cycling of the matter between the different components of the system (parts of the body). Using their knowledge of body systems, students can probably trace the flow of salt from their food to their blood, but they need to **ask questions [SEP-1]** about the possible **causes [CCC-2]** of the thirst sensation (e.g., Do you actually need to drink, or does the salt just trigger your nervous system into thinking that you need to drink?). As students discuss each possible cause, they use evidence to rule some of these ideas out. They then propose investigations that could test the remaining ideas. Students can **conduct an investigation [SEP-3]** to observe how cells react to water with different concentrations of salt (using plant cells rather than animals due to safety and logistical concerns). By thinking of the cell as a system, students can explain the shrinking of a plant cell in saltwater by the flow of matter out of the system.

The assessment boundary for MS-LS1-2 emphasizes that students should be able to explain the role the cell wall/membrane plays as the boundary of the cell system, and how its **structure supports this function [CCC-6]**. To refine their **model [SEP-2]** of cell boundary behavior, students use DCIs from physical science about how matter is made of particles (5-PS1-1). They can represent saltwater as a mixture of particles including water particles and "salt particles." Which flows across the cell wall (or membrane) more easily, water particles or salt particles? Even though a model with salt as a single particle is an oversimplification, it is consistent with what students know and have observed. For that reason, one could argue that applying this "incorrect'" model is more scientifically accurate in that it exemplifies the tentative nature of scientific models built on observable evidence. Students will revise this model of saltwater later in high school when they find that a single "salt" particle cannot explain the electrical conductivity of saltwater.

Earth Systems

The salt tolerance of plants is a topic for agriculture and also motivates a transition to looking at a larger system of systems, the planet Earth. What happens to plants near the coast when rising sea level brings salty water into the soil? Students can **obtain information [SEP-8]** about saltwater intrusion in coastal aquifers as an entry point into thinking about the entire planet Earth as a system of interacting subsystems. In grade five students learned that planet Earth can be thought of as four major systems (table 5.3). Some scientists argue that there should be a fifth sphere called the anthroposphere that highlights the importance of humanity and all its creations.

Table 5.3. 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

While in grade five, students focused on the functioning of each individual system. In the grade six they progress to understanding the Earth as a singular system where each of the Earth systems they learned about in grade five is now viewed as a component or subsystem of the larger scale planet system. Learners of all ages generally expect that definitions, especially those in science, should be precise and either/or. For example, the geosphere is *either* its own system or a component of a larger system, but not both at the same time. Older students of science often advance beyond rigid either/or thinking toward both/and nuances and complexity. In the case of saltwater intrusion, rising temperature in the atmosphere exchanges energy with water in the hydrosphere causing it to warm and expand. That water ultimately infiltrates into soil in the geosphere, where it becomes a part of groundwater. There, plant roots bring it into the biosphere. When thinking about Earth systems, water is commonly exchanged as output from one subsystem and input to a different one, but water is also considered a subsystem of its own (the hydrosphere). This ambiguity highlights how system boundaries can often be challenging to define. The person modeling the system (scientist, teacher, student) has the freedom to choose the boundaries of the system based upon the goal of the modeling. Table 5.4 indicates the boundaries that different people might choose when studying water on Earth based on different goals of their investigations. Students also gain insight into system boundaries by explicitly comparing the boundaries in body and cell systems to boundaries in the Earth system. Students can practice identifying the appropriate boundaries for investigating phenomena from other domains explored in earlier grades (e.g., What causes an egg to break when it drops? [PS2.A] Why do animals move into the city during a drought? [LS2.C] Why is gold so expensive? [ESS3.A]).

Table 5.4. Different System Boundaries for Investigating Water on Earth

INVESTIGATION TOPIC	SYSTEM BOUNDARY	MATTER INPUT/OUTPUT
Forecasting changes in the water cycle due to global warming	Planet Earth and all its subsystems	Very little water enters or leaves the planet
Predicting changes in sea level for known global warming scenarios	All Earth's oceans and ice	Rainfall and streamflow in, evaporation out
Tracking down the source of pollution in a creek	An entire watershed, including surface and groundwater	Rainfall enters, pollution enters, water flows out to the ocean and evaporates
Getting freshwater for a farm	Groundwater aquifer	Water soaking in from the surface, pumping out
Surfing at the beginning and end of the day	A local beach, including seafloor shape	Tidewater in/out (energy in from waves, out from crashing)
Cleaning a city's sewage before it drains into the ocean	City sewage treatment facility	Sewage in, clean water and waste out

Table by Dr. Art Sussman, courtesy of WestEd

Just as the boundaries between systems can be difficult to define, the boundary between IS1 and IS2 is also nebulous. The goal of IS1 is to deepen student understanding of systems and system models and therefore includes systems from several disciplines. Instructional segment 2 then goes into the details of system models of the water cycle and weather systems.

IS2

Integrated Grade Six Instructional Segment 2: Earth System Interactions Cause Weather

An integrated approach to weather phenomena investigates the causes of weather in terms of a PS understanding of energy transfer, the mechanisms of weather in terms of ESS systems, and the effects of weather on living systems. When drawing DCIs from all the disciplines, students apply their understanding of **systems [CCC-4]** from IS1. Students will consider **cause and effect mechanisms [CCC-2]** at a broad range of **scales [CCC-3]** from the level of particles of matter up through the entire Earth system.

INTEGRATED GRADE SIX INSTRUCTIONAL SEGMENT 2: EARTH SYSTEM INTERACTIONS CAUSE WEATHER

Guiding Questions

- Why is the weather so different in different parts of California?
- How is weather related to the transfer of energy?
- How do models help us understand the different kinds of weather in California?

Performance Expectations

Students who demonstrate understanding can do the following:

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-ESS2-6. 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.*]

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

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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.*]

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-ETS1-3. 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.

**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 [SEP-8] Obtaining, Evaluating, and Communicating Information	ESS2.C: The Roles of Water in Earth's Surface Processes ESS2.D: Weather and Climate PS3.A: Definitions of Energy PS3.B: Conservation of Energy and Energy Transfer ETS1.A: Defining and Delimiting Engineering Problems ETS1.B: Developing Possible Solutions ETS1.C: Optimizing the Design Solution	[CCC-3] Scale, Proportion, and Quantity [CCC-4] System and System Models [CCC-5] Energy and Matter: Flows, Cycles, and Conservation

INTEGRATED GRADE SIX INSTRUCTIONAL SEGMENT 2: EARTH SYSTEM INTERACTIONS CAUSE WEATHER

Highlighted California Environmental Principles and Concepts:

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

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

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

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

CA CCSS for ELA/Literacy Connections: SL.6.5, RST.6–8.1, 3, 7, 9 WHST.6–8.1, 7, 8

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

Different parts of California experience dramatically different weather. As an anchoring phenomenon for this instructional segment, students will consider how some parts of California are dry with desert vegetation while others are greener and wetter. When students examine a true color satellite image of California (figure 5.4), they notice the effects of weather patterns: green coastal ranges, brown deserts, fluffy white clouds, and snowcapped peaks of the Sierra. Students ask **questions [SEP-1]** about specific **patterns [CCC-1]** that they notice and what might **cause [CCC-2]** them. Understanding the processes that drive day-to-day weather can help explain these longer-term weather patterns. The vignette below describes a learning sequence that focuses on explaining the phenomenon of California's climate zones drawing in DCIs from Earth and space sciences and physical science. Students will look at this same phenomenon through a lens that also integrates life science during IS3 and IS4.

Figure 5.4. Satellite View of California

Source: NASA 2014
Long description of Figure 5.4.

INTEGRATED GRADE SIX VIGNETTE 5.1: INTERACTIONS OF EARTH SYSTEMS CAUSE WEATHER

Performance Expectations

Students who demonstrate understanding can do the following:

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-ESS2-6. 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.*]

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

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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.*]

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-3] Planning and Carrying Out Investigations [SEP-4] Analyzing and Interpreting Data [SEP-6] Constructing Explanations (for science) and Designing Solutions (for engineering) [SEP-7] Engaging in Argument from Evidence [SEP-8] Obtaining, Evaluating, and Communicating Information	ESS2.C: The Roles of Water in Earth's Surface Processes ESS2.D: Weather and Climate PS3.A: Definitions of Energy PS3.B: Conservation of Energy and Energy Transfer	[CCC-1] Patterns [CCC-2] Cause and Effect: Mechanism and Explanation [CCC-3] Scale, Proportion and quantity [CCC-4] System and System Models [CCC-5] Energy and Matter: Flows, Cycles and Conservation

CA CCSS Math Connections: 6.NS.7b, 6.NS.8, 6.EE.9, 6.SP.4

CA CCSS for ELA/Literacy Connections: RST.6–8.1, 4; WHST. 6–8.1, 7; SL.6.1, 2, 3

CA ELD Connections: ELD.PI.6–8.1, 9, 10b

Introduction

Weather phenomena naturally integrate all disciplines of science and engineering. Processes usually classified as "physical science" govern the movement and changes of matter, those classified as "Earth science" describe these processes at the macroscopic scale, and "life science" processes describe how organisms respond to these weather conditions. Engineers design solutions to minimize weather hazards and for building devices that gather detailed weather data (especially satellite imagery) that helps inform other scientists.

Days 1–2: What is Smoke/Fog/Steam?

Students make observations and ask questions about a mystery material.

Days 3–4: A Watched Pot Never Boils

Students collect data about how temperature changes as ice is heated until it melts and boils. They relate these observations to energy changes in different states of matter.

INTEGRATED GRADE SIX VIGNETTE 5.1: INTERACTIONS OF EARTH SYSTEMS CAUSE WEATHER

Days 5–9: Questions about California's Climate Zones

Groups of students research individual climate zones in California and report back to the class. Students ask questions about what they learn.

Days 10–11: Planning an Investigation

Students plan and conduct an investigation to compare the effects of heat on water versus air.

Day 12: Crafting an Explanation

Students create, critique, and revise a scientific explanation that explains their observations from the previous day's investigation.

Days 13–14: Analyzing Rainfall Data

Students make graphs showing the relationship between elevation and precipitation in California and relate these findings to changes of state from previous days.

Day 15: Explaining California Climate

Students synthesize their understanding from the previous three weeks to re-examine California's climate zones and explain the patterns they see.

Days 1–2: What is that Smoke/Fog/Steam?

Anchoring phenomenon: Students confront a mystery material that they describe as smoke/fog/steam.

In small group and whole-class discussions, students reviewed the reservoirs of the water cycle that they learned about in grade five. They described the physical state of water (solid, liquid, gas) in each of the reservoirs. However, even when they included the atmosphere as a reservoir of the water cycle, students tended to emphasize liquid water in clouds rather than the invisible water vapor gas in air.

Ms. L then got their attention by bringing out an insulated container with dry ice in it. She poured 91 percent isopropyl alcohol into the container to create an extremely cold bath that bubbled. Something visible formed and flowed around the insulated container. Students described it as smoke, fog, or steam. Ms. L challenged the students to make careful, detailed observations; to discuss these observations in small groups; and to make an **evidence-based [SEP-7]** claim about the nature of the smoke/fog/steam (SFS). She pointed out that while they were discussing, she put some small pieces of dry ice into a latex-free surgical glove, and tied off the end of the glove. That way the gloves captured some of the mystery SFS material so students could investigate its properties.

The students reached a general consensus that the SFS was visible, that it felt sort of cool and moist, and that it seemed to be flowing downwards around the container. They **argued with evidence [SEP-7]** that the SFS cannot be water vapor because it is visible. However, there was much more confusion than consensus about what the SFS could be.

When Ms. L lifted the hugely expanded glove, students laughed about its shape, and wanted

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to know more about the properties of SFS. Just before Ms. L cut one of the glove fingers to release the material, she asked students to predict what they expected to see. Ms. L never let her students make a prediction without explaining what influenced their expectation. She prompted students to describe what similar situation, background knowledge, and/or observations they based this prediction upon. Ms. L cut the glove and released the trapped material in a controlled manner. While they could see the glove deflating, students were surprised that nothing appeared to come out. After Ms. L extinguished a lit candle by "pouring" some of the invisible gas over it, they reached the conclusion that this material must be a gas denser than regular air. What was the relationship between the invisible gas and SFS? Had it somehow changed when inside the glove?

Students returned to their small groups to make a list of the most important observations and tried again to make **claims supported by evidence [SEP-7]** about the nature of the SFS. All the student groups realized that its visibility means that SFS could not be water vapor or carbon dioxide. Gradually, discussions within the groups and then between them resulted in the conclusion that SFS must be water drops that condense from water vapor in the air. One team shared a **model drawing [SEP-2]** that they made that illustrated a progression of three stages:

1. cold carbon dioxide gas flowing over the edge of the container and then sinking downward;
2. water vapor in the air cooling as the cold CO_2 gas contacted it;
3. the cooled water vapor condensing into small drops (fog).

Investigative phenomenon: Water in a test tube freezes when placed into the dry ice/isopropyl alcohol bath.

Ms. L concluded the lesson by putting a test tube of water with an inserted temperature probe into the dry ice/isopropyl alcohol bath. She showed how quickly the water froze. She called on students to read the temperature on the probe, and they noted that it was in minus degrees Celsius, meaning that it was colder than the freezing point of water. She took the test tube out and carefully suspended it in warm water. Students recorded the increase in temperature as the super-cooled ice warms towards zero degrees C.

Days 3–4: A Watched Pot Never Boils

Investigative phenomenon: When ice is heated until it melts and boils, the temperature does not increase steadily the entire time.

The following day the students reviewed their observations of the super-cooled ice. Students then worked in teams to slowly and steadily heat a mixture of ice and water. They recorded the temperature every minute and also wrote a description about how much the ice

INTEGRATED GRADE SIX VIGNETTE 5.1: INTERACTIONS OF EARTH SYSTEMS CAUSE WEATHER

was melting each time. The handout that she provided included a data table for recording temperature, elapsed time, and whether melting was happening. For safety reasons, the students stopped their experiments when the temperature of their water reached 45°C.

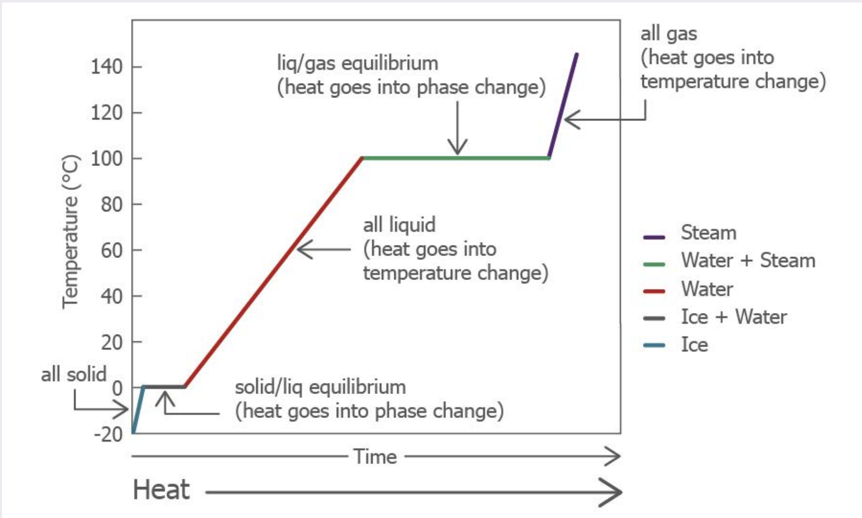
Using graph paper, each student team created a labeled graph and entered their data on the graph. The students generally obtained graphs that showed a mostly flat temperature line near 0°C during the time of melting, and then a steady rise in temperature after all the ice melted.

Ms. L then asked the teams to predict on their graph what it would look like the next day when she would demonstrate heating the water until it boiled and while it kept boiling. They also needed to note on their prediction when the boiling would happen just as they had noted when the ice was melting.

The following day the teams shared their predictions and their reasoning. Then Ms. L demonstrated the heating of water to the boiling stage and for a period of continued boiling. Students recorded the observed temperatures on their graphs and compared the observations with their predictions. At the end of the demonstration, students discussed the results as a whole class.

The next day, Ms. L projected a graph of changes in the state of water that was posted on the Web by a chemistry teacher. Students discussed this graph in small groups, and wrote explanations for what they thought was happening in the parts of the graph labeled A, B, C, D and E (figure 5.5).

Figure 5.5. Temperature Changes When Constantly Heating Ice



Continuously adding thermal energy increases the temperature from supercooled ice to superheated steam. Heating does not cause the temperature to significantly increase during the state changes of melting (B) and boiling (D). Heating when there is no state change happening results in temperature increasing (A, C, and E).
[Long description of Figure 5.5.]

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The students consistently identified temperature as a measure of the average kinetic energy of invisible particles of water. They correctly related higher temperatures with increased particle motion, and lower temperatures with decreased particle motion. Using data from their own experiments and the teacher's demonstration, students readily **explained [SEP-6]** that the upward lines occur when there is no state change happening. They also readily observed that the flat lines at B and D occur when there was a state change happening. However, they had a hard time clearly explaining why the temperature did not increase during melting and boiling even though more thermal energy was being added.

Ms. L then displayed a graphic showing the state changes as equations (figure 5.6). She walked students through the example of melting, pointing to each component as she described it: "If you start with water as a solid (ice) and add energy, you get liquid water." Then, she asked students to identify which of the equations applied to the day's observations. Once they identified the right equation, she told students to use that equation to **explain [SEP-6]** why the temperature remained fairly constant during evaporation even though thermal energy continued to be added. After five minutes, one of the student group started clapping and cheering. Other students asked them what happened.

Figure 5.6. Equations Representing State Changes in Water

Evaporation:	Water (liquid) + Energy ➔➔➔ Water (gas)
Condensation:	Water (gas) ➔➔➔ Water (liquid) + Energy
Melting:	Water (solid) + Energy ➔➔➔ Water (liquid)
Freezing:	Water (liquid) ➔➔➔ Water (solid) + Energy

Evaporation and melting involve absorption of thermal energy. In contrast, condensation and freezing involve the release of thermal energy. Illustration by Dr. Art Sussman, courtesy of WestEd.

Long description of Figure 5.6.

One student stood up and said that they thought they had finally explained it, but didn't know if they could repeat the explanation. After encouragement, they said, "The hot plate kept giving off thermal energy. Usually that makes the water particles move faster, so then the temperature went up. But once the water boiled, the hot plate energy made the boiling thing happen instead of making the particles move faster. So then the temperature did not change. I think I just said that the right way, didn't I?"

INTEGRATED GRADE SIX VIGNETTE 5.1:
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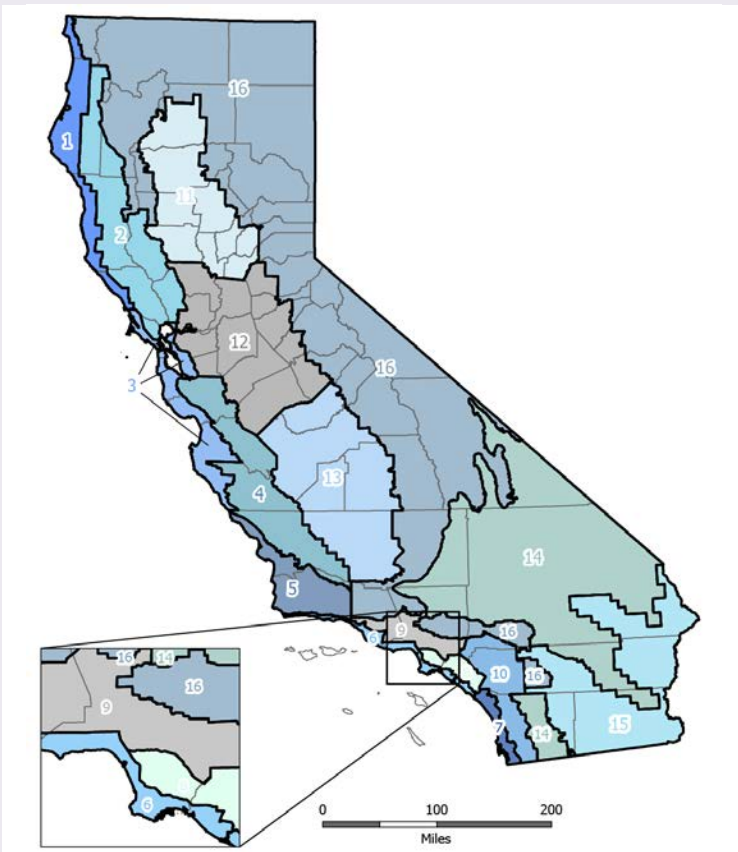
Days 5–9: Questions about California's Climate Zones

Investigative phenomenon: California has different climate zones

Ms. L began the next set of lessons by asking students how many different kinds of places they knew about in California. The conversation led to a beginning list with names of some cities, and also some descriptions based on types of natural environments (beach, mountain, desert, redwood forest). She then distributed a map showing 16 different California climate zones (figure 5.7). Students worked in eight groups to identify the previously listed locations on the map and any new locations that the map made them think about. They also discussed what they thought a "climate zone" meant.

Figure 5.7. California Map Showing 16 Different Climate Zones



California can be described as having 16 different climate zones. *Source:* California Energy Commission 2015

Long description of Figure 5.7.

INTEGRATED GRADE SIX VIGNETTE 5.1: INTERACTIONS OF EARTH SYSTEMS CAUSE WEATHER

After the students had time to engage with the task and do a preliminary sharing with the whole class, Ms. L provided a handout describing eight representative zones that she condensed from the *Pacific Energy Center's Guide to California Climate Zones*. She used a combined student-choice/teacher-assignment technique to allocate the eight zones among the groups. Each team researched one climate zone and developed posters **communicating [SEP-8]** key features about their climate zone including topography, geographic location, distinctive climate features, and representative graphs of annual temperatures and precipitation.

Students shared and learned about the different climate zones through a gallery walk of the posters, listening to presentations by the groups, and **asking questions [SEP-1]**. Most of the student questions were about factual matters at first, so Ms. L encouraged students to ask about the relationship between different features (i.e., "Your picture shows a flat desert. Is the desert dry because it's flat?") or to compare one geographic region to another (i.e., "Why is your region so much hotter than my region during June when they have such similar temperatures in December?"). Facilitated whole-class discussions helped summarize the differences between weather and climate, the different climate zones in California, and possible **causes [CCC-2]** for the differences in annual temperatures and precipitation. Students highlighted key **patterns [CCC-1]** (e.g., **effects [CCC-2]** of latitude, altitude, closeness to the ocean, and closeness to mountains). Student teams also recorded any **cause and effect [CCC-2]** or "why" questions they had about the data.

Toward the end of the week, each team shared their "why" **questions [SEP-1]**. The questions tended to cluster into four groups:

- Why it is so much colder in Northern California than in Southern California even though they are both in the same state?
- Why do places near the ocean have temperatures that change less between day and night?
- Why do higher altitudes have so much rain?
- Why are deserts located where they are?

Ms. L concluded this discussion by saying that they would conduct some investigations during the next week to help answer the last three questions, and that they would cover the first question in their next instructional segment about climate around the world.

Days 10–11: Planning an Investigation

Investigative phenomenon: Air heats up faster than water.

At the start of the third week, Ms. L provided students a procedure to **investigate [SEP-3]** differences between heating air and heating water. They used an electric light to heat two identical bottles closed with rubber stoppers. One of the bottles was filled with water and the other bottle is filled with air. Their task was to record and graph the temperatures for 10 minutes while the light was on and then another 15 minutes after turning off the light. Ms. L

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found that her students took poor-quality measurements when they did not understand the procedures. While one approach was to ask students to plan the entire investigation themselves, she found that they were not quite ready at this point in the school year to design sophisticated investigations. Ms. L developed a technique to scaffold the planning of investigations. Her handout of procedures had two columns—one with the procedures and a second one with the label “reason for this step” that also had blanks for students to record data. Ms. L demonstrated how to fill in the table by demonstrating what she would write as the justification of step 1. For step two, she wrote two possible justifications and asked the students to select the explanation that they think was most clear. For step three, she wrote an incomplete reason and asked students to evaluate why the explanation was insufficient. Ms. L then had students work in groups to record the reasons for the remaining steps. Ms. L called their attention to the data sheet and labeled graph that she had included in the written procedures. She told them that in future experiments, student teams would design their own data sheets and graph labels. Before students recorded any actual data, she had them draw a sketch of what they thought the graph would look like after the experiment. As she circulated around the room, she prompted students to add labels to their sketches to indicate what might cause key changes in their graph.

Both bottles started at a temperature of 20°C. With the light on, the temperature in the air bottle increased on average to 55°C while the temperature in the water bottle only increases on average to 23°C. After the lights were turned off, the air bottle temperature generally decreased about 30°C, while the water bottle decreased on average only 1.5°C. Ms. L had the students compare their prediction to the actual observations and discuss whether anything was unexpected.

After **conducting the investigation [SEP-3]**, each student team created and displayed a poster showing their results. In the poster, each team made a claim about the differences between heating air and heating water, and they wrote or illustrated the **evidence [SEP-7]** for their claim. After a gallery walk and whole-class discussion, the class reached a consensus claim that the same amount of added thermal energy **caused [CCC-2]** the temperature of air to increase much more than the temperature of water, and that the water released its thermal energy much more slowly than the air did.

One student group agreed with the statement about the increase in temperature. However they **argued that the evidence [SEP-7]** for a difference in cooling was very weak. It is not fair, they point out, to compare cooling from 55°C with cooling from 23°C. Ms. L took this unplanned opportunity of the excellent student critique to ask if there was a way to make a better comparison of the cooling rates of air and water. Several student groups proposed pre-heating bottles of air and water to the same temperature, and then comparing their rates of cooling. A team of students volunteered to demonstrate the experiment the following day. Their subsequent demonstration confirmed that the same volume of water cooled at a much slower rate than the same volume of air. Since thermal energy depends on the amount of the material (its mass) rather than the volume of material, the student comparison was not the

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most scientifically accurate. MS-PS4-3 requires that students be able to design an experiment that holds mass constant, but Ms. L was happy to see that her students recognized the need for consistency when they used equal volumes of material.

Investigative phenomenon: A small amount of water heats up faster than a larger amount of water in a beaker.

She pointed out to students that the bottle with water feels much heavier and wondered if that has something to do with it. This prompted another demonstration comparing two different masses of water. Students completed this exercise realizing that both the amount (mass) of the material and the type of material affect how quickly its temperature changes.

Day 12: Crafting an Explanation

Everyday phenomenon: Coastal towns have mild climates while inland valleys have temperature extremes.

Ms. L challenged her students to use the key ideas from their investigation to **explain [SEP-6]** the **pattern [CCC-1]** that California locations near the ocean have less variation in day/night temperature than locations farther away from the ocean. Each team then **communicated [SEP-8]** its explanation and reasoning to a different team. The process of creating, critiquing, and revising these explanations took an entire class period.

Days 13–14: Analyzing Rainfall Data

Everyday phenomenon: It rains and snows a lot in the mountains.

Having discussed the temperature differences among California regions, students transitioned to their questions about the precipitation differences. Students knew it snows in the mountains, so Ms. L decided to have them investigate the amount of rainfall in east-west transects across California. Students obtained rainfall amounts from an online database by clicking stations on a map (see California Data Exchange Center at https://www.cde.ca.gov/ci/sc/cf/ch5.asp#link3). For each station, the database reported the latitude, longitude, monthly rainfall, and the elevation of the station (along with other weather data). Students made a graph of rainfall versus longitude and a graph of elevation versus longitude (figure 5.8). Because they wanted to compare the shapes of the two curves, Ms. L taught students how to plot the two lines on the same graph using different vertical axes.

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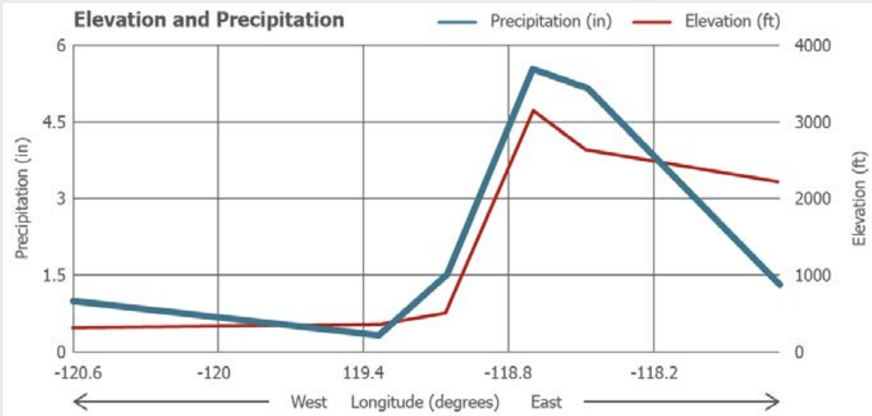
Figure 5.8. Profile of Annual Rainfall Across California Heading East From San Luis Obispo

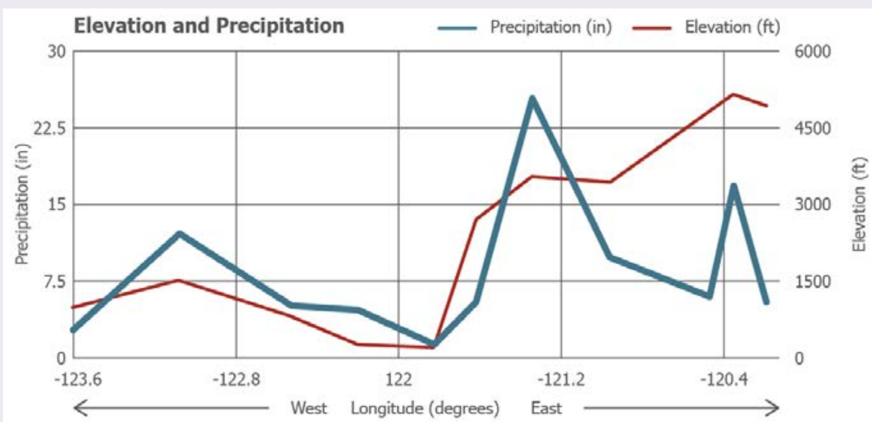


The thinner red line shows the elevation at each point. Chart by M. d'Alessio with data from California Department of Water Resources 2015

Long description of Figure 5.8.

Different students plotted different locations in California and they all discovered a remarkable **pattern [CCC-1]** where the rainfall seemed to go up as elevation went up (figure 5.9).

Figure 5.9. Profile of Annual Rainfall Across California Passing through Chico



The thinner red line shows the elevation at each point. Chart by M. d'Alessio with data from California Department of Water Resources 2015

Long description of Figure 5.9.

When Ms. L asked students to explain what caused this relationship, students came up with some crazy theories. Students did know that it tends to be colder in the mountains, so Ms. L asked them to relate this idea back to the condensation they learned about earlier in the lesson sequence. What happened to water when it got colder? Ms. L asked students to

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write an explanation in their science notebooks that responded to the prompt, "It rains more at higher elevations because______." In the middle grades, their model was relatively simplistic and did not include the effects of relative humidity, but they were able to tie together many of the essential concepts.

Some students noticed that the eastern part of the graphs tended to be high elevation, but the rainfall was lower there. They **asked questions [SEP-1]** about what could cause this pattern. Ms. L showed them animations of satellite maps of atmospheric moisture and precipitation for several storms moving across California. The storms tended to move from west to east, with the precipitation stopping as the storm moved to Eastern California. Ms. L introduced the idea that the matter had moved. Students needed to develop a conceptual model to describe the movement of water in space and time through all these different forms.

Based on the California climate data that they had learned, each of the student teams drew a systems **model [SEP-2]** of the water cycle for a location in their assigned climate zone during two different seasons of the year. As a class, they began by reviewing the features of a systems diagram (boundary, components, inputs/outputs, interactions, and system property).

After the student teams completed their initial models, Ms. L initiated an activity that helped them create more accurate and complex water cycle diagrams. She knew from experience and research that while students often can list where water is located, they tend to have limited or simplified ideas about the dynamic nature of the interconnections among these reservoirs. For example, even though they may have seen clouds disappear because of evaporation of their water back into the atmosphere, they tend to think that water in clouds can only precipitate (Ben-zvi-Assarf and Orion 2005). Students also tend to forget about all the possible pathways water can take to leave a reservoir. For example, they tend to model water in a river as only flowing into the ocean, whereas in reality the river water can evaporate, soak into the ground, or be taken into the body of a plant or animal.

To help students consider these complexities, Ms. L led students through a simple kinesthetic game. Each student played the role of a water particle (or H_2O molecule if students are comfortable with that terminology) and moved around the room through different stations that represented different places where water is located (ocean, soil, plant, atmosphere, cloud, mountain glacier, polar ice cap, etc.). At each station, the student rolled dice and read from an instruction sheet whether to stay at that station for another turn or move to a different station as part of a water cycle process. In essence, the students used their own bodies as components in a physical **model [SEP-2]** of all the processes of the water cycle.

After the exercise, students commented about it and summarized what they learned. Key points included

- the number of inputs and outputs for the different reservoirs;
- the different residence times in the reservoirs;
- the changes in state associated with the water cycle interconnections;
- the cyclical, rather than linear, nature of the water cycle; and
- the role of gravity in **causing [CCC-2]** precipitation, downhill flow of surface water, infiltration of surface water into the ground, and downhill flow of glacial ice.

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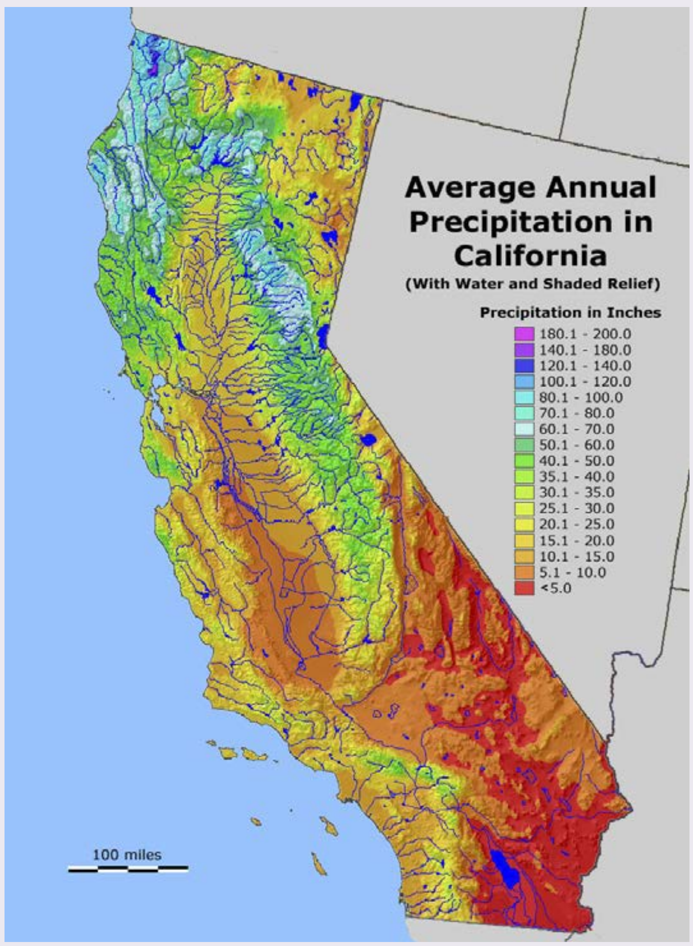
After this kinesthetic lesson, student teams returned to their regional water cycle diagrams and incorporated more of these interconnections, inputs and outputs. Students then shared their regional water cycle diagrams, critiqued and extended each other's presentations, and achieved a more complete group understanding of water reservoirs and processes. As a whole class activity, they created a color-coded map representing the average annual precipitation that included all of their California regions. To create this representation, they needed to collaborate on deciding the range of values to use, and how to represent the entire spectrum of data. They compared their whole-class model with a representation that Ms. L had downloaded from the Internet (figure 5.10), which they then used to complete and revise their state map.

Figure 5.10. Map of Average Annual Precipitation in California



Color-coded map of average annual precipitation in different California regions with mountains indicated by shaded relief. *Source:* Geology Cafe 2012
Long description of Figure 5.10.

INTEGRATED GRADE SIX VIGNETTE 5.1: INTERACTIONS OF EARTH SYSTEMS CAUSE WEATHER

Day 15: Explaining California Climate

The lesson sequence concluded with presentations that the class made for different audiences about California climates. In each presentation, students highlighted the **patterns [CCC-1]** of temperature and precipitation in each of the eight California regions that they had investigated. They also **explained [SEP-6]** the different factors that were involved in **causing [CCC-2]** significant climate patterns such as the comparatively small variation in coastal day/night temperatures, high levels of mountain precipitation, and the rain shadows of coastal mountains and the Sierra Nevada on the Central Valley and on Eastern California respectively.

Vignette Debrief

In this multi-week vignette, students applied physical science concepts to explain an Earth and space science observation about climate and a life science observation about habitats. Ms. L struggled with how long to spend on each section but quickly realized that spending even three weeks on this learning sequence felt rushed. She allowed students to plan their own experiment, grapple with revising their models of changes of state, and construct well thought out scientific explanations with evidence and reasoning; all these activities took much longer than she thought. But her assessment of student work showed that students gained a much better understanding using this student-centered approach than when she sped through things, as in previous years.

This vignette illustrates the CA NGSS vision of blending SEPs, DCIs, and CCCs. Ms. L began each part of the lesson sequence with an engaging phenomenon and spent each lesson applying the three dimensions. While the lesson describes this blend, the sections below focus on relevant aspects of each dimension in isolation, along with ties to the CA CCSS and the EP&Cs.

SEPs. As the students became more engaged with the content and comfortable with the underlying physical science concepts, they began to have larger roles in **designing and conducting the investigations [SEP-3]**.

DCIs. Days 1–2 focused on different states of matter (PS1.A) and the definition of thermal energy (PS3.A). Students built on this definition on days 3–4. On days 5–9 the focus was on general observations of weather and climate in California (ESS2.D). On days 10–12, they explored the relationship between thermal energy, states of matter, and a particle model of matter (MS-PS1-4). On days 13–15, students engaged in integrating the physical science and Earth and space science ideas, using the PS mechanisms to explain ESS phenomena.

CCCs. In the process, students developed system **models [CCC-4]** of their regional climates and engaged with key factors that **cause [CCC-2]** climate patterns, such as increased precipitation at high elevations. The observed weather and climate effects in California of latitude, altitude, proximity to the ocean, and locations of mountains all set the stage for deeper explorations in IS2 and IS3 of the **patterns [CCC-1]** that determine regional climates (MS-ESS2-6).

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EP&Cs. As written, Ms. L did not explicitly address any of the EP&Cs, though students will build on their understanding of California climate later in the course when they consider human impacts to the Earth system. Her focus on explaining the California climate is important because it provides a familiar context and on day 9 students were able to ask informed questions based on their own experiences.

CA CCSS Connections to English Language Arts and Mathematics. On day 4 and days 13–14, students focused on developing and interpreting graphs (6.SP.4). Students obtained and evaluated information about California's climate zones on days 5–9. Students engaged in structured discourse with teams throughout the vignette, including evaluating and reviewing the ideas of their peers on days 5–9 and again on day 15 (SL.6.1). They practiced writing an informational text with the explanation on day 12 (WHST. 6–8.1, 7).

Resources:

Ben-zvi-Assarf, Orit, and Nir Orion. 2005. "A Study of Junior High Students' Perceptions of the Water Cycle." *Journal of Geoscience Education* 53 (4): 366–373.

California Energy Commission. 2015. California Building Climate Zone Areas. https://www.cde ca.gov/ci/sc/cf/ch5.asp#link4

Geology Cafe. 2012. Precipitation and Relief Map of California. https://www.cde.ca.gov/ci/sc/cf/ch5.asp#link5

The Water Cycle in the Earth System

In IS1, students looked at Earth's systems and began to consider the water cycle that involves all of them. When students consider all the places that they see water in its many forms, water is often moving (raindrops fall, a river flowing, steam rising, etc.). In IS2, students investigate the physical mechanisms that drive this process. MS-ESS2-4 highlights the special role of sunlight in driving the state changes that occur as water moves in multiple pathways between the reservoirs of the water cycle. The first learning sequence in the IS2 vignette focused on these state transitions and the associated movements of thermal energy, almost all of which entered the Earth system in the form of sunlight.

The force of gravity also **causes [CCC-2]** movement of water between reservoirs of the water cycle. Most students can explain the role of gravity in causing precipitation ("raindrops fall") or surface water ("rivers flow downhill"), but they often overlook the crucial role that gravity plays in the infiltration of surface water into the groundwater, the flow of groundwater itself through tiny pores (similar to the way a saturated sponge drips water down out of the bottom), and the flow of ice downhill in glaciers (illustrated by time-lapse videos of glacier movements).

Opportunities for ELA/ELD Connections

To reinforce these **cause and effect relationships [CCC-2]** involving gravity and sunlight, engage students in understanding the water cycle processes by investigating the levels of the tides in one coastal city. After identifying and documenting **patterns [CCC-1]** in the tides and the position of the Sun and Moon, students use a cause and effect chart to illustrate the role that gravity plays in causing water to move between reservoirs in the water cycle such as the ocean and a nearby estuary. Students then create a commercial to pitch to local fishermen on the best time to fish according to the tidal patterns of that coastal city. Provide feedback on the student-created commercials to make sure they include appropriate vocabulary and accurately demonstrate actions that convey the roles of gravity and sunlight on tidal patterns.

CA CCSS for ELA/Literacy Standards: WHST.6–8.4; SL.6–8.1, 4, 5
CA ELD Standards: ELD.PI.6–8.9

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 to add to its own supply (Klausmeyer and Fitzgerald 2012). In this way, California itself can be considered a **system [CCC-4]** with inputs and outputs. Of the developed water supply for the state, more than 75 percent of it goes to agriculture and helps California grow more food than any other state.

Integrated Grade Six Snapshot 5.1: 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. Recently, 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 is 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 tap water. Students observed

Integrated Grade Six Snapshot 5.1: What's in the Water?

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 amount of contamination in a water sample. Each group constructed a bar graph showing the relative amount of contaminants and then compared their measurements to the other groups. Were the differences related to the measurement technique or to 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.

Water is one of California's most important natural resources (ESS3.A). 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 evaluated how their water compares to another city (such as Flint, Michigan which experienced unacceptable levels of lead contamination in 2015). They learned the distinction between organic contaminants (like bacteria) and inorganic ones (like lead and arsenic). To link to PS1.A (Structure and Properties of Matter), students drew a diagram in which they **modeled [SEP-2]** the liquid water and heavy metals as particles too small to be seen that move and interact. They used this model to address the question, Why does the solution appear clear and clean when it is actually contaminated? Inorganic contaminants such as heavy metals often take many years to cause observable health effects, so Mrs. N decided to focus on infectious diseases with their short-term health impacts.

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

While students could see the differences in both the real-life water and the 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 cholera and typhoid. An outbreak in 1850 may have killed 15 percent of Sacramento residents (Roth 1997).

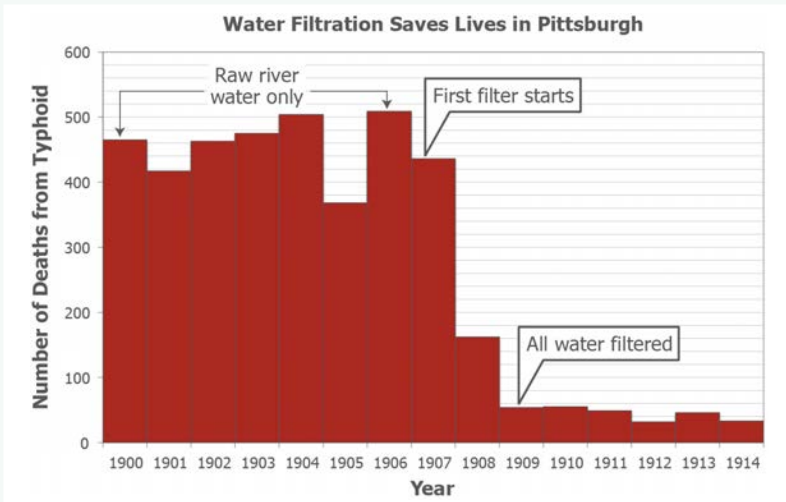
Investigative phenomenon: When Pittsburgh installed a citywide water filtration system, the number of people dying from disease dropped within a year or two.

Sacramento was not an unusual situation. Infectious diseases were a major problem in U.S. cities until midway through twentieth century. Mrs. N was born in Pittsburgh

Integrated Grade Six Snapshot 5.1: What's in the Water?

where the rate of death from diseases in 1900 was the highest of any major U.S. 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 ten within two years (figure 5.11). Mrs. N emphasizes ETS2.B ("Influence of Engineering, Technology, and Science on Society and the Natural World").

Figure 5.11. Effect of Water Filtration on Typhoid Deaths in Pittsburgh



Source: Adapted from Pittsburgh City Photographer 1917.
Long description of Figure 5.11.

Mrs. N wanted to make sure that students were able to see the connection between the water-filtration technology, the diseases, and the 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 in the following week they would design and test their own water filters.

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 people releasing materials like sewage into a river is called water pollution. She asked students if they are 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 dripped from cars that then flowed down the gutters on the street and into the storm drains. One of the students mentioned that she had 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

Integrated Grade Six Snapshot 5.1: What's in the Water?

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 (the discussion sets the stage for the grade eight performance expectation MS-ESS3-4).

Mrs. N asked students if they think that we still dump our sewage into rivers and water. They then learned more about modern wastewater treatment (see "Our Water: Sources and Uses" at https://www.cde.ca.gov/ci/sc/cf/ch5.asp#link6) in preparation for a trip to a local wastewater treatment plant.

Physical Science Models of the Water Cycle

Students experience the water cycle as everyday weather, and the process of weather forecasting is one way that scientists use measurements to model and predict interactions in the water cycle. Students can explore weather forecasts and weather maps and notice the different variables being tracked, especially temperature. Weather is ultimately driven by uneven heating of the planet. How do these temperature differences cause air movements that drive weather changes? In grade five, students learned that objects that they could see or touch have kinetic energy when they move and that matter is made of particles too small to be seen. In grade six, students combine these ideas to show how temperature is just kinetic energy at the invisible scale of particles. The snapshot below presents a phenomenon that allows students to begin to relate motion at the macroscopic scale to motion at the microscopic scale and temperature.

Integrated Grade Six Snapshot 5.2: Motions and Thermal Energy

Anchoring phenomenon: Our hands warm up when we rub them together.

Mr. A began IS2 by eliciting what students knew about the forms and transformations of energy based on daily experiences or what they remembered from classroom investigations in grades four and five. He steered student small group discussions toward phenomena in their daily lives such as the warming effect of rubbing hands together or doing vigorous exercise. Building on those kinds of experiences, students **conducted investigations [SEP-3]** that connected motions of objects with changes in thermal energy. Mr. A emphasized these **energy [CCC-5]** transformations because these experiences from our macroscopic level of reality are necessary to help students connect the motion energy of invisible particles with the observed temperature of materials.

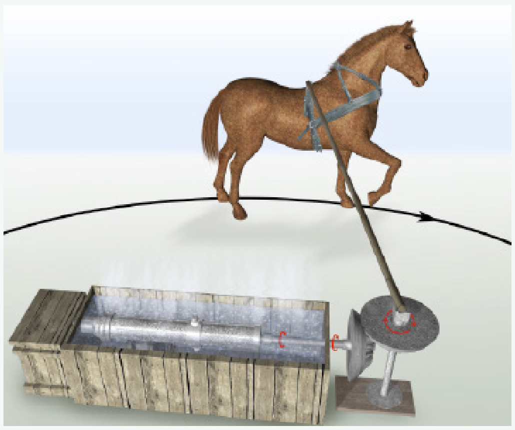
Investigative phenomenon: Count Rumford showed a horse was able boil water by running around in circles to turn a metal cylinder.

For homework, students read an illustrated one-page handout about a scientific paper published by Count Rumford in 1798. Count Rumford was born with the name Benjamin Thompson in Massachusetts. During the War of Independence, Thompson fought for the British against the American revolutionaries, and had to flee from his home to save his life.

In Europe after the war, Thompson became famous as a scientist and inventor and he was honored with the title and name of Count Rumford. In one famous public experiment, Count Rumford used the process of making a cannon to investigate the change of motion energy to thermal energy. He set up an experiment in which a horse trotting in a circle caused a metal borer to dig a hole into an iron cylinder that was completely covered with water (figure 5.12). All the people watching were amazed when the friction of the borer grinding into the cannon **caused [CCC-2]** the water to boil.

Integrated Grade Six Snapshot 5.2: Motions and Thermal Energy

Figure 5.12. Count Rumford's Energy Conversion Experiment



The kinetic energy of a horse moving in a circle heated water surrounding a cylinder of iron so much that the water boiled without any fire. *Source:* Sussman 2006

Long description of Figure 5.12.

The day after the homework reading, the students in small groups discussed the **flows of energy [CCC-5]** that were involved in the making of the cannon. They diagrammed the **cause and effect [CCC-2]** relationships that were happening at the macroscopic level (horse, metal boring machine, water) and also at the invisible level of the water particles. After extensive small-group and teacher-facilitated whole-class sharing of diagrams and discussions, they reached the following consensus statements:

- The motions that the people saw caused the heating and boiling that they could feel and see.
- At the macroscopic level (our level), kinetic energy of the horse was transferred to kinetic energy of the iron boring machine, which was transferred to thermal energy of the water.
- At the particle level, kinetic energy of the boring machine was transferred to kinetic energy of the water particles.

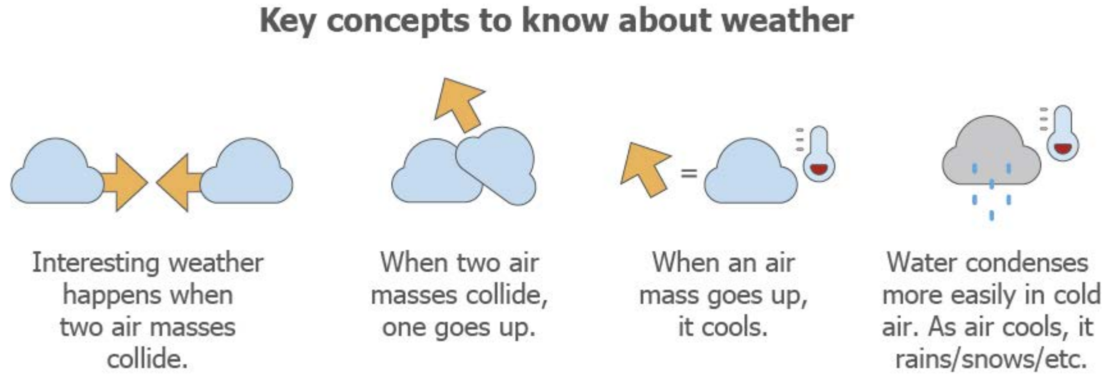
The following day, Mr. A introduced the design challenge for students in teams of three to **design, construct, and test a device [SEP-6]** that either minimized or maximized the transfer of thermal energy. Mr. A facilitated a whole-class discussion about constraints (such as safety, cost, class time, and availability of materials and equipment) and criteria for success. Student teams brainstormed the materials and the **flows of thermal energy [CCC-5]** that they would investigate. In their initial design proposal, they specified the materials and processes they would use and how they would test their devices. Student teams provided most of the feedback to each other, with Mr. A intervening only as absolutely needed to keep the teams on task and within the criteria and constraints. The engineering challenge concluded with student teams presenting and comparing their project results and how their projects developed over time.

Students need opportunities to investigate how different materials respond to heating (solids such as ice melting, liquids such as a pot of miso soup, gases such as a flask with a balloon on top, or a comparison of soil and water being heated). After initial observations of the phenomena, they should determine ways to systematically monitor the mass and temperature to see if changes in either of these quantities can help explain the macroscopic behaviors they see (MS-PS3-4). As they **analyze their data [SEP-4]**, they find that mass is unaffected by heating or cooling changes, but temperature changes are systematically based on the amount and type of material. With scaffolding, students can be prompted to try to **apply a model [SEP-2]** of matter made up of tiny particles to **explain [SEP-6]** each of the phenomena, slowly enhancing their understanding of the **conservation of matter and flows of energy [CCC-5]**. Students refine these models using computer simulations of solids, liquids, and gases, observing relationships between temperature and particle motion in the simulation (PhET https://www.cde.ca.gov/ci/sc/cf/ch5.asp#link7). Students will return to these models in grade seven (MS-PS1-4). In grade six, students can use this conceptual model to **explain [SEP-6]** how air masses become less dense as they warm up, and how particle motions change as matter changes state between solid, liquid, and gas. These simulations also introduce students to the physical basis of air pressure. Density and pressure differences along with state changes drive air movements and precipitation.

Explaining Weather Patterns

Students then use their models of the water cycle, air pressure, and state changes to investigate specific weather patterns. Using animations of real-time observations (such as satellite data from visible light that reveals clouds and other wavelengths that reveal water vapor; see Geostational Satellite Server: GOES Western U.S. Water Vapor at https://www.cde.ca.gov/ci/sc/cf/ch5.asp#link8), 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; figure 5.13). They also use these maps to predict the motion of air masses and predict the weather. 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.

Figure 5.13. 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 5.13.](#)

These same physical principles allow students to explain weather patterns within California. Why does it rain and snow more at higher elevations than lower elevations in California? Why is the temperature near the coast milder than areas further inland? Why is it cooler in the mountains than lower elevations? The EEI Curriculum unit *Precipitation, People, and the Natural World* at https://www.cde.ca.gov/ci/sc/cf/ch5.asp#link9 provides a variety of resources that can support this instruction.

Students may be able to share based on personal experience that mountain temperatures tend to be cooler than temperatures at lower elevations. A very important climate consequence of the colder temperatures at higher altitudes is that rising air becomes colder and can hold less water vapor. As a result of this cooling, water condenses, clouds form, and there is a much greater likelihood of precipitation in the forms of rain or snow. The **analyses [SEP-4]** of California climate regions revealed this correlation of increased precipitation with higher elevations.

Two generalizations could emerge from consistent research. If wind from a moist area is blowing toward a mountain range, it is very likely that there will be high amounts of precipitation on the side of the mountains that the winds first hit (called windward or upwind). The other side of the mountain (leeward or downwind) tends to be much drier because most of the water vapor has condensed and precipitated on the other side of the mountain. On the other hand, if the wind blowing toward the mountain has very low humidity, then it is likely that both sides of the mountain will be dry. This condition tends to occur in the middle of continents or locations where the prevailing winds tend to blow toward the ocean.

The temperature and amount of humidity in a mass of air reflects where that mass of air first formed. If it first formed over a warm ocean, the air mass will be warm and humid. If it first formed over a dry continental area, the air mass will be dry and its temperature will depend on whether the continental area was hot or cold.

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 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 [SEP-6]** **patterns [CCC-1]** with less time devoted to memorizing symbols.

Engineering Connection: Finding the Optimal Site for a Wind Farm

As air masses move, they go up, over, or around mountains. The landscape shape therefore has a big impact on wind speeds. Students **analyze data [SEP-4]** showing the average wind speed at different locations around their city. They look for **patterns [CCC-1]** that provide evidence that the landscape shape influences wind speed. Using information about topography and typical wind speeds and directions, they determine the optimal placement of a wind farm that could provide clean energy for their city. They might also need to consider human constraints such as how the land is currently used and who owns it (EP&C V).

Integrating the CCCs in Grade Six Instructional Segment 2

The CCC of **Scale, Proportion, and Quantity [CCC-3]** at the middle grades level includes the notion that "[t]ime, space and energy phenomena can be observed at various scales using models to study systems that are too large or too small." Clearly this concept applies when we relate the macroscopic property of temperature with the submicroscopic motions of particles. Similarly, both weather and climate describe the same conditions of the atmosphere (temperature, moisture, and movement), but at different **scales [CCC-3]** of time (and space). In general, climate describes a relatively long period of time (decades to millennia) and often applies across relatively large geographic areas. Weather generally refers to the same conditions at a specific location during a very short period of time.

The color-coded map of average annual precipitation in California in figure 5.10 is an example of a model that describes phenomena (climate properties) that occur at scales that are too spatially and temporally large to directly observe. Each small area of color corresponds to a calculated average based on many locations that measured and recorded the amount of precipitation each day for decades or perhaps a century or more. This kind of map is a systems **model [SEP-2]** that is especially useful and prevalent in Earth and space science. Color-coded maps can display data in ways that reveal important **patterns [CCC-1]** related to spatial location. Students may initially respond to the aesthetics of the colors rather than the science patterns and the vast amounts of data that these kinds of **models [SEP-2]** summarize and communicate.

While this kind of color-coded modeling representation is also used to some extent in other scientific disciplines, its special appropriateness in Earth and space science topics helps reveal a general principle about CCCs. While the CCCs do apply across many domains, they still may apply in somewhat different ways and extents in the different scientific disciplines.

The CCC of **Systems and System Models [CCC-4]** that is featured so prominently in IS1 still has a very significant presence in IS2. It is a vital and underlying aspect of many of the other CCCs. As mentioned when discussing **scale [CCC-3]**, many systems involve interactions at scales that are so large or so small that they are best understood through system models. Descriptions of the CCC **Energy and Matter [CCC-5]** often refer to tracking the flows of energy and matter into and out of systems. Finally, each of the California regional climates investigated in IS2 is an example of a whole system property that emerges or arises from the interactions of the components of the regional system with each other and with the incoming sunlight.

IS3 Integrated Grade Six Instructional Segment 3: Causes and Effects of Regional Climates

INTEGRATED GRADE SIX INSTRUCTIONAL SEGMENT 3: CAUSES AND EFFECTS OF REGIONAL CLIMATES

Guiding Questions

- Why is the climate so different in different regions of the planet?
- Why are organisms so different in different regions of the planet?
- What makes organisms so similar to but also different from their parents?
- What makes animals behave the way they do, and how does their behavior affect their survival and reproduction?

INTEGRATED GRADE SIX INSTRUCTIONAL SEGMENT 3: CAUSES AND EFFECTS OF REGIONAL CLIMATES

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-LS1-5. Construct a scientific explanation based on evidence for how environmental and genetic factors influence the growth of organisms. [Clarification Statement: Examples of local environmental conditions could include availability of food, light, space, and water. Examples of genetic factors could include large breed cattle and species of grass affecting growth of organisms. Examples of evidence could include drought decreasing plant growth, fertilizer increasing plant growth, different varieties of plant seeds growing at different rates in different conditions, and fish growing larger in large ponds than they do in small ponds.] [*Assessment Boundary: Assessment does not include genetic mechanisms, gene regulation, or biochemical processes.*] Introduced in IS3 but not assessed until IS4.

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.*] Revisited from IS1.

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

MS-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.*]

INTEGRATED GRADE SIX INSTRUCTIONAL SEGMENT 3: CAUSES AND EFFECTS OF REGIONAL CLIMATES

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*].

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.*]

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 [SEP-8] Obtaining, Evaluating, and Communicating Information	LS1.B: Growth and Development of Organisms LS1.D: Information Processing LS3.A: Inheritance of Traits LS3.B: Variation of Traits ESS2.C: The Roles of Water in Earth's Surface Processes ESS2.D: Weather and Climate PS3.A: Definitions of Energy PS3.B: Conservation of Energy and Energy Transfer	[CCC-2] Cause and Effect [CCC-3] Scale, Proportion, and Quantity [CCC-4] Systems and System Models

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

INTEGRATED GRADE SIX INSTRUCTIONAL SEGMENT 3: CAUSES AND EFFECTS OF REGIONAL CLIMATES

CA CCSS Math Connections: 6.SP.2, 4, 5; MP.2, MP.4

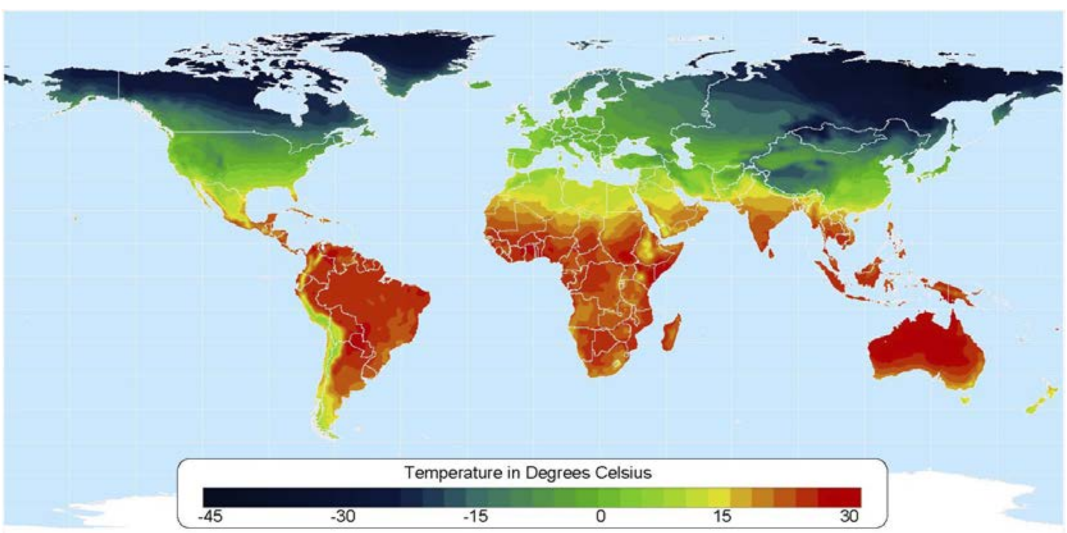
CA CCSS for ELA/Literacy Connections: RST.6–8.1, 2, 3, 4, 7, 9; RI.6.8, WHST.6–8.1, 2, 7, 8, 9; SL.6.5

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

In this instructional segment, students grapple with the anchoring phenomenon that it is warm in the tropics and cold at the poles. In IS2 students **analyzed climate data [SEP-4]** for eight different California regions. As a result of that analysis, four key factors were identified as having strong **causal effects [CCC-2]** on regional climates: (1) latitude, (2) altitude, (3) proximity to mountains, and (4) proximity to the ocean.

Figure 5.14 illustrates the combination of these four factors at the **scale [CCC-3]** of regional climates around the planet. Students begin IS3 by investigating the temperature at different latitudes and different times of year around the globe. These investigations lay the groundwork for Integrated Grade Eight when students will finally explain the seasons (MS-ESS1-1) after collecting data on seasonal weather patterns since kindergarten.

Figure 5.14. Average Annual Temperatures



Color-coded map of average annual temperature around the world. Note the major effect of latitude, and the colder high-elevation regions, such as the Himalayas in Asia. *Source:* Used by permission of The Center for Sustainability and the Global Environment, Nelson Institute for Environmental Studies, University of Wisconsin-Madison

[Long description of Figure 5.14.](#)

In IS2, students **explained [SEP-6]** that the oceans have a strong effect on temperatures near the coast because the water retains heat much longer than the surrounding land or air. In IS3, students extend their analysis of ocean effects on temperature by **investigating [SEP-3]** the effects of ocean currents that transport thermal energy from equatorial regions to colder temperate regions. This analysis is then connected to the more global **scale [CCC-3]** of ocean currents and wind patterns.

Having attained deeper understandings of the many intersecting factors and Earth system interactions that **cause [CCC-2]** regional climates, students then focus on the **effects [CCC-2]** that these very different regional climates have on organisms. In grade four, students cited internal and external structures of plants and animals as **evidence [SEP-7]** that organisms have structural adaptations that support survival, growth, behavior, and reproduction. In grade five, students **developed models [SEP-2]** that described how organisms survive only in environments in which their specific needs can be met.

Students deepen and revisit these concepts in grade six, IS3 by **investigating [SEP-3]** how plant and animal **structures [CCC-6]** are adapted to climatic and other abiotic conditions in an ecosystem. In elementary school, students provided evidence that animals had specific structures and behaviors that enable them to survive in specific conditions (3-LS4-3). But how is it that all the organisms in a specific environment have the structures and behaviors that allow them to take advantage of that specific environment? This instructional segment lays the foundation for understanding natural selection in grade eight. It focuses on both adaptation and introduces sexual reproduction. It uses specific phenomena related to attracting mates to also introduce sensory stimuli and the nervous system. While adaptation ties well to climate, these other topics are part of a life science storyline that easily could be separated out into its own instructional segment.

Climate Depends on Latitude

Keeping this broad outline of the IS3 sequence in mind, students begin exploring more deeply the effects of latitude on climate. Students should observe maps and ask detailed **questions [SEP-1]** about what they see. They should be able to describe **patterns [CCC-1]** they see, such as the reddish areas in figure 5.14 that clearly indicate that latitudes closer to the Equator are generally much warmer than latitudes that are further north or south.

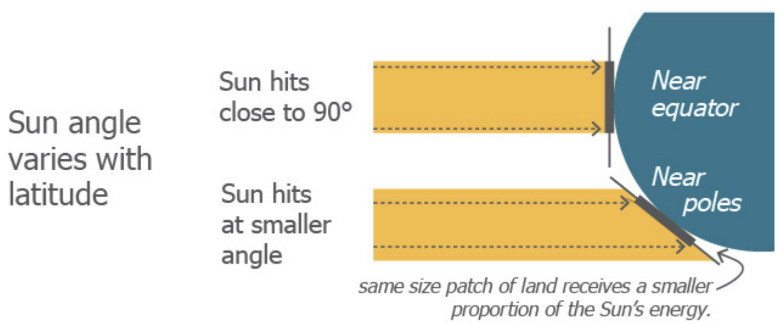
How can the Equator appear to receive more energy than either of the poles despite the fact that they all receive their energy from the same Sun? The key is that the Earth is a sphere. Sunlight arrives at Earth as parallel rays (figure 5.15), but hits the surface at nearly a 90° angle near the Equator 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 5.16), 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 5.15. 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 5.15.

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 5.16. 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°, the energy is spread out over a larger area. Diagram by M. d'Alessio.
Long description of Figure 5.16.

Thermal Energy Transport

Movements of thermal energy are major factors in **causing [CCC-2]** the observed **patterns [CCC-1]** of regional climates. One major concept is that **thermal energy [CCC-5]** moves from warmer locations/objects to cooler locations/objects. A related major concept is that these movements of thermal energy occur in three distinct ways (table 5.5). Students can **investigate [SEP-3]** and research each of these three ways of heating, create a brief report about one or more of them, and **explain [SEP-6]** the differences in terms of the underlying science. Given the state of their physical science knowledge, the mechanisms need to be stated in fairly general terms. For example, conduction and convection can be described in terms of particles vibrating or moving, and radiation can be described as waves of energy similar to sunlight that move through space and transfer energy.

Table 5.5. Thermal Energy Moves in Three Ways

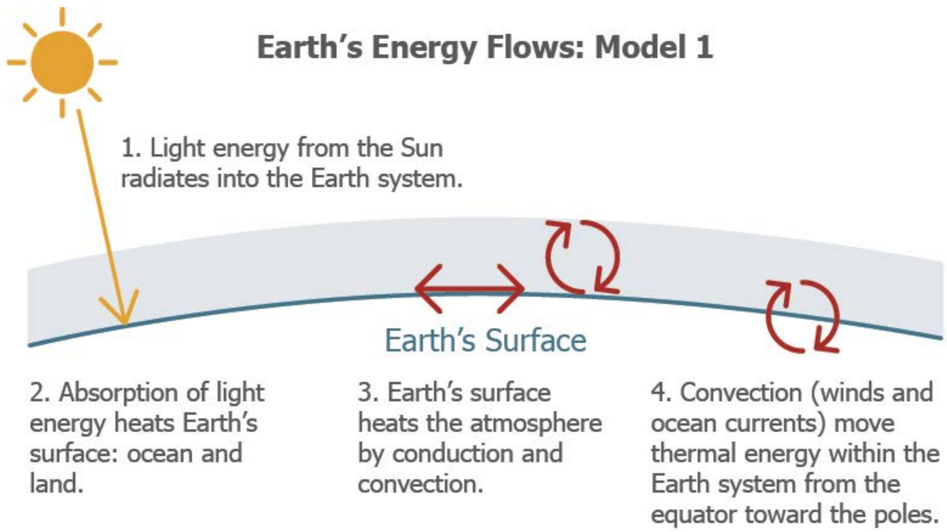
WAYS THERMAL ENERGY MOVES	PHYSICAL SCIENCE	EXAMPLES
CONDUCTION	Warm object touches cooler object and makes it warmer. Electromagnetic waves are not involved.	Hot sand burns your feet. Hot ground warms air that touches it.
CONVECTION	Handle of heated pan becomes hot.	Rainfall and streamflow in, evaporation out.
RADIATION	Warm liquid or gas flows into cooler area and makes it warmer. Electromagnetic waves are not involved.	Warm air rises and is replaced by cooler air. Hot water in heated pot rises from bottom to top.

Contrasting the three different ways that thermal energy moves from warmer objects to cooler objects based on the underlying physical science. Table created by Dr. Art Sussman, courtesy of WestEd.

Students can reflect on and discuss a simplified **model [SEP-2]** to apply their experiences and knowledge of the three modes of thermal energy movement to the context of the Earth system (figure 5.17). Sunlight travels as radiation from the Sun to enter the Earth system where it initially mostly heats the surface (ocean and land). Earth's surface transfers some of the thermal energy to the atmosphere by conduction, and convection then moves that energy within the atmosphere.[1]

1. In instructional segment 4, students will learn via Model 2 that radiation from Earth's surface also plays a very significant role

Figure 5.17. Earth's Energy Flows



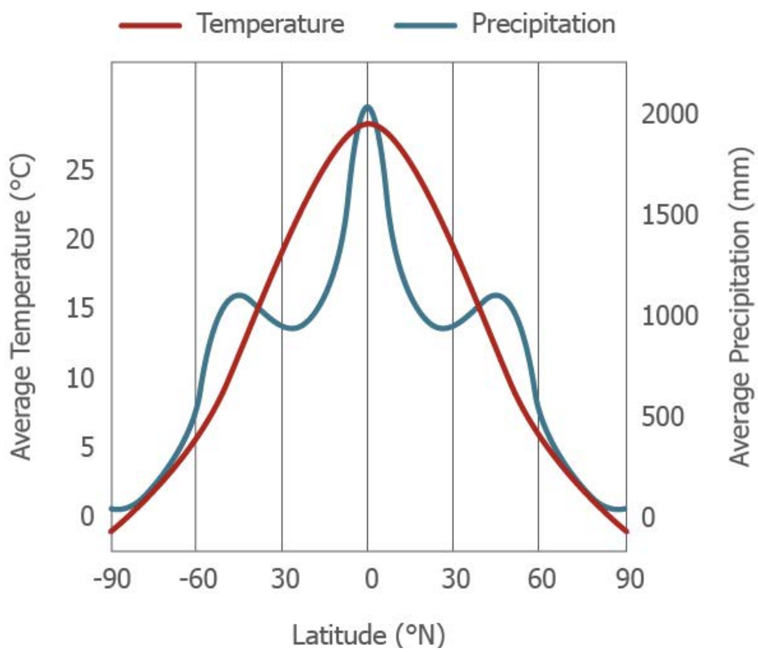
A simplified model illustrating energy flows that have major effects on weather and climate.
Illustration by Dr. Art Sussman, courtesy of WestEd.
Long description of Figure 5.17.

The teacher can prompt students to think about and discuss concept number four in figure 5.17, the transfer of thermal energy by convection. Why does thermal energy move from the equator toward the poles? Student **explanations [SEP-6]** should include the evidence from prior **investigations [SEP-3]** that sunlight hits equatorial regions at angles closer to 90° than the smaller angles at the poles, and also that **thermal energy [CCC-5]** moves from warmer regions toward colder regions. Students may find it contradictory that there is such a large difference in temperature between the equator and the poles when convection tends to equalize temperature differences. It turns out that the poles would be much colder and the tropics much hotter if winds and ocean currents did not move thermal energy away from the equator.

Students can collect data from cities around the world and create a graph showing the average temperature at different latitudes (figure 5.18). They also know from IS2 that when air masses rise, they cool and condense. They should be able to predict that warm air rising from the equator should cause higher rainfall there. By analyzing data from their cities, students confirm this is true, but recognize another pattern as well. There is another peak in rainfall near 50° latitude (both north and south). Students can **use this evidence to make an argument [SEP-7]** that air could be rising there as well.

in heating the atmosphere and in Earth's global climate.

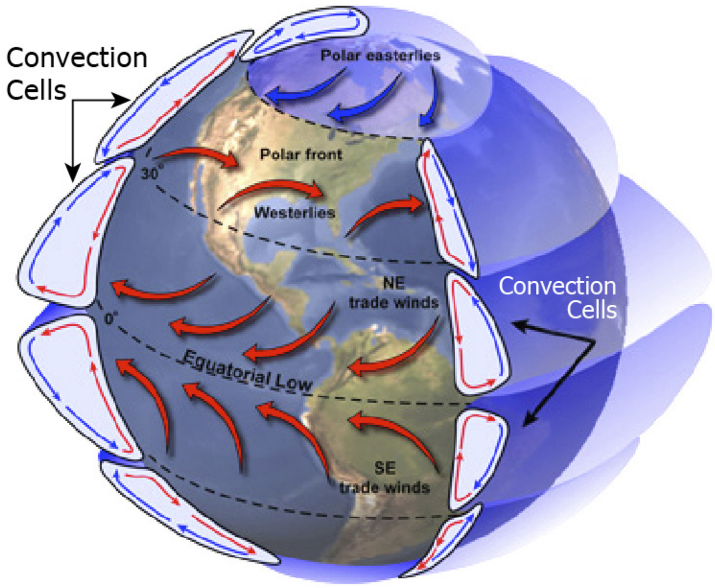
Figure 5.18. Temperature and Rainfall Vary Systematically with Latitude



Source: Thebiologyprimer 2015
Long description of Figure 5.18.

The rainfall versus latitude analysis provides evidence that the wind convection from the equator toward the poles actually happens via sequential “steps” that are called convection cells (figure 5.19). The two convection cells just north and just south of the equator (indicated by the line labeled 0°) each have skinny red arrows representing warm air traveling toward the poles and skinny blue arrows representing colder air from the polar regions traveling toward the equator. The illustration shows three sequential convection cells connecting the equator and South Pole. Similarly, three sequential convection cells connect the equator and the North Pole (though the third cell near the South Pole is not visible from the angle shown in figure 5.19). This illustration also shows thicker arrows that represent winds that blow east and west.

Figure 5.19. Thermal Energy and Wind Convection Cells



Wind convection in the atmosphere moves thermal energy from the 30° latitude toward the poles (skinny red and blue arrows in the convection cells). Image credit: Adapted from Summey n.d. Long description of Figure 5.19.

Students can then combine all they have learned in IS2 and IS3 into one summary of the evidence from their data of relationships between the movement of air masses at different scales and weather patterns (table 5.6; MS-ESS2-5). Because many of the conditions that determine weather are "permanent" on the timescale of ecosystems (latitude, topography, proximity to water bodies), the weather patterns in a region remain relatively consistent. The word *climate* refers to these consistent patterns of weather that each location experiences. It rarely snows in San Francisco or Los Angeles, and it almost always rains more often on the western side of the Sierra Nevada than the eastern side, and it rains a lot more in Northern California (closer to the upward motion of air masses for Earth's two northern convection cells) than it does in Southern California (closer to the downward motion of air masses from convection cells).

Table 5.6. Air Movements and Weather

CONDITION	AIR MOVEMENT	WEATHER	SAMPLE LOCATION
Convection cell near equator	Warm moist air rising	Thunderstorms; Heavy precipitation	Equatorial Pacific Islands
Convection cell at 30° latitudes	Dry air sinking	Desert	Sahara Desert Arabian Desert
Warm air mass and cold air mass collide	Warm air rising	Clouds and precipitation likely	Variable
Windward side of coastal mountain	Moist air rising	Rain and/or snow	California Coast and Sierra Nevada
Leeward side of mountain	Dry air sinking	Clear weather	Central Valley Southwest US desert
High pressure system	Air sinking	Clear and sunny weather	Variable
Low pressure system	Air rising	Cloudy and wet weather	Variable

Table created by Dr. Art Sussman, courtesy of WestEd

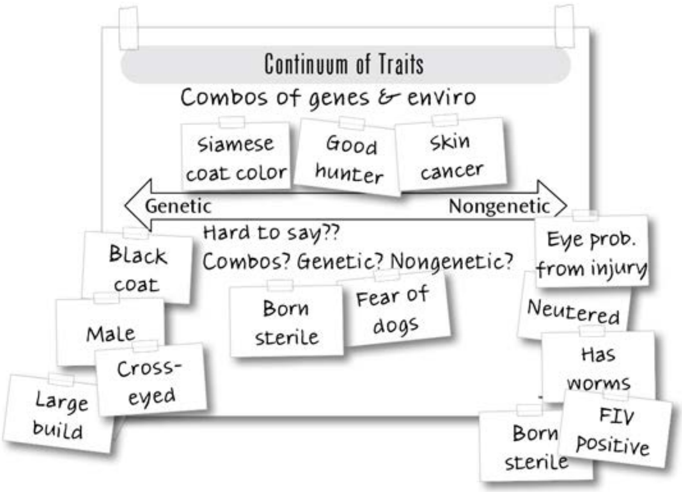
Organism Traits, Heredity, and Reproduction

Ecosystems develop around the abiotic conditions such as climate because these abiotic factors strongly influence the kinds of organisms that can live in an environment. Organisms with certain structures and behaviors (adaptations) survive in the unique conditions present in each environment while organisms without those adaptations might not. Teams of students can research a distinctive environment (e.g., the barren granite of the peaks in the Sierra Nevada, the dark shade beneath towering coastal redwood trees, or the brackish mud of a salt marsh), organize and **communicate information [SEP-8]** about the plant and animal traits that promote success in that environment. Sharing across teams that have **investigated [SEP-3]** very different kinds of environments can then lead to generalizations about significant **patterns [CCC-1]**. The question is, how do these traits develop in organisms? This provides the transition to heredity and reproduction. Students have been gathering evidence that organisms look and act like their parents since grade one (1-LS3-1; 3 LS3-1). Now, they begin to develop models of the mechanisms for heredity.

Structures and behaviors of organisms are features that generally apply to all members of a species. Examples of human features are eye color, body size, blood type, and personality 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. Many features vary across a wide spectrum of possibilities, and we usually clump these variations into groups that we generalize and simplify, such as describing people's height feature as being very short, short, average, tall, or very tall. For the middle grades student, this discussion of traits goes beyond scientific facts (Health Education Standards 7–8.1.8G, 7–8.2.2.G).

Discussions of traits can get sidetracked by arguments about the roles of genes and/or the environment in determining traits. Students gathered evidence in grade three that traits can be inherited (3-LS3-1) or influenced by the environment (3-LS3-2), and now they must integrate these two seemingly separate ideas. As discussed early in IS1, many features and processes of the natural world occur across a wide spectrum of possibilities and often do not fall definitively at one end of the spectrum or the other. 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 large environmental component (e.g., large muscles due to exercise or being able to play the guitar). Most traits, however, are a combination of genetic and environmental influence, and can be placed somewhere along the spectrum between the extreme examples (figure 5.20).

Figure 5.20. Genetic Versus Environmental Traits



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 5.20.

Students can experience the interplay between genetics and environment by **analyzing [SEP-4]** actual height data from provenance studies in trees. Ponderosa pine trees have a large range and have been extensively studied. In some areas of the western United States, 100-year-old ponderosa pines might be 60 feet tall, but in other areas they tower more than 150 feet (Meyer 1938). Students can ask questions about what climatic conditions can explain these differences. Then, students can **plan an investigation [SEP-3]** that would determine if any of the height difference is due to genetic differences in the trees rather than the environment. While students can't actually wait decades for the results of their investigations, they can determine what they would control for and what they would vary in an experimental design. Then, they can obtain information from actual provenance studies where seeds of trees from different environments are brought together and grown under the same conditions (Callaham 1962). Seeds from some regions do indeed produce trees that are shorter than other regions under all growing conditions; however, the tree that grows tallest depends on the specific growing conditions in the experiment. For example, a seed whose parents lived at high altitude in Northern Arizona grows taller than a seed from the Sierra Nevada foothills of California in research trials when the days are cold and the nights are warm, but the California seeds grow taller when both day and night are moderate temperatures. In other words, students are now able to provide an evidence-based explanation based on scientific data from the field (MS-LS1-5) for the patterns they observed in the classroom in grade three (3-LS3-1, 3-LS3-2).

In addition to a general emphasis on adaptations that promote growth and survival (MS-LS1-5), the performance expectations in IS3 emphasize evaluating factors that promote reproductive success (MS-LS1-4) and analyzing different modes of reproduction (MS-LS3-2). Students know that some plants depend on animals from lessons in grade two when they developed a simple design that mimicked the role of animals in pollinating flowers (2-LS2-2). Students can examine how climate alters the reproductive behavior of plants by examining the differences between insect-pollinated and wind-pollinated plants. What are the benefits and disadvantages of each? Students consider if different climate conditions would be more favorable to one method over another, providing their reasoning. They then compare the structures of wind-pollinated plants with insect-pollinated plants, eventually sorting through pictures and trying to identify the mode of pollination from the structure (InquireBotany n.d.). Students construct an **argument [SEP-7]** supporting how these structures increase the chance of successful reproduction (MS-LS1-4).

Integrated Grade Six Snapshot 5.3: 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 transition from their analyses of the causal connections between genes and traits to **developing a model [SEP-2]** to compare asexual and sexual reproduction (MS-LS3-2). Basing the activity on an interactive lesson from the University of Utah Learn.Genetics Web site (Sexual versus Asexual Reproduction accessed at https://www.cde.ca.gov/ci/sc/cf/ch5.asp#link10). 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. Student teams then had time to explore the Web site (in a computer lab, in class with tablets, at home, or in a library) to select two organisms that have different processes of sexual reproduction.

The following day, student teams made **system models [CCC-4]** of the reproduction processes for each of their two selected organisms. Each of the system models had to **explain [SEP-6]** why the progeny would have identical or different genetic information from each other. Students posted one of their system models on the wall, and then individually walked around the room, and **analyzed [SEP-4]** each posted model. They posted sticky notes next to the models with any questions or **disagreements [SEP-7]** they had with respect to the conclusions and/or evidence. After the presenters had time to look at the sticky notes, the whole class listened carefully as each presenting team appropriately **responded [SEP-8]** to the comments.

Sexual reproduction in animals can then lead to **investigations [SEP-3]** that link back to the body systems concepts in IS1. Students compile each of the reproductive processes described in the online Learn.Genetics resource to list and compare all animal behaviors that play a significant role in the reproduction. To do so, the students discuss the criteria for how they will categorize different behaviors. If students have difficulty suggesting valuable criteria, the teacher can prompt the discussion with examples such as choice, rigid instinctive behavior, memory, reasoning, and flexibility. Students can do more research about some of the examples that may lead to surprising findings, such as the amount of navigation, memory, analysis, learning, and communication involved when a honeybee chooses where to fly to from the hive to gather nectar.

Students then tie their understanding of reproduction back to regional climate. Are there certain climate conditions where asexual reproduction might be advantageous (e.g., when a successful organism needs to quickly reproduce) or where sexual reproduction might be better (e.g., when climate conditions change and identical offspring will all be equally vulnerable

Integrated Grade Six Snapshot 5.3: Asexual and Sexual Reproduction

to dying off)? Ms. Z presents students with several brief case studies and asks students to **construct an argument [SEP-7]** about which reproductive style is likely to be most successful in each situation.

Investigative phenomenon: Bowerbirds, peacocks, fruit flies, and vervet monkeys all put on displays where the male "shows off" for the female.

Ms. Z instructed students to extend their **investigations [SEP-3]** into behaviors by focusing on female choice in reproduction (not including humans). Key factors related to these investigations include stimuli provided by the male, female sensory receptors, female behavioral response, and female memory (MS-LS1-8). The teacher provided a list of possible examples (such as bowerbirds, peacocks, fruit flies, and vervet monkeys). For example, female vervet monkeys respond more favorably to males that show caring behavior toward infants. As a result, male vervet monkeys behave better toward infants when a female is watching. Student teams picked one of the suggested examples of female choice or a different one that they independently researched and **evaluated [SEP-8]**.

After the teams conducted the first round of research, the whole class decided on the criteria for a complete investigation and report. Teams extended and concluded their investigations by developing and presenting a report to the class about their example of female choice including **explaining [SEP-6]** the evidence and reasoning how the behavior affects the probability of successful reproduction (MS-LS1-4).

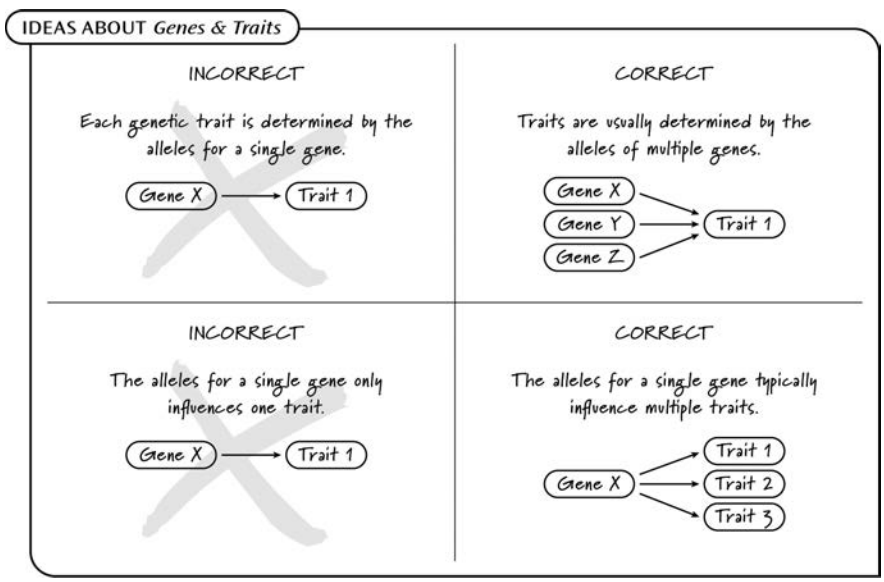
These life science learning experiences in grade six provide a foundation for deeper explorations in grade seven (performance expectations and DCIs focused on LS2: Ecosystems) and in grade eight (performance expectations and DCIs focused on L3: Heredity and L4: Biological Evolution).

Animals and plants have intricate structures and behaviors for sexual reproduction, but why? Whenever students identify **patterns [CCC-1]** in **structure/function relationships [CCC-6]**, they should be encouraged to ask about the **cause/effect mechanisms [CCC-2]**. In this case, each parent contributes to the traits of the offspring therefore leading to greater diversity of traits. To connect this otherwise unconnected topic back to climate, students can consider the question, How could a greater diversity of traits help an organism survive in a wider range of climates? Students **analyze [SEP-4]** the results of Mendel's experiments with pea plants or other simple examples of genetic inheritance that allow students to develop models of inheritance. The clarification statement of MS-LS3-2 indicates that students should be able to construct **models [SEP-2]** of inheritance such as Punnett squares or other depictions and simulations.

While these simple models are useful, 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 counter these preconceptions by citing **evidence [SEP-7]** such as that the ABCC11 gene on chromosome 16 influences the type of earwax a person has and also the amount of underarm odor.

Figure 5.21 contrasts incorrect and correct conceptions about the **causal [CCC-2]** linkages between genes and traits. As part of the developmental progression of the CA NGSS, students do not need to understand the specifics mechanisms or terminology of DNA or protein synthesis until high school.

Figure 5.21. 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 5.21.

IS4 Integrated Grade Six Instructional Segment 4: Effects of Global Warming on Living Systems

INTEGRATED GRADE SIX INSTRUCTIONAL SEGMENT 4: EFFECTS OF GLOBAL WARMING ON LIVING SYSTEMS

Guiding Questions

- How do human activities affect Earth systems?
- How do we know our global climate is changing?

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-LS1-5. Construct a scientific explanation based on evidence for how environmental and genetic factors influence the growth of organisms. [Clarification Statement: Examples of local environmental conditions could include availability of food, light, space, and water. Examples of genetic factors could include large breed cattle and species of grass affecting growth of organisms. Examples of evidence could include drought decreasing plant growth, fertilizer increasing plant growth, different varieties of plant seeds growing at different rates in different conditions, and fish growing larger in large ponds than they do in small ponds.] [*Assessment Boundary: Assessment does not include genetic mechanisms, gene regulation, or biochemical processes.*]

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-ESS3-5. 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

INTEGRATED GRADE SIX INSTRUCTIONAL SEGMENT 4: EFFECTS OF GLOBAL WARMING ON LIVING SYSTEMS

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.]

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.

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

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

Highlighted Science and Engineering Practices	Highlighted Disciplinary Core Ideas	Highlighted Crosscutting Concepts
[SEP-1] Asking Questions and Defining Problems [SEP-2] Developing and Using Models [SEP-6] Constructing Explanations (for science) and Designing Solutions (for engineering) [SEP-7] Engaging in Argument from Evidence [SEP-8] Obtaining, Evaluating, and Communicating Information	LS1.B: Growth and Development of Organisms ESS3.C: Human Impacts on Earth Systems ESS3.D: Global Climate Change ETS1.A: Defining and Delimiting Engineering Problems ETS1.B: Developing Possible Solutions	[CCC-2] Cause and Effect [CCC-4] System and System Models [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.

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

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

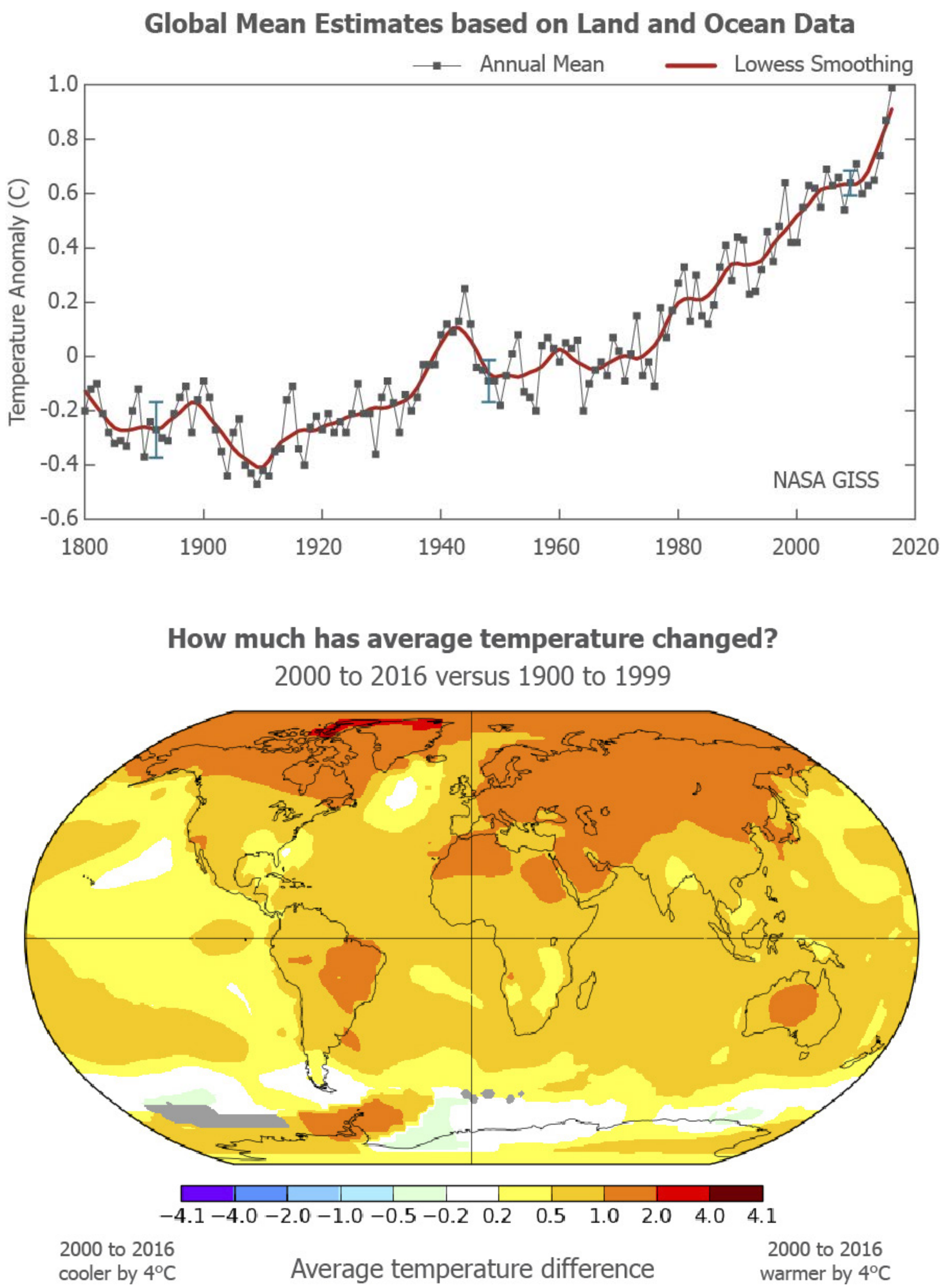
CA CCSS for ELA/Literacy Connections: RI.6.8, RST.6–8.1, 2 WHST.6–8.7, WHST.6–8.8

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

In this instructional segment, students collect evidence that Earth's climate is changing. At the grade six level, the scope of their understanding is intended to be limited. Students **analyze data [SEP-4]**, recognize **patterns [CCC-1]**, and **ask questions [SEP-1]** about what **causes [CCC-2]** these patterns. Students in the middle grades are not expected to explain why the Earth is warming in much detail—they will develop models explaining the causal mechanisms when they get to high school. The clarification statement for MS-ESS3-5 indicates that emphasis should be placed on the way human activities might influence the climate.

For this instructional segment, the anchoring phenomenon is that the temperature on Earth has warmed over the last 150 years, but the pattern of warming is complex. Students begin to **analyze data [SEP-4]** showing the temperature history over the last century (figure 5.22). While graphs like figure 5.22 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, https://www.cde.ca.gov/ci/sc/cf/ch5.asp#link11). 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 5.22 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 yet in grade six.

Figure 5.22. 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 5.22.

Opportunities for ELA/ELD Connections

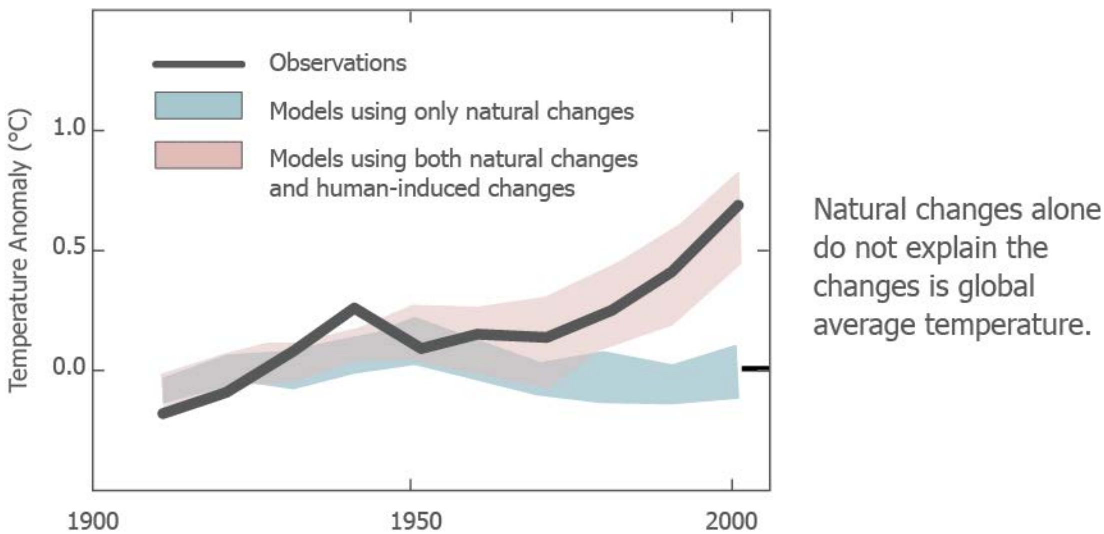
To help data come alive and help students compile it for a particular audience, have them **obtain information [SEP-8]** about the **effect [CCC-2]** temperature **changes [CCC-7]** have on sea level, glaciers, or storm intensity. In groups, or pairs, students research one aspect of the effect of temperature change on sea level, glaciers, or storm intensity using government reports summarizing these changes (such as EPA Climate Change Indicators, National Climate Assessment, or NASA's Climate Effects Web portal). Working in groups, students collaborate on creating a one-page campaign advertisement for an environmental magazine that includes a headline, a picture, and a visual that **represents [SEP-8]** the data gathered. Have each group present its advertisement to the class as if the class were the editing team of the environmental magazine. To ensure that students who may need it have time to rehearse or practice speaking, have the group decide each member's role, including English learners, so all students understand their part in the presentation.

CA CCSS for ELA/Literacy Standards: RST.6–8.2, 7; WHST.6–8.7, 9; SL.6–8.5
CA ELD Standards: ELD.PI.6–8.9

Causes of Climate Change

Several possible natural mechanisms 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, atmospheric composition, and volcanic activity (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 5.23). But there are also changes that are caused by human activity (EP&Cs III, IV). Many aspects of modern society result in the release of carbon dioxide and other greenhouse gases. These 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 whose digestive processes 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 very similar **patterns [CCC-1]** in the change in temperature (figure 5.24). In fact, computer models of climate show that human activities are an important part of the **cause [CCC-2]** of global temperature changes (figure 5.23).

Figure 5.23. Global Climate Outputs

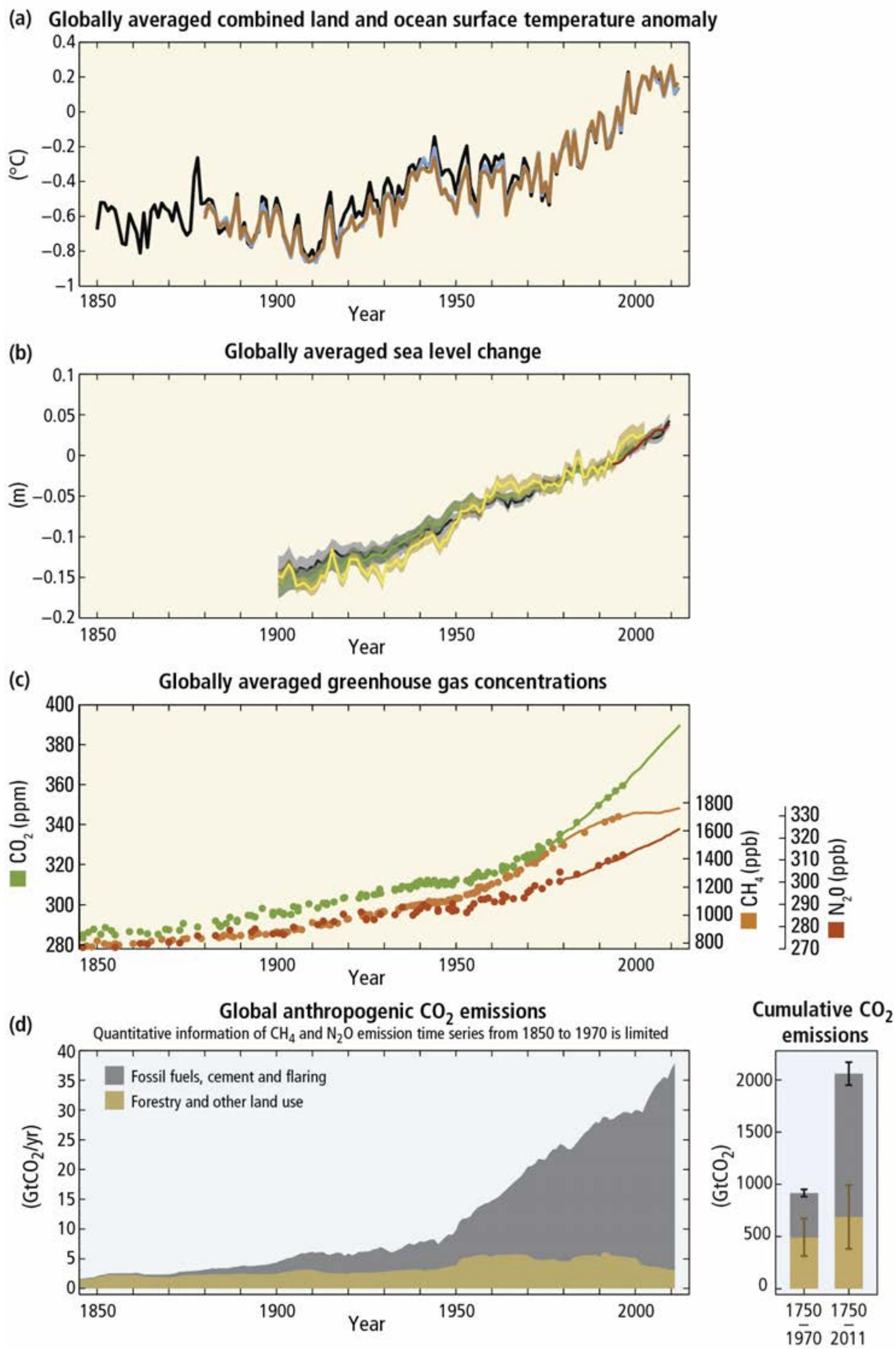


Outputs of different computer models of global climate compared to observations. The colored bands are thick because they represent hundreds of different models created by many different researchers using different assumptions. While the models have slight variations in their output, only models that 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 5.23.

Opportunities for Mathematics Connections

Global average temperature rises as human activity emits more greenhouse gases. This rate of emission depends on two key variables: population growth and energy consumed per person. Students should **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" 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 2012), 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 2012), 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 on the continent of Africa. These comparisons are examples of using 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 United States 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. In high school, students will use computer simulations to explore the effects of these assumptions (HS-ESS3-5).

Figure 5.24. 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 5.24.

Impacts of Climate Change on the Biosphere

Organisms have structural and behavioral adaptations that help them succeed and reproduce in their current environment (MS-LS1-4). The climate changes that have already happened affect behaviors of species, especially the timing of migrations, blooming, and maturing of seeds. Computer analyses of business-as-usual climate change scenarios project more dramatic and rapid changes that are likely to have deleterious effects on many organisms (MS-LS1-5).

Each of the integrated courses for the middle grades includes performance expectations that relate to human impacts on the environment. These are generally associated with DCI LS2 (Ecosystems: Interactions, Energy, and Dynamics) and DCI ESS3 (Earth and Human Activity). In addition to the global climate topic highlighted in the previous snapshot, Integrated Grade Six includes MS-ESS3-4, which is focused on designing a method for monitoring and minimizing a human impact on the environment. The following snapshot addresses that performance expectation and has an emphasis on engineering design.

Integrated Grade Six Snapshot 5.4: Monitoring and Minimizing Human Environmental Impacts

Anchoring phenomenon: Monarch butterflies fly long distances every year.

Following their **investigations [SEP-3]** related to climate change, students in Ms. D's class became concerned about the ways that climate change can harm organisms and ecosystems. Monarch populations west of the Rocky Mountains escape winter by flying long distances to California. Ms. D's students live in a coastal town with one of the major California winter nesting areas for monarch butterflies. They were concerned when they learned that climate change was affecting the migration of an organism important to the local community. Ms. D divided her students into three teams (A, B, and C) that each designed a different solution that could help the monarchs.

Students in Team A already volunteered with the local conservation group to protect their public monarch protection area. The scale of the global climate change issue inspired them to think at a broader **scale [CCC-3]** about all the places that the butterflies needed during the summer and on their long journey to Central and Southern California. They decided to gather information about the major threats that the butterflies faced on their long journey and to network with schools on that pathway to collaborate on monitoring the monarch population, identifying local threats to the monarchs (especially related to habitat, food and climate), and developing possible local solutions to those threats (MS-ESS3-3).

Integrated Grade Six Snapshot 5.4: Monitoring and Minimizing Human Environmental Impacts

Investigative problem: How can we get more output from our solar panels?

Students in Team B argued that the monarchs, and many other organisms, needed long-term solutions to climate change, such as switching to renewable energy sources. They **gathered information [SEP-8]** about making electricity from solar photovoltaic cells. Their project integrated physical science and Earth and space science DCIs into designing a solution to a life science problem. The school was in the process of seeking funds to purchase and install some solar modules. Team B started investigating how much extra solar electricity the school could get if the solar cells tracked the Sun during the day rather than remaining stationary, and whether those gains would be worth the cost. They also investigated other issues related to the placement of the solar cells. They created a poster that **explained [SEP-6]** how solar cells are energy conversion devices (PS3.A, B) and included a **model [SEP-2]** of how sunlight travels in straight lines (PS4.B) until it is absorbed by the solar cells, which are most efficient when oriented at a specific angle relative to the incident light rays.

Investigative problem: How can we reduce the amount of energy and water we use?

Students in Team C had learned about a different school in the county that had instituted a successful major energy saving program. They wanted their school to monitor and minimize consumption of electricity and natural gas (MS-ESS3-3). Team C started **analyzing data [SEP-4]** about the school energy sources and consumption, and what resources in the school and community were available for collaboration, especially the local utility company. They were particularly interested in digital devices that could monitor and control consumption of energy. These devices helped the students measure and reduce the per capita energy consumption, which they will discuss again in grade eight (MS-ESS3-4).

Ms. D assisted all three teams, helping them to establish a shared understanding about clearly articulating criteria that could be used to evaluate the success of their project and the constraints that could limit and impede success. In addition to collaborating and sharing within their team, the students also had regular meetings to share across the teams so they could gain insights and feedback from a larger and more diverse group. Ms. D also encouraged the three teams to include in their criteria and constraints the longer-term prospects for each of their projects, and how they could use different communication systems to implement their project and begin to support its sustainability.

The focus in IS4 on monitoring/minimizing human environmental impacts as well as on global climate change, complete the year's science education and reconnect with the systems thinking explored in IS1, especially the emphasis on properties of the whole **system [CCC-4]**. Earth's web of life is a property of the whole system that emerges from the interactions of organisms with each other and with the huge diversity of Earth environments. Similarly, the global climate is a whole-system property that emerges from the interactions of the Earth subsystems, with each other, and with the inflow of sunlight. Human actions can change the Earth system's components and interactions in ways that profoundly alter organisms and climate at local, regional, and global levels. The Integrated Grade Six course can help build a middle grades foundation of science and engineering understandings and practices related to citizenship and sustainability that can grow in depth in the succeeding middle and high school grades. (Two EEI Curriculum units, *Energy: It's Not All the Same to You* https://www.cde.ca.gov/ci/sc/cf/ch5.asp#link12 and *Responding to Environmental Change* https://www.cde.ca.gov/ci/sc/cf/ch5.asp#link13 provide a variety of resources that can support this instruction.)

Grade Seven Preferred Integrated Course Model

This section is meant as a guide for educators on how to approach the teaching of the California Next Generation Science Standards (CA NGSS) in grade seven according to the Integrated Model (see the introduction to this chapter for details regarding different models for grades six, seven, and eight). This section 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 into integrated groups that can effectively guide instruction in four sequential instructional segments (IS). There is no prescription regarding the relative amount of time to be spent on each instructional segment. As shown in figure 5.25, the overarching guiding concept for the entire year is "Natural processes and human activities cause energy to flow and matter to cycle through Earth systems."

Figure 5.25. Grade Seven Integrated Storyline

Guiding Concept: Natural processes and human activities cause energy to flow and matter to cycle through Earth systems.

Instructional Segment	1 Living and nonliving things are made of atoms	2 Matter cycles and energy flows in systems of all scales within the Earth system.	3 Natural processes and human activities have shaped Earth's resources and ecosystems.	4 Human activities help sustain biodiversity and ecosystem services in a changing world.
Life Science (LS)	Organisms are made of molecules of mostly six different elements.	Organisms grow and get energy by rearranging atoms in food molecules.	Matter cycles and energy flows among living and nonliving parts of ecosystems. Resource availability affects organisms and ecosystem populations. Ecosystems have common patterns of organism interactions.	Biotic and abiotic changes affect ecosystem populations. Design solutions can help maintain biodiversity and ecosystem services.
Earth and Space Sciences (ESS)	Earth materials are mostly made of eight different elements. Earth has mineral, energy, and water resources.	Earth's cycles of matter are driven by solar energy, Earth's internal thermal energy, and gravity.	Fossils, rocks, continental shape, and seafloor structures provide evidence of plate motion. Geoscience processes unevenly distribute Earth's mineral, energy, and groundwater resources.	Geoscience processes change Earth's surface. Damage from natural hazards can be reduced.
Physical Science (PS)	The interaction and motions of atoms explain the properties of matter. Thermal energy affects particle motion and physical state.	Chemical reactions make new substances and can release or absorb thermal energy. Mass is conserved in physical changes and chemical reactions.	Chemical reactions make new substances. Mass is conserved in physical changes and chemical reactions.	Synthetic materials impact society.
Engineering, Technology, and Applications to Science (ETS)	N/A	Design criteria. Evaluate solutions. Analyze data. Iteratively test and modify.	N/A	Design criteria. Evaluate solutions. Analyze data.

Each of the four instructional segments integrates the different disciplines. Concepts across the domains integrate within each of the four instructional segments. Each instructional segment has a summary sentence; for IS1 it is "Living and nonliving things are made of atoms." Figure 5.25 also indicates a sequence of concepts within each discipline such as the progression in life science from the idea that organisms are made of molecules (IS1) to photosynthesis (IS2) to ecosystem cycles of matter (IS3) to biodiversity concepts (IS4).

Students begin their exploration by categorizing the kinds of living and nonliving matter in a natural environment. Guided research and hands-on investigations lead to discussions and understandings about atoms and molecules. By comparing various solids, liquids, and gases, students begin constructing an understanding that the interactions and movements of submicroscopic particles result in properties of matter that we observe at our macroscopic level of reality. Thoughtful applications of a crosscutting concept (CCC) can help with the learning of the specific topic and simultaneously deepen the understanding of the CCC. Instructional segment 2 expands the instructional focus by including a highly detailed vignette that describes instruction over a much longer time period.

In IS 2, students **investigate [SEP-3]** physical changes and chemical reactions in the contexts of organisms and rocks. With chemical reactions, atoms rearrange their connections and form new substances. Chemical reactions also often involve the absorption or release of energy. The formation by plants of food consumed by other organisms and the breaking down of this food sets the stage for one strand of understanding cycles of matter and flows of energy. The transformations of minerals and rocks provide a complementary strand of physical and chemical changes that also involve **cycles of matter and flows of energy [CCC-5]**. As they engage with these changes in very different contexts, students can attain a deeper appreciation that the amount of matter always remains the same. In physical changes and in chemical reactions, the numbers of each type of participating atom remains the same (MS-PS1-5).

As the year progresses, students begin exploring cycles of matter and flows of energy at larger **scales [CCC-3]**, such as in different kinds of natural environments and their ecosystems. Ecosystems by their very nature embody the integration of Earth science and life science. This integration is especially evident in the flows of matter and energy that connect organisms with each other and with their physical environments.

Students also investigate the geoscience processes that change Earth's surfaces at varying time and spatial **scales [CCC-3]**, and that results in the uneven distribution of Earth's mineral, energy, and groundwater resources. These physical environments play large roles in determining features of the organisms that live in the local ecosystems.

Students explore biotic and abiotic interactions within these ecosystems, and the resulting macroscopic cycles of matter, flows of energy, and changes in organism populations. These general **patterns [CCC-1]** apply across ecosystems that may otherwise appear to be very different from each other.

Toward the end of the year, students address challenges to sustainability by applying their understanding of the natural processes and human activities that shape Earth's resources and ecosystems. These environmental challenges can cover a wide variety of contexts such as adverse consequences of synthetic materials, natural hazards (e.g., earthquakes and hurricanes), climate change, and habitat destruction.

In IS4, students research issues related to sustaining biodiversity and ecosystem services. They then have the responsibility to design engineering solutions that rely on the basic science skills that they developed in earlier instructional segments. They apply their knowledge, such as a **systems-based [CCC-4]** understanding of how Earth's organisms, including humans, are intimately connected with each other and with Earth's **cycles of matter and flows of energy [CCC-5]**. In their design challenges, students define the problem, balance criteria and constraints, and evaluate their proposed solutions.

IS1

Integrated Grade Seven Instructional Segment 1: Organisms and Nonliving Things Are Made of Atoms

According to the developmental progressions in the CA NGSS (see appendix 1 of this framework), **patterns [CCC-1]** at the middle grades level include the concept that "[m]acroscopic patterns are related to the nature of microscopic atomic-level structure." Instructional segment 1 constantly moves back and forth between these two **scales [CCC-3]** as students confront phenomena and try to use models to explain them at the atomic level.

INTEGRATED GRADE SEVEN INSTRUCTIONAL SEGMENT 1: ORGANISMS AND NONLIVING THINGS ARE MADE OF ATOMS

Guiding Questions

- How does the matter in living and nonliving things differ?
- How does adding or removing thermal energy affect the physical states of matter?
- How do interactions at the atomic level help us understand the observable properties of organisms and nonliving matter?

Performance Expectations

Students who demonstrate understanding can do the following:

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).] (Introduced, but not assessed until IS3)

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.*] (Introduced, but not assessed until IS3)

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,*

INTEGRATED GRADE SEVEN INSTRUCTIONAL SEGMENT 1: ORGANISMS AND NONLIVING THINGS ARE MADE OF ATOMS

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-PS1-3. 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.*] (Introduced, but not assessed until IS4)

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.]

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) [SEP-8] Obtaining, Evaluating, and Communicating Information	ESS3.A: Natural Resources PS1.A: Structure and Properties of Matter PS1.B: Chemical Reactions PS3.A: Definitions of Energy	[CCC-2] Cause and effect [CCC-3] Scale, Proportion, and Quantity [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.

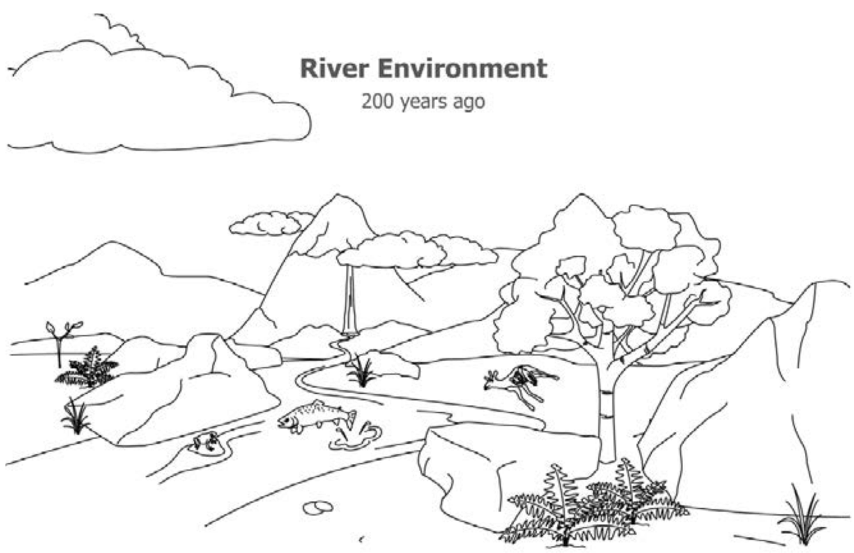
CA CCSS Math Connections: 6.EE.6, 6.RP.3, 6.NS.5, 7.EE.4, MP.2, MP.4

CA CCSS for ELA/Literacy Connections: RST.6–8.1, 7, WHST.6–8.2, 8

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

For this instructional segment, the anchoring phenomenon is based on students looking at the world around them and considering, What are things in the world made out of? Students can go outside to the schoolyard or nearby natural setting and sit silently, recording in their notebook all the different materials they see nearby. Do they observe **patterns [CCC-1]** that allow them to group matter into different categories (like living, nonliving, or once living; solid, liquid, or gas)? Students can compare the local environment around them to a picture or diagram of an environment that includes a full range of materials that can motivate the rest of the unit (figure 5.26; see the Environment Diagrams produced by WestEd for this purpose, https://www.cde.ca.gov/ci/sc/cf/ch5.asp#link14). Environment diagrams should be selected so that they include living and nonliving parts of environments (to motivate MS-LS2-3 in IS3) and illustrate processes that may cause uneven distribution of resources in different environments (to motivate MS-ESS3-1 in IS3). A single-environment diagram ties together all of grade seven (e.g., rivers), though students can also periodically break out into small groups to apply their understanding to other environment diagrams.

Figure 5.26. A River Environment



A river environment with diverse forms of living and nonliving matter. *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 5.26.

Particle Models of Materials in the Environment

A key feature of an environment diagram is the existence of water in all three states (solid, liquid, and gas). Water is something students directly observe in their everyday life (at least in two of its three states, as water vapor is hard to directly observe, even though they see its effects regularly), and they have explored the water cycle in grade six. As such, water is the perfect bridge between the concrete observations that characterized elementary school and observations in the middle grades where students use what they can see in everyday life to infer what occurs at **scales [CCC-3]** that they cannot directly experience. What is water made of, and what actually happens when it changes between solid, liquid, and gas?

Just as organisms are made of building blocks (cells) that are too small to see with the naked eye (grade six MS-LS1-1), all matter is made of building blocks (particles) that are orders of magnitude smaller, and that cannot be seen even with the most powerful light microscopes. In grade five, students developed a model of matter made up of particles too small to see. In the CA NGSS, students will progressively refine this model throughout the middle grades and high school. In grade seven, students will include the following features:

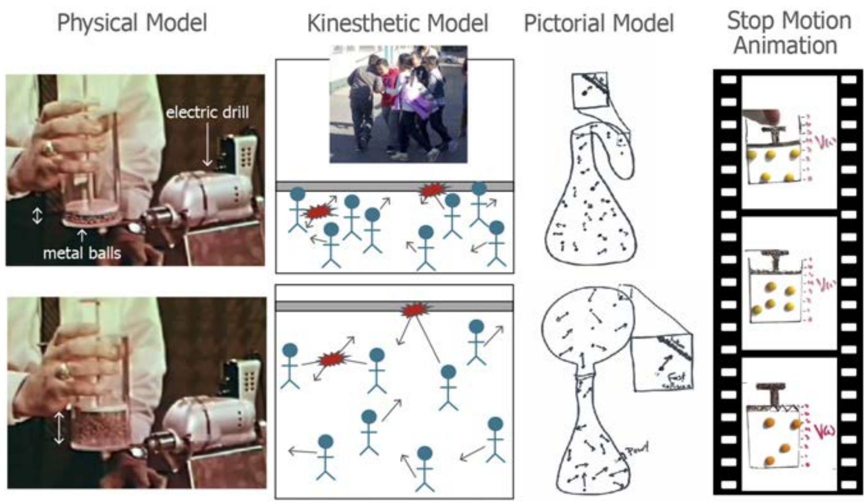
- Particles are always moving.
- Particles can interact (including collide, attract, and repel one another).
- Particles can be complex structures called molecules that are made up of smaller particles called atoms. Or, particles can be individual atoms.

It is not until high school that students add the additional refinement that atoms have an internal structure and are made up of parts that have positive and negative electrical charges.

The **structure [CCC-6]** of atoms, the periodic table, and the details of chemical 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 1998 CA Science Content Standards, where the periodic table was introduced in grade five and the interior **structure [CCC-6]** of atoms was introduced in grade eight. Part of the motivation is that these features are best understood in light of a more complete understanding of electromagnetic interactions, which are complex enough that they are introduced in high school. Teachers are expected to use the names of elements and compounds essential for life and use language that describes the atoms bonding together, but the features that make the elements different and the details of chemical bonds are not required at the level of understanding expected for the middle grades. Taking the time to develop a robust, particulate model of matter is a significant undertaking and lays key foundations for success in high school physical science. To emphasize this slow developmental progression, teachers should maintain the grade five terminology of matter made as particles in the first part of the instructional segment and then formally introduce the distinction between atoms and molecules near the end.

In Integrated Grade Six, students investigated objects heating up as energy transferred to them. These investigations introduced the DCI that thermal energy is really just the energy of motion of individual particles (PS3.A). When studying the water cycle in grade six, students also recognized changes in the state of matter (MS-ESS2-4). In grade seven, they will **develop models [SEP-2]** that explain the relationships between thermal energy, changes of state, and the motion of particles at scales too small to see (MS-PS1-4). Because the focus is on developing a conceptual model, students spend most of their time in this instructional segment observing simple phenomena involving heat transfer and trying to develop a model at the level of particles for each situation. The evidence statement for MS-PS1-4 outlines a range of "Connections" where students can *connect* their model to the real world (in other words, students should be able explain or predict phenomena using their model). In many cases, computer simulations or animations can quickly illustrate key concepts, but these models should not be introduced to students until they have time to grapple with the observations and develop their own models. The specific representation they use to depict their conceptual models can be physical, kinesthetic (using their bodies), pictorial (a diagram), stop-motion animation, or anything else the students can dream up (figure 5.27). As students create and manipulate their models, they are forced to decide how to represent things; they must figure out where to move their bodies in a kinesthetic model, what to draw in a diagram, etc. Each of these decisions requires them to think about what actually happens in the physical system. This process takes considerable time, and a simple two-minute demonstration can sometimes spur model development and revision that takes several class periods. For example, fill a cup with water and push a cork down to the bottom of the cup and release it. It quickly rises to the surface. Do the same thing with a penny and it stays at the bottom. In both cases, the water seems to be "pushing down" on the objects, so how do individual collisions between particles cause the cork to rise up? If collisions are pushing the cork upwards, why doesn't it just keep going up and launch out of the water? And if we figure all those things out, where in the **system [CCC-4]** does the **energy [CCC-5]** come from to push the cork up? This particular example is too complex for grade seven and not part of the evidence statement of MS-PS1-4, but we include it in this framework as an illustration to help teachers recognize that students will confront simple phenomena and have to think about them very abstractly. Students should confront phenomena in a sequence of increasing complexity, where each example requires them to build on the model they refined in the previous example.

Figure 5.27. Different Models of Gases



Source: Diagram by M. d'Alessio with image adapted from Exploratorium Teacher Institute 2016.
Long description of Figure 5.27.

First, students must refine their understanding that the temperature of a material depends on the average speed of the particles that make it up. When students drop food coloring into hot water, they observe that it spreads out more quickly than in cold water. Students represent the water as closely spaced particles and the dye as different particles and, through drawings, stop-motion animation, or other modeling techniques, illustrate how collisions between particles spread the dye at a rate that depends on the temperature.

Students can consider the everyday phenomenon of measuring the air pressure in bicycle tires on a cold morning and again later in the day after riding on hot pavement. To make sense of the changes they see on the tire gauge, they should consider the question, What is air pressure? To bring the phenomena into the classroom for **investigation [SEP-3]**, students can heat a flask topped by a balloon and watch as the air inflates the balloon and then deflates as it cools. Repeating the process over and over again helps convince students that the air is not escaping the **system [CCC-4]** as it "deflates," but there is some change of the air inside the system. Students must then use their model of matter as particles separated by empty space to explain how the density of the air changes and how the particles push each other apart as they collide.

Changes in particle kinetic energy can have other dramatic effects at the macroscopic level, notably changes in physical state. Students can describe the differences they observe at the macroscopic level between solids, liquids, and gases. Then, they must relate these changes to interactions between particles at the particle level (table 5.7). Thinking about water specifically can help this process because students share the familiar experience of water changing from one state to another. This change requires only a change in temperature (and therefore kinetic energy of particles). The phenomenon that "you cannot pull many solids apart" is a good clue that there must be some force that holds particles together in addition to the collisions that push them apart.

Table 5.7. Comparing Solids, Liquids and Gases

PHYSICAL STATE	PARTICLE PERSPECTIVE	MACROSCOPIC PROPERTIES
Solid State associated with lowest temperatures and/or highest pressures.	Particles have the least freedom of motion. Forces of attraction between particles lock them in their local neighborhood where they vibrate in place.	Solids maintain their volume and keep their shape independent of their container.
Liquid State associated with "moderate" temperatures and/or "moderate" pressures.	Particles have some freedom of motion. Forces of attraction keep each particle associated with nearby particles. Particles have too much kinetic energy for the attraction to lock them in place, so the particles slide past each other and change their neighborhoods.	Liquids flow as a unit and maintain their volume. Liquids adapt their shape to the shape of their container. If the container has more volume than the liquid, then the liquid does not fill the container.
Gas State associated with high temperatures and/or "low" pressures.	Particles have so much kinetic energy that they break completely free of the attractive force that would keep them in the liquid state. Particles are far enough apart that they do not interact except when they collide with other particles.	Gases have no fixed volume and will spread out within any size container.

Given the example of solids and liquids, students can fill out the bottom row of this table (from right to left) using their model of gases. Table developed by Dr. Art Sussman, courtesy of WestEd.

Students have already investigated the gas state in grade five and Integrated Grade Six, so they should have the knowledge to make the claim that the empty space in the unfilled glass actually has matter in the gas state (air consisting mostly of nitrogen gas and oxygen gas). Students can explore interactive computer simulations that help them visualize the accepted scientific model of molecular motion and extend their own model so that they can **explain [SEP-6]** phase changes between solids, liquids, and gases, and the transfer of **energy [CCC-5]** in terms of colliding molecules.

Many students hold the preconception that water is one of the only materials that can exist in all three states of matter. This false idea arises because it is one of few materials that changes state over the range of temperatures in common, everyday experience. Students can apply what they have learned about states of water to predict the behavior of different substances. For example, copper is a solid at room temperature. What does this tell us about the attraction between particles of copper compared to particles of water? Particles of helium have very weak attraction with themselves or other particles. Students can **use their model [SEP-2]** of phase changes to predict something about the relative freezing temperature of helium compared to other gases like nitrogen, the biggest component of air (table 5.8).

Table 5.8. Physical States at Normal Atmospheric Pressure

ELEMENT	GAS STATE	LIQUID STATE	SOLID STATE
Water	Above 100°C	From 0°C to 100°C	Below 0°C
Copper	Above 2,560°C	From 1,084°C to 2,560°C	Below 1,084°C
Helium	Above -270°C	Below -270°C	Never
Nitrogen	Above -196°C	From -196°C to -210°C	Below -210°C

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

Opportunities for ELA/ELD Connections

As a concluding activity, students create a set of true/false text cards with statements that summarize particle interactions that happen under different conditions and the resulting macroscopic properties of solids, liquids, and gases. Working in groups, students exchange the cards with other students so they can use what they have learned about states of water (see table 5.7 Comparing Solids, Liquids, and Gases) to discuss the statements on the cards. They then use the true cards as reasoning to help explain the behavior of different substances (such as helium, nitrogen, and copper as shown in table 5.8).

CA CCSS for ELA/Literacy Standards: RST.6–8.2; SL.6–8.1

CA ELD Standards: ELD.PI.6–8.3

For the next "everyday phenomenon," students return to the environment diagram (figure 5.26), which shows a snow-capped mountain. In grade six, students observed patterns that led them to the Earth and space science DCI that water condenses into rain drops as air masses rise and therefore precipitation is more likely at high altitude. Why? And why is it colder at high altitudes? Students must use their model of particles and physical science DCIs to develop the definition of air pressure in terms of particles. How does a change in pressure cause a change in temperature? Students can investigate air pressure in the classroom by exploring the phenomena of inflating a tire with a bicycle pump (which warms up), and then rapidly deflating the tire and feeling the valve cool down.

Looking further at the environment diagram, what other effects can students explain? Why are rocks hard and resistant to erosion? (They must be made from materials where the attraction between them is strong). What happens when water flows over a rock and weathers it into pieces? (The collision of water particles with the rock particles must be strong enough to break the attraction between rock particles). How does a stream move sediment grains? (Collisions between water particles and rock particles push the rock downstream).

Particles Can Be Simple Atoms or Complex Molecules

As students explore matter as particles, they notice that not all particles behave the same. We breathe in oxygen but breathe out something called carbon dioxide. We drink water and eat sugar. Each of these names is just a label to describe a material with distinct properties. Some of these materials are made of simple particles that we call *atoms*, but often two or more simple particles can combine to make much more complicated particles called *molecules*. Teachers can introduce this terminology of atom and molecule by providing 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 the 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. Students will build on this terminology in IS2.

Today, mass spectrometers, x-ray diffractometers, and other devices allow scientists to take materials, crush them into a powder, and determine their composition (atoms and molecules). If students could take objects from the environment diagram and place them in these devices, they would find that the majority of living things are made of just a few types of atoms. These same types of atoms are common in the nonliving parts of the environment and in synthetic materials as well (MS-PS1-3, assessed in IS3). Teachers can simulate this process using an interactive Web page where students click on objects or use flashcards with object pictures on one side and a simplified molecular and atomic composition of the object on the other side. Exploring this data set, students can identify **patterns [CCC-1]** in the common types of atoms in the natural environment and begin to develop models of how **matter cycles [CCC-5]** in the environment. They will examine these cycles in more detail in IS2.

IS2 Integrated Grade Seven Instructional Segment 2: Matter Cycles and Energy Flows through Organisms and Rocks

Students apply their understanding of materials to the **cycling of matter [CCC-5]** in two different **systems [CCC-4]**, the cycle of rock material in the geosphere and the cycling of biomass between organisms. In each case, the **flow of energy [CCC-5]** within the system is intimately tied to the flow of matter.

INTEGRATED GRADE SEVEN INSTRUCTIONAL SEGMENT 2: MATTER CYCLES AND ENERGY FLOWS THROUGH ORGANISMS AND ROCKS

Guiding Questions

- How do rocks and minerals record the flow of energy and cycling of matter in the Earth?
- How do we get energy from our food?
- How are hot objects different than cold objects? What changes when they heat up or cool down?

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.*]

INTEGRATED GRADE SEVEN INSTRUCTIONAL SEGMENT 2: MATTER CYCLES AND ENERGY FLOWS THROUGH ORGANISMS AND ROCKS

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-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-PS1-5. 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.*]

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.*

INTEGRATED GRADE SEVEN INSTRUCTIONAL SEGMENT 2: MATTER CYCLES AND ENERGY FLOWS THROUGH ORGANISMS AND ROCKS

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-6] Constructing Explanations (for science) and Designing Solutions (for engineering) [SEP-7] Engaging in Argument from Evidence	LS1.C: Organization for Matter and Energy Flow in Organisms PS1.A: Structure and Properties of Matter PS1.B: Chemical Reactions PS3.D: Energy in Chemical Processes and Everyday Life ESS2.A: Earth's Materials and Systems ETS1.A: Defining and Delimiting Engineering Problems ETS1.B: Developing Possible Solutions ETS1.C: Optimizing the Design Solution	[CCC-1] Patterns [CCC-5] Energy and Matter: Flows, Cycles, and Conservation [CCC-7] Stability and Change

Highlighted California Environmental Principles and Concepts:

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, MP.2, MP.4, 6.SP.4, 5, 7.EE.3, 7.SP.7

CA CCSS for ELA/Literacy Connections: RST.6–8.1, 2, 3, 7, WHST.6–8.2, 7, 8, 9, SL.7.5

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

Students have been investigating the relationships between plants and animals since kindergarten (K-LS1-1), and they supported the claim that plants get the matter they need from air and water in grade five (5-LS1-1), thus tying the biosphere to the rest of Earth systems. The vignette below illustrates one approach to teaching about energy and matter flows in living systems in the middle grades.

INTEGRATED GRADE SEVEN VIGNETTE 5.2: PHYSICAL AND CHEMICAL CHANGES IN ORGANISMS

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.*]

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-PS1-5. 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.*]

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.

INTEGRATED GRADE SEVEN VIGNETTE 5.2:
PHYSICAL AND CHEMICAL CHANGES IN ORGANISMS

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-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 and Designing Solutions [SEP-7] Engaging in Argument from Evidence	LS1.C: Organization for Matter and Energy Flow in Organisms PS1.A: Structure and Properties of Matter PS1.B: Chemical Reactions PS3.D: Energy in Chemical Processes and Everyday Life ETS1.A: Defining and Delimiting Engineering Problems 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-4] System 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.

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

CA CCSS Math Connections: MP. 5

CA CCSS for ELA/Literacy Connections: RST.6–8.7, 9; SL.7.1

CA ELD Connections: ELD.PI.6–8.1, 9

Introduction

This vignette illustrates the integration of life and physical science concepts surrounding **energy and matter flows [CCC-5]** in living **systems [CCC-4]**. It is designed to illustrate a large section of IS2 within the Integrated Grade Seven course. Instruction spans nearly three weeks, beginning at the scale of entire ecosystems, zooming down to the **scale [CCC-3]** of individual atoms and molecules, and then returning back to the scale of individual organisms within the ecosystem.

INTEGRATED GRADE SEVEN VIGNETTE 5.2: PHYSICAL AND CHEMICAL CHANGES IN ORGANISMS

Day 1: Classifying changes in a natural environment

Students identify changes that happened over 200 years in a river environment and ask questions about the similarities and differences between these changes.

Day 2: Identifying and Defining Chemical Changes

Students analyze observations of substances before and after they interact to determine features characteristic of chemical changes.

Days 3–4: Models of Photosynthesis

Students engage in a short engineering design challenge to find an effective physical model for atoms and molecules in the photosynthesis reaction.

Day 5: Energy and the chemical reaction of respiration

Students struggle with and discuss how to represent energy using their physical model of the respiration reaction.

Days 6–8: "Energy Love" Investigations

Students explore hands-on stations with different devices that use or give off energy and try to develop a definition of energy (a task as difficult as defining love). When that fails, they resort to categorizing different forms of energy.

Day 9: Models of Energy from Food

Students grapple with models of the flow of energy in a chemical system.

Days 10–13: Engineering design challenge to quantify energy released

Students refine the design of a food calorimeter that converts chemical potential energy into thermal energy.

Day 14: Organism energy/matter system diagram

Students develop a model of the energy flow and matter cycling at the scale of organisms in an ecosystem.

Day 1: Classifying changes in a natural environment

Anchoring phenomenon: Within a river environment, a lot changes in 200 years. Plants and animals live and grow.

In IS1, students noted the kinds of matter that exist in natural environments. They had begun with whole-class discussions focused on a river environment viewed 200 years ago (figure 5.26). To start IS2, Mr. G presented students with a new illustration of the same location today (figure 5.28). What has changed?

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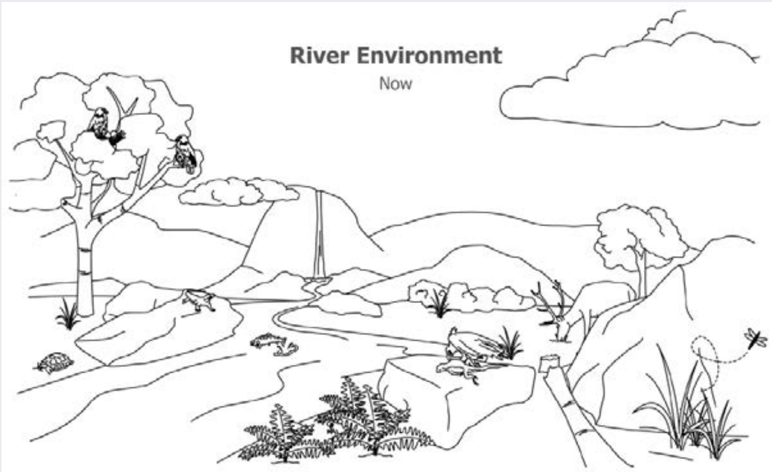
Figure 5.28. River Environment



The previously viewed river environment 200 years later. *Source:* From Making Sense of SCIENCE: Earth Systems (WestEd.org/mss) by Daehler and Folsom. Copyright © 2013 WestEd. Adapted with permission.
Long description of Figure 5.28.

Students excitedly began working in groups to compare the two diagrams. Students listed many differences including trees that had fallen or that had grown considerably, and the appearance of a live deer. Then they included more subtle changes such as the disappearance of the deer carcass, erosion of rock, and widening of the river at the base of the waterfall.

After the whole class shared and reached a class consensus about the changes, Mr. G distributed a short illustrated reading about the differences between a physical change and a chemical reaction. Reading and writing individually, and then discussing in pairs, students generated a list of scientific **questions [SEP-1]** about the changes that had happened in the natural environment. In the subsequent whole-class discussion, questions emerged about physical and chemical changes.

Juanita had argued, “A change can be both a physical change and a chemical change. Why does it have to be only one of them?” Alex had taken that **argument [SEP-7]** in a different direction by saying some of the changes should be classified as “biological changes,” a third category separate from the other two. Mr. G asked the students to think about these and other questions as they completed the homework reading and questions about physical and chemical changes.

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Day 2: Identifying and Defining Chemical Changes

Investigative phenomenon: When substances mix, sometimes unusual things happen and sometimes they don't.

When students mixed substances together in grade five, they found that sometimes new substances formed and sometimes they did not (5-PS1-4). Mr. G set up a similar series of **investigations [SEP-3]** to pinpoint specific changes in physical properties (change in color, bubbling of a gas, or an increase in temperature) that tended to indicate a chemical change had happened. They **analyzed [SEP-4]** the results of their investigations by organizing their observations and looking for **patterns [CCC-1]** in what they saw, heard, smelled, or felt (MS-PS1-2). Students liked the idea that the changes in physical properties were similar to clues in a mystery story or crime scene investigation. The investigation included some examples that appeared to be chemical changes (gas bubbling out of a soda can) but were really *just* physical changes. This emphasis on the word "just" helped students distinguish between the two kinds of changes.

Juanita shared a Venn diagram that she had made to answer her own previous question about whether something could be both a physical and a chemical change. Her diagram showed that both kinds of changes had alterations in physical properties (the shared circle in the middle), but only chemical changes had changes in the bonding of the atoms within molecules. The physical change circle showed water boiling with the words "It's all still H_2O." The chemical change circle showed a wood fire and smoke with the words "New substances appear." Lorena was particularly troubled by this phrase and asked, "How do these substances magically appear?" Mr. G encouraged Lorena and Juanita to repeat several of the investigations in a sealed bag so that no matter could enter or leave and watch to see if the mass changed. As they found in grade five (5-PS1-2), the mass remained the same after each change. "See, whatever stuff starts in the bag stays in the bag," gloated Lorena. Juanita recognized that her words were misleading and erased them to read, "Old substances change into new substances." Mr. G highlighted the new phrase to the class and asked students to work in teams to rewrite Juanita's idea using the terms *atoms* and *molecules*. After students shared their ideas, Mr. G introduced the new term, *chemical bond* to describe how the atoms stay together as molecules. "What exactly is a chemical bond?" asked Pedro.

Days 3–4: Models of Photosynthesis

Investigative phenomenon: Trees grow using air and water

In the next lesson, Mr. G connected the student questions about changes in atomic connections with the chemical change that all the student groups had identified in the river environment— the photosynthesis that had enabled the tree to grow so much. Mr. G asked

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students to call out what plants need to grow. He pointed out that air and water are both made of molecules. Within the plant, these substances change into new substances. Mr. G rewrote the needs as chemical formulas and then wrote out the rest of the balanced equation for photosynthesis on the board. He emphasized that the arrow in the chemical equation represented the chemical change. He then provided interconnecting plastic toy bricks to students and instructed them to create a **model [SEP-2]** of that reaction. Each group of students had a variety of colorful toy bricks that they could assemble in their work areas.

Marco, the reporter for one student group, described how they used a different type of toy brick for each molecule. Most 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 type 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. She also pointed out, "In case you did not notice it, I was making an **argument based on evidence [SEP-7]**."

Juanita and Alex called everyone's attention to their group. Alex explained that they had tried to use models where each type of toy brick represented a different kind of atom. Their group liked that idea because they thought it would help show how the connections between the atoms changed during the reaction. However, when they tried to put the glucose molecule together, "The whole thing got very messy and we argued about whether our **model [SEP-2]** was really helping us understand the chemical reaction."

Mr. G used this discussion as an opportunity to share illustrations of models that scientists use to represent the bonding within molecules and the shapes of common molecules (carbon dioxide, water, glucose, and oxygen). He asked teams of students to discuss what kind of materials that they might use to represent those molecules and the photosynthesis equation. As students presented their ideas, Mr. G emphasized that the class was engaging in a simple engineering design problem. This prompted them to discuss the problem in terms of the criteria and constraints. They noted one constraint was that they could only use inexpensive materials. One significant criterion was that there needed to be different representations for each kind of atom so they could track the changes in bonding associated with the reaction. By the end of the class period, students had reached a consensus on using different colored sticky notes to represent the three different types of atoms involved (figure 5.29). Students also wanted to use a smaller size sticky note to represent hydrogen since they knew that it was the smallest atom.

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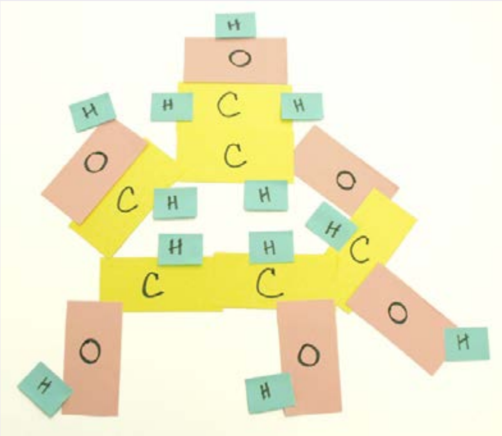
Figure 5.29. Classroom Model of a Glucose Molecule



A model of a glucose molecule with different colors representing carbon (C), oxygen (O) and hydrogen (H). Provided by Dr. Art Sussman, courtesy of WestEd. Long description of Figure 5.29.

At the start of the next day, each group gathered supplies of sticky notes and began to assemble them to **model [SEP-2]** photosynthesis. Most of the student groups successfully created a model of a glucose molecule. They had also used the correct numbers of all the molecules. They were able to use the model as **evidence to explain [SEP-6]** that in the reaction none of the atoms had disappeared, and that there were also no new atoms in the products (MS-PS1-5). The products side of their model had exactly the same numbers and kinds of atoms as the reactants side of their model. Mr. G reinforced their use of the term *conservation of matter* to describe this feature of chemical reactions. Students inquired if physical changes also featured this rule of conservation of matter. After some discussion and additional modeling, they agreed that all changes followed this rule.

Days 5: Energy and the chemical reaction of respiration

Investigative phenomenon: Animals can get their energy from eating plants.

In the next lesson, Mr. G displayed the two river-environment diagrams and facilitated the students in discussing and reporting about the different chemical reactions. They all identified the deer and the bird as examples of organisms that were doing respiration. Marco noted that back in grade six they had learned that respiration happened in both plant cells and in animal cells, so plants must do respiration, too.

Following that introduction, Mr. G challenged the students to use the sticky notes to **model [SEP-2]** the reaction of respiration. There was some grumbling about having to make the sugar molecule again, but Mr. G reminded them that not only did plants always make sugar without any whining, the plants also did not complain about being eaten. While his comment was sarcastic, Mr. G recognized that he had not always spent so much time on topics before moving on in the past. He went on to explain that practicing their skills and applying them to new situations is what leads to effective learning.

When it was time to share in groups, the students seemed comfortable with the concept that photosynthesis and respiration were examples of chemical reactions. They also cited the **evidence [SEP-7]** that in chemical reactions the atoms changed their

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connections and that the amount of mass remained constant. Students knew that plants get energy from photosynthesis and animals get energy from plants, so they asked Mr. G about how they should model the energy in these chemical reactions.

Marco said that his group had talked about attaching a red sticky note to their glucose molecule, but they argued about where to put it and whether they needed to put a different red sticky note in each place where the atoms connected with each other. Kelly added that the group also had **questions [SEP-1]** about whether they should attach red sticky notes to the other molecules, and how to represent the energy that was released during the respiration chemical reaction.

Other students joined in with their own ideas to **argue [SEP-7]** whether and how to represent energy in their models, and what was actually happening with energy in the reaction. By the end of the class discussion, there seemed to be general agreement that they would not use sticky notes to represent energy because "energy was like a whole different kind of thing or idea than matter." The students concluded that they needed to spend more time talking and learning about energy, and specifically the changes in **energy [CCC-5]** during chemical reactions.

Days 6–8: "Energy Love" Investigations

Investigative phenomenon: (Students investigate a range of devices that use or give off energy.)

Mr. G set up stations around the room for students to explore different forms of energy. Each station had cryptic labels and instructions such as a ball labeled "Drop me," a bowl of fresh fruit with the label "Eat me," and a radio playing music with the label "Dance with me." On the board, Mr. G had written the instructions, "Describe how each station relates to energy." As the students circulated between the stations, they discussed everything they knew and wondered about energy from their previous science classes and real-world experiences. Mr. G helped them develop and compare Frayer diagrams about the concept of energy. In the end, they concluded that there was no simple definition of energy that they could memorize and repeat back word for word on a test question to prove that they understood the science concept of energy. Some students seemed to find some consolation when they could not agree on a definition of "love." Alex summed it up by saying, "I can't define love, but I know different kinds of love when I see and feel them. Maybe it will be the same with energy."

Over the next several days, Mr. G referred to the different stations and subsequent hands-on experiences as their "energy love" investigations. Mr. G then asked the students to categorize the investigations based on **patterns [CCC-1]** they noticed. After some discussion, the class settled on two categories and developed a summary table that listed examples of "Energy of Motion" and "Energy of Position." With that common background established, Mr. G steered the class back to the chemical reactions of photosynthesis and respiration.

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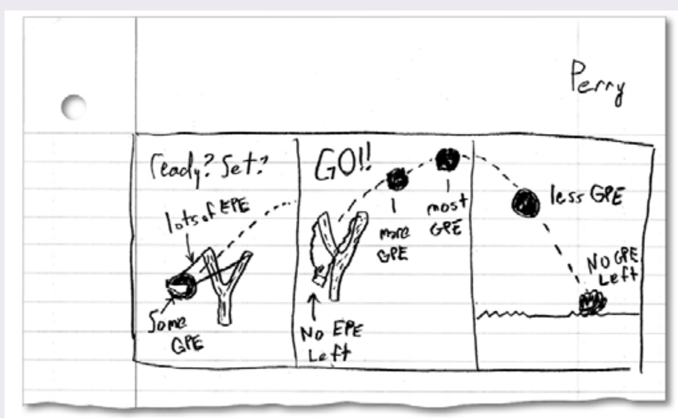
ENERGY OF MOTION Energy due to the motion of matter	**ENERGY OF POSITION** Energy due to the relative positions of matter
Kinetic Energy Thermal Energy "often called Heat Energy" Light Energy Sound Energy Electrical Energy	Gravitational Potential Energy Elastic Potential Energy Chemical Potential Energy Magnetic Potential Energy Electrostatic Potential Energy

Source: From Making Sense of SCIENCE: Energy (WestEd.org/mss) by Daehler, Shinohara, and Folsom. Copyright © 2011a WestEd. Adapted with permission.

Investigative phenomenon: Pulling back a slingshot just a few inches can launch a walnut all the way across the schoolyard.

In the final investigation of the "energy love" series, students **modeled [SEP-2]** the changes in potential energy when using a slingshot to propel a walnut across the schoolyard (employing appropriate safety precautions). The prompt involved listing examples of three forms of potential energy (elastic, gravitational, and chemical), and the changes in those forms of potential energy. Perry's diagram was typical for the class (figure 5.30).

Figure 5.30. Student Diagram of Changes in Potential Energy



Student diagram of changes in potential energy accompanying the propulsion of a walnut by a slingshot. EPE was the abbreviation the class used for elastic potential energy and GPE for gravitational potential energy. *Source:* From Making Sense of SCIENCE: Energy (WestEd.org/mss) by Daehler, Shinohara, and Folsom. Copyright © 2011a WestEd. Reproduced with permission.
[Long description of Figure 5.30.](#)

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In debriefing the investigation, Mr. G pointed out that the assignment had specified describing the chemical potential energy within their diagram, yet most diagrams did not mention chemical potential at all. Perry defended his diagram by saying, "We did elastic and gravitational, but there is no food in this diagram so we did not include chemical."

After Marco pointed out that the walnut is food, Perry replied, "Okay, the walnut is food and has chemical potential energy, but that energy didn't change in the experiment. We didn't eat or burn the walnut."

Talking in groups, students discussed whether there was anything else in the diagrams that had chemical potential energy. While at first there was resistance and a tendency to identify the chemical potential energy only with food, the group and class discussions eventually led to the realization that all the matter in the diagram had chemical potential energy: air, ground, slingshot wood, and slingshot rubber band.

Day 9: Models of Energy from Food

Everyday phenomenon: We get hot when we exercise.

After all this "energy love," Mr. G returned to the question, "How do we get energy from our food?" and asked students to draw or write a response for their warm-up. Most students chose to write a response, and most included the phrase, "Chemical potential energy gets converted into kinetic energy." While they all had "correct" answers, Mr. G pointed out that most of the class used the passive voice that energy "gets converted." What does the converting? How does that happen? Trying to convey enthusiasm about a new unexplained challenge, Mr. G said, "I think that we still don't have a good **model [SEP-2]** of what **causes [CCC-2]** that energy conversion. If we did, more of you would have drawn that model." Mr. G next provided students a clue—he cited the everyday phenomenon that people get all hot and sweaty when they exercise. Why do we get hot? Mr. G reminded students where they left off yesterday that **all** materials have chemical potential energy stored in their bonds. The students worked in teams to refine their model of the changes in energy that go into cells as food and then molecules get rearranged during cellular respiration (MS-LS1-7). During whole-class discussion, teams held up molecules from their sticky note models of respiration and said that the chemical energy in the products (water and carbon dioxide) must be smaller than the total chemical energy of the reactants (glucose and oxygen) because energy left the **system [CCC-4]** as thermal energy or kinetic energy when the atoms got rearranged into new molecules. Mr. G then asked them if they could imagine a situation where a system would get cooler because of a chemical reaction, and they replied that energy would have to come into the system to make the energy of the products greater than the energy of the starting reactants. They discussed the chemical reactions in a first aid cold pack (figure 5.31).

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Figure 5.31. Two Different Categories of Chemical Reactions

Energy-Releasing Actions	Energy-Absorbing Actions
Total Energy of Reactants > Total Energy of Products	Total Energy of Reactants > Total Energy of Products
	

Comparing the total energy of reactants and of products, and relating their relative amounts to whether a reaction releases or absorbs energy. Provided by Dr. Art Sussman, courtesy of WestEd. Long description of Figure 5.31.

Days 10–13: Engineering design challenge to quantify energy released

Investigative Problem: How do we capture as much of the energy as possible in a calorimeter so that we can measure the chemical potential energy in food?

One of Mr. G's favorite hands-on activities to do with students had been to burn different kinds of foods to quantify and compare the amounts of thermal energy released per gram of food item. Several years ago he had stopped using this activity as he had concluded that while the students had enjoyed the activity, it had not reinforced their understandings of chemical potential energy in the ways that he had wanted. After participating in the CA NGSS professional development and planning with his middle grades team, he decided to try this activity in a different way that emphasized engineering design. He also wanted students to have more active roles than simply following directions, recording their results on a data sheet created by the teacher, and then doing the calculations based on a formula provided by the teacher.

The activity began with students bringing in food labels. Sharing the food labels with each other, the students raised **questions [SEP-1]** and also provided answers about food contents, the meaning of calories, and the connections with chemical reactions and chemical potential energy. Mr. G then showed the students a prototype calorimeter made out of a soda can. Students would refine this device to convert the chemical potential energy in the food to thermal energy (MS-PS1-6) that they can use to determine the number of calories of a food sample. The calculations were advanced for his middle grades students (they would complete this activity in the high school Three Course Model Chemistry in the Earth System course), but but Mr. G had set up an interactive spreadsheet where all they do is enter their measurements

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and they get the estimate of the food's calorie content. Mr. G wanted the students to optimize this prototype so that it created more accurate estimates. Students brainstormed a list of major **criteria [SEP-1]** for their design challenge that included safety, cost, and accuracy (MS ETS1 1). To make the device more accurate, they needed to capture as much of the **energy [CCC-5]** from the food as possible. Safety concerns placed constraints on the types of materials they could use (they must be non-flammable).

The student groups had numerous opportunities to share plans with each other, critique each other's ideas (MS-ETS1-2), and refine their plans before getting approval from Mr. G to proceed with the construction and testing of their devices. The class as a whole determined the foods that would be tested, again using the same design criteria but being especially cognizant of the issue of food allergies. Students collaboratively worked on designing the data sheets that they would use. In addition, students had multiple opportunities to iteratively test and improve their device subject to limitations imposed by the teacher and the rest of the class (MS-ETS1-4). During each test, students used the same food with a known calorie content and checked to see how well their device reproduced the known value and identified design elements of the calorimeters that worked best (MS-ETS1-3). At the end of the design and testing, students could use their calorimeter to measure the calorie content of other foods. Groups then shared posters that **communicated [SEP-8]** their design to their peers. They included diagrams with annotations that described how the different **structures [CCC-6]** and materials helped make the device meet the design criteria. Mr. G ensured that students made the connection that the transfer of energy from the food to the calorimeter was analogous to the energy transferred from food to animals as they eat and digest their food.

Day 14: Organism energy / matter system diagram

Investigative Phenomenon: Animals survive and grow by eating food.

Mr. G wanted the students to think about the food and calorimeter as a system, so he elicited from the students what they knew about **systems and system models [CCC-4]** in terms of drawing the boundary of a system, identifying the parts of the system, and identifying the system's inputs and outputs. As a whole class, they agreed on the conventions they would use in drawing the system. The students began by drawing a simple diagram of the energy transfer in their food calorimeter. Then, Mr. G told the class they were going to "zoom out" to **cycles of matter and the flows of energy [CCC-5]** in a larger system.

Returning to the river environment diagram, students worked in pairs and developed a system model to illustrate the **flows of matter and energy [CCC-5]** into and out of the deer and also into and out of the grass (MS-LS1-6). The class developed a consensus diagram (figure 5.32) after students worked on their separate team diagrams, critiqued each other's diagrams, iteratively improved them, and then finalized the diagram after whole-class discussion.

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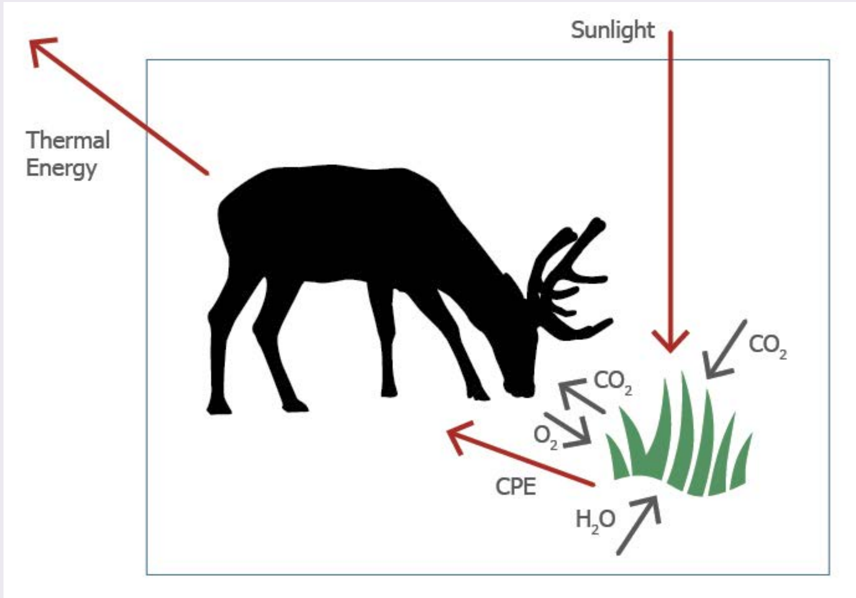
Figure 5.32. System Model to Illustrate Flows of Matter and Energy



Flows of energy and matter into, within, and out of a model of a Deer-Grass System. Thin red arrows represent energy and thick gray arrows represent matter. CPE is chemical potential energy. Provided by Dr. Art Sussman, courtesy of WestEd.
Long description of Figure 5.32.

Vignette Debrief

In this vignette, the teacher introduced phenomena related to physical and chemical changes using a comparison of the changes that had occurred in a river environment after 200 years. Students noticed changes to both the nonliving and living components of the environment. The vignette focused more on lessons that connected the physical and chemical changes with the life science processes of photosynthesis and respiration. Modeling the photosynthesis reaction was a major highlight that helped students conclude that atoms rearrange in chemical reactions, mass is conserved, and energy can be absorbed or released. In subsequent lessons within IS2, students will reach the same conclusions regarding Earth science processes.

This vignette illustrates the CA NGSS vision of blending SEPs, DCIs, and CCCs. While the lesson description describes this blend, the sections below focus on relevant aspects of each dimension in isolation, along with ties to CA CCSS and the EP&Cs.

SEPs. Students focused on **developing models [SEP-2]** throughout this vignette, by spending all of days 3-4, 8, 9, and 14 grappling with phenomena and trying to model them. These modeling experiences were not designed as assessments of learning at the end. Instead, Mr. G used these modeling opportunities to motivate and frame the learning—students recognized limitations and missing pieces in their understanding when they built the

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models. For example, the “Energy Love” investigations on days 6–8 were included because students did not know how to represent energy in their models because they didn’t understand enough about energy yet. On days 1–2, students **analyzed data [SEP-4]** in the sense that they looked for **patterns [CCC-1]** in their qualitative observations and made categories based on those patterns. Mr. G chose to introduce the distinctions of “physical versus chemical change” by having students discover the categories themselves and then refine their labels to reflect the current state of scientific vocabulary, rather than beginning with definitions of the scientific terminology.

DCIs. Chemical reactions (PS1.B), the energy in chemical reactions (PS3.D), and energy and matter flow in organisms (LS1.C) were the common thread through the entire lesson. Students extended their understanding of matter made up of atoms and molecules (PS1.A) through their physical modeling on days 3–5 and 9. On days 6–8, students grappled with the definitions of energy (PS3.A). The engineering challenge on days 10–13 allowed students to focus on all aspects of engineering design (ETS1) and they even briefly addressed these core ideas on day 3 when they tried to find the best way to represent molecules using a physical model.

CCCs. Student models focused on the exchange of **energy and matter [CCC-5]** between components of chemical systems (days 3–5), macroscopic physical systems (days 6–8), a calorimeter system (days 10–13), and a small section of an entire ecosystem (day 14). While students had tracked the flow of matter in elementary school, tracking energy as it changed between various forms was the key addition to understanding CCC-5 at the middle grades level (see the progressions in appendix 1 of this framework). While **systems [CCC-4]** were inherent in the modeling, very little discussion in the vignette, as written, was explicitly devoted to thinking of these situations as system. That explicit discussion would be done as part of the classroom discourse not captured in this vignette.

EP&Cs. As written, Mr. G did not explicitly address any of the EP&Cs, though the skills students developed discussing the cycling of matter in their modeling were crucial for understanding EP&C IV (“The exchange of matter between natural systems and human societies affects the long-term functioning of both”). Mr. G easily could have extended this vignette another day to fast forward into the future with another environment diagram showing human impacts from pollution, or by tracking toxins in the day 14 diagrams that show matter exchanged between organisms.

CA CCSS Connections to English Language Arts and Mathematics. Students engage in structured discourse (SL.7.1) with teams throughout the vignette, including evaluating and reviewing the ideas of their peers on days 2, 3–4, during the engineering design challenge on days 10–13 and again on day 14. The students calculate the calories in food samples using an interactive spreadsheet (MP.5).

Resources:

Daehler, Kirsten, and Jennifer Folsom. 2013. *Making Sense of SCIENCE: Earth Systems*. San Francisco: WestEd.

Daehler, Kirsten, Mayumi Shinohara, and Jennifer Folsom. 2011a. *Making Sense of SCIENCE: Energy*. San Francisco: WestEd.

Rock Cycles and Earth's Energy Flows

The second half of IS2 involves applying the same physical science concepts explored in the vignette to the **cycling of Earth's materials [CCC-5]** and the **flows of energy [CCC-5]** that drive these processes (MS-ESS2-1). Rocks and minerals make up the vast majority of the planet's mass. They provide homes for organisms, make many of Earth's surface landforms, and provide the basis for all of Earth's soil. Students return to the environment diagram of figure 5.28 and focus on the rocks. Can they identify evidence of places where rocks are forming or changing? The class makes a list of all the different things they can think of that can happen to rocks: eroded by the river, erupted from a volcano, buried at the bottom of a landslide, broken up by roots, eaten as a speck of soil on a piece of grass, dust blown by the wind, etc. Students engage in a jigsaw where different students read a short article about a particular location on Earth that exemplifies one transformation in the rock cycle. The articles have pictures of rocks and the locations where they were found that highlight the evidence for the change (i.e., a volcanic rock has holes in it that are evidence of gas bubbles, and it came from a long outcrop that heads straight downhill providing evidence that the material once flowed as a liquid at the surface). Students then come together for a "rock summit" to describe the possible events that can befall a piece of rock.

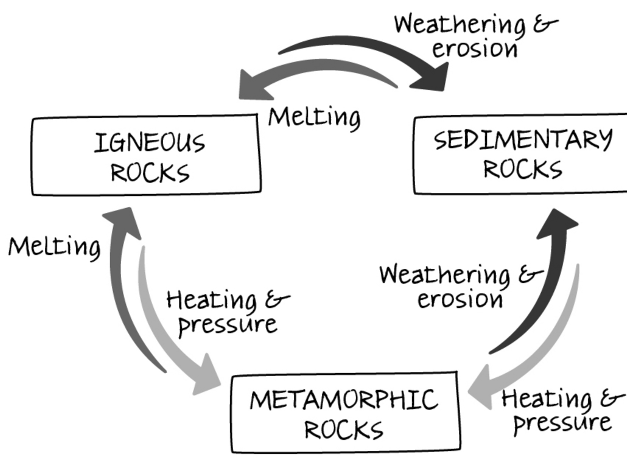
Students write a fictional short story tracing the path of one rock through many adventures. As an illustration for this piece, they depict the path of their imaginary rock on a flowchart. As students compare their flowcharts, they see that no two rocks follow the same path. This idea is critical because it counters the preconception that many students have when they read materials about the "rock cycle"—since these materials are written on a page they have a linear flow that implies there is only one path. Next, students work in groups to create a physical model of one rock story using crayons or sugar cubes. Both these materials can be melted, solidified, broken apart, dissolved (for sugar), pressed together (for crayons). Students will record the process in a video that captures how their rock changes. They start by making a storyboard to plan the physical processes they will depict in each scene and also their narration for that scene. In the narration, they must emphasize where the **energy [CCC-5]** comes from that drives the transformation in each scene. They discuss both the energy in the physical model as well as where the energy source would be in the real Earth system. If students have uncertainty about where the energy comes from in the Earth system, they return to the jigsaw articles or the teacher can engage in whole-class discussions and provide additional information. The paragraphs below provide some of this background for teachers, and curriculum developers can find excellent examples within California and beyond of case studies that exemplify and describe these processes and the evidence for them.

Many rock changes are driven by the transfer of Earth's internal thermal energy. 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. Rocks can melt as they move closer to Earth's hot interior, and molten rock can solidify as it rises towards Earth's surface where temperatures are cooler. The movement of rocks upward and downward is often related to the motions of plate tectonics. 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.

Near the surface, rocks also form and break down by interacting with other Earth systems—namely, the atmosphere, hydrosphere (Earth's water including ice), and biosphere (Earth's life). For example, exposure to air, wind, and biological activity all **cause [CCC-2]** rock to weather (change physically or chemically). Chemical weathering by the atmosphere, hydrosphere, and biosphere occurs when chemical reactions break down the chemical bonds that hold rocks together. Physical weathering causes rocks to physically break into smaller pieces but does not change the rock's chemical bonds. Energy that drives these surface processes comes from the Sun (which provides thermal energy that drives chemical reactions and also causes the movements of wind and water in the atmosphere and biosphere), gravity (and its constant downward pull on air, water, and rock), and the chemical potential energy within the biosphere (which ultimately comes from the Sun).

After students have explored and modeled these processes, they can label them with scientific terms. Observation and explanation of phenomena drive instruction in the CA NGSS, not terminology. With this terminology, students can develop something like figure 5.33, 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). Students can **evaluate [SEP-8]** the benefits and limitations of this classic rock cycle diagram (table 5.9).

Figure 5.33. Classic Rock Cycle Diagram



The classic rock cycle diagram summarizes the three types of rocks and a circular pattern of movements of rock materials. *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 5.33.

Table 5.9. 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 (students encountered this information at the end of IS1 when they simulated data collection of materials in the environment diagram of the river). Just six elements (aluminum, iron, magnesium, calcium, sodium, and potassium) make up practically all the rest of Earth's crust. Atoms of these eight elements combine to form the vast majority of 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 relatively **stable [CCC-7]**.

IS3 Integrated Grade Seven Instructional Segment 3: Natural Processes and Human Activities Shape Earth's Resources and Ecosystems

When students look out on a landscape, they might see trees in some places but not others and a gold mine on one hill but not another. In this instructional segment, students focus on explaining why things are located where they are, including organisms within an ecosystem and resources and hazards on the planet. In both cases, interactions within and between different Earth systems determine these distributions. Humans both depend on these distributions and can dramatically alter them. The goal of integrating these topics is that the questions students learn to ask about the distribution of resources on the planet can serve as a template for understanding the relationships between organisms in an ecosystem, and vice versa.

INTEGRATED GRADE SEVEN INSTRUCTIONAL SEGMENT 3: NATURAL PROCESSES AND HUMAN ACTIVITIES SHAPE EARTH'S RESOURCES AND ECOSYSTEMS

Guiding Questions

- How can we use interactions between individual rocks or individual organisms to understand systems as big as the whole geosphere or whole ecosystem?
- How can we use patterns in geosphere interactions to predict the location of resources?
- How can we use patterns in ecosystem interactions to predict how organisms compete and share resources?

Performance Expectations

Students who demonstrate understanding can do the following:

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-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.]

INTEGRATED GRADE SEVEN INSTRUCTIONAL SEGMENT 3: NATURAL PROCESSES AND HUMAN ACTIVITIES SHAPE EARTH'S RESOURCES AND ECOSYSTEMS

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.*]

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-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.*] (Revisited from IS1, but not assessed until IS4)

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.*]

INTEGRATED GRADE SEVEN INSTRUCTIONAL SEGMENT 3: NATURAL PROCESSES AND HUMAN ACTIVITIES SHAPE EARTH'S RESOURCES AND ECOSYSTEMS

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	LS2.A: Interdependent Relationships in Ecosystems LS2.B: Cycles of Matter and Energy Transfer in Ecosystems ESS1.C: The History of Planet Earth ESS2.B: Plate Tectonics and Large-Scale System Interactions ESS3.A: Natural Resources PS1.A: Structure and Properties of Matter PS1.B: Chemical Reactions	[CCC-1] Patterns [CCC-2] Cause and Effect: Mechanism and Explanation [CCC-5] Energy and Matter: Flows, Cycles, and Conservation [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 complex and involve many factors.

CA CCSS Math Connections: 6.EE.6, 9, 6.SP.4, 5, 6.RP.3,7.EE.4, MP.2

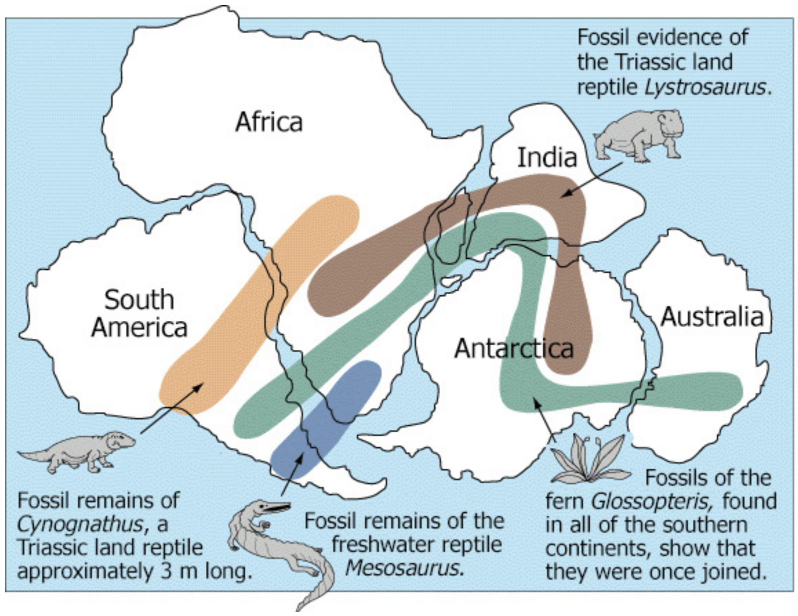
CA CCSS for ELA/Literacy Connections: RST.6–8.1, 2, 7, 9, WHST.6–8.1, 2, 9, SL.7.1, SL.7.4, SL.7.5

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

Back in Integrated Grade Six, students examined a satellite view of California and explained some of the features they saw (figure 5.4). In grade seven, they return to that image and look for evidence of mountains. California has two main mountain ranges, one along the coast and one on the east side. The anchoring phenomenon the students consider is that both of these mountain ranges run roughly parallel to the coastline. Is the fact that all three of these features are aligned a coincidence? Students engage in a case study of a scientist from the early 1900s named Alfred Wegener, who also began by looking at the locations of mountain ranges and noticed some **patterns [CCC-1]** (MS-ESS2-3). Students begin by reading short geologic descriptions of rocks in the Appalachian Mountains, the Scottish Highlands, South Africa, Brazil, and a few other localities (thrown in for contrast) based on scientific journal articles that Wegener himself read back in the early 1900s. Students identify that the rocks in the Appalachian Mountains have very similar features to those in the Scottish Highlands; rocks from South Africa and Brazil are also similar to one another but different from the other pair. Despite the fact that each pair of rock formations is relatively distinct, each has a matching partner half way around the world. Wegener **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. Students can repeat this jigsaw puzzle activity with paper and scissors and identify specific places where it works well and others where it does not.

Even more persuasive was **evidence [SEP-7]** from fossils. Students can engage in an activity in which they collect samples from around the globe and place them on a map. They discover dozens of different species, but which species support Wegener's claim? Do any of them provide evidence that contradicts his claim? They might end up with a map similar to figure 5.34 that 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 5.34. Fossil Evidence of Continental Drift



A summary of Wegener's fossil evidence that Southern Hemisphere continents were once joined together. *Source:* United States Geological Survey (USGS) 1999
Long description of Figure 5.34.

Wegener also traced the past positions and motions of ancient glaciers based on grooves in rocks cut by those glaciers, and also by rock deposits that the glaciers left on different continents. After **obtaining information [SEP-8]** about how to recognize these features, students can **analyze [SEP-4]** pictures of rock outcrops from around the world and decide if they show evidence of ancient glacial activity. Plotting these locations on a map, they can compare them to the locations of present-day glaciers. Like Wegener, they find that locations currently near the equator show evidence of ancient glaciers, an extremely unlikely situation if the continents had not moved. If the continents moved as Wegener hypothesized, those glaciers would have formed much closer to the South Pole.

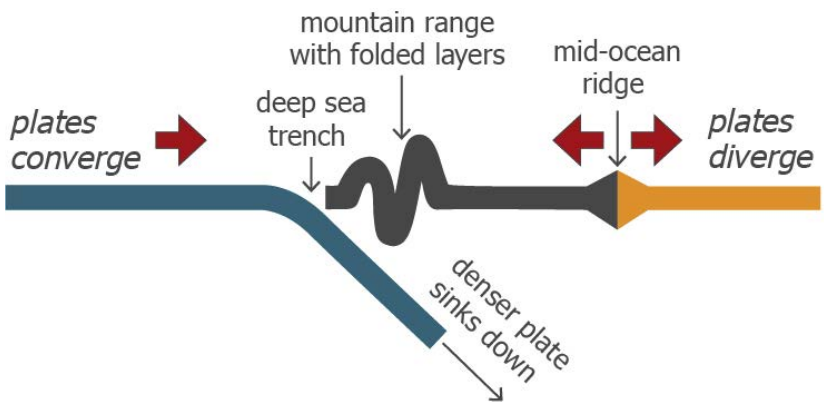
While we often say that Wegener compiled **evidence [SEP-7]**, it is important to note that he built on the work of dozens of scientists of the day. At the time Wegener lived, there was no way to determine the exact age of rocks, but geologists could reconstruct the relative timing of events by correlating sequences of rock layers from one place to another (MS-ESS1-4, as discussed in IS4). Even though Wegener never visited the Andes and 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 drifting apart of the Atlantic Ocean. 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, early twentieth-century geologists rejected Wegener's claims. Middle grades students focus first on **analyzing [SEP-4]** the evidence accumulated since Wegener's time that provides even more definitive evidence that there has been motion of plates (MS-ESS2-3). 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 water 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.

With some ocean basins 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 appearing to get smaller in other locations. Scientists had long recognized **evidence [SEP-7]** for "shortening" on Earth because of evidence from sedimentary rock layers. In IS2, students discussed sedimentary rocks that 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. If the seafloor was known to spread 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 floor of 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 just a simple consequence of the geometry of a bending block, with the trench forming at the inflection point where the block plunging downward starts to curve (figure 5.35). 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 5.35. 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 5.35.

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 provide strong **evidence [SEP-7]** that plates move apart at some locations, move together at others, and slide past one another in still 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 and Earth Resources

In IS1, students **obtained information [SEP-8]** about how synthetic materials come from natural resources (MS-PS1-3). Many of these resources are related to plate tectonic processes, which means that different parts of the world have access to different raw materials and different parts of the world are impacted differently by resource extraction. Students should be able to **explain [SEP-6]** why certain mineral, energy, and groundwater resources exist where they do on Earth (MS-ESS3-1). Students can begin by **analyzing [SEP-4]** maps showing the spatial distribution of different resources on Earth, recognizing **patterns [CCC-1]**, and **asking questions [SEP-1]** about what they see. Using computer-based mapping programs, students can turn on and off different layers to help see how locations of different resources compare to one another and other geologic features like plate boundaries.

Students might notice that 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 utilize geothermal resources, but there are no geothermal power plants east of North Dakota in the United States. Why? After **obtaining information [SEP 8]** about geothermal power, students can **construct an explanation [SEP 6]** linking their distribution to plate boundaries. 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.

Copper, gold, and other precious metal resources, however, seem to be located all over the world and not always related to plate boundaries. Why? Students **obtain information [SEP-8]** about how metal ores form and develop a **pictorial model [SEP 2]** showing the steps: 1) hot fluids dissolve metals from rocks deep underground; 2) hot fluids carry the metals until conditions change and the metals solidify in concentrated zones; 3) plate tectonic forces push the mineral deposits close to the surface where they can be easily mined; 4) time passes and plate boundaries can change. Plate motions are usually involved in the first three stages, but the fourth stage means that today's mineral resources can be very far away from today's plate boundaries.

Fossil fuel distribution is one the most politically important uneven distributions of energy resources: it is also tied to plate tectonics. The Middle East has about half of the world's proven reserves of crude oil and California has less than 0.2 percent. Why? 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 this process in high school.

Next students can **evaluate the claim [SEP-7]**, "Without plate tectonics, we would have no groundwater resources." Students **obtain information [SEP-8]** about where groundwater basins are located and how they form. The best groundwater basins are in valleys where a large amount of sediment has continuously been deposited, such as the Central Valley, which receives 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 grade six, 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.

Opportunities for ELA/ELD Connections

As a summarizing activity regarding how the process of plate tectonics influences the uneven distribution of Earth's natural resources, students are placed in triads. Each student explains how Earth's mineral, energy, or groundwater resources have given shape to some of Earth's features. The P-E-E structure (Point, Evidence, and Explanation) can be used by each student. In the triads, students take turns sharing their findings.

CA CCSS for ELA/Literacy Standards: WHST.6–8.1, 7; SL.6–8.1

CA ELD Standards: ELD.PI.6–8.3

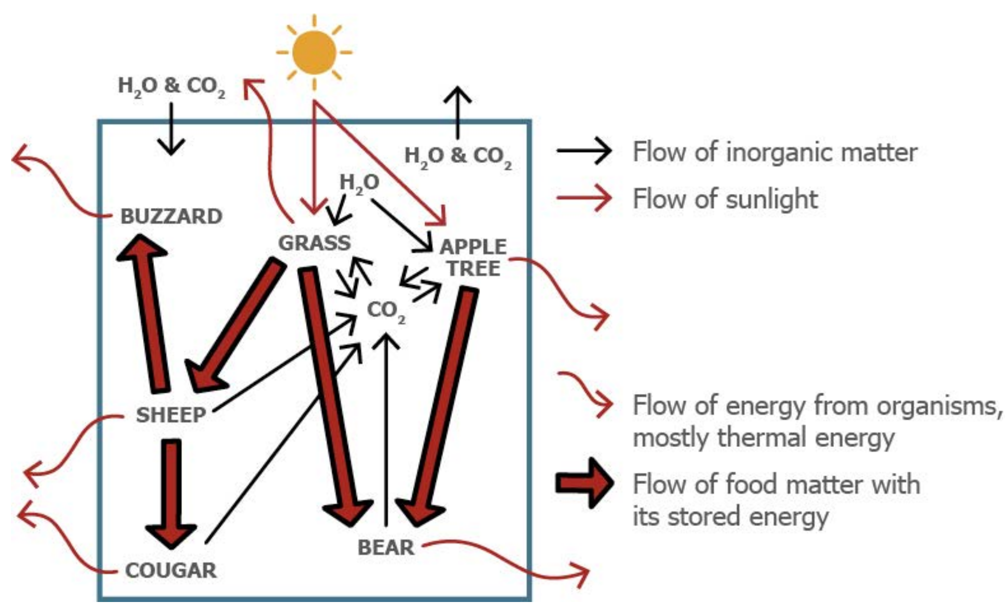
Ecosystem Models

Water and other natural resources provide strong links with the IS3 life science ecosystem performance expectations and DCIs. In IS2, students traced the path of an individual piece of rock matter and then came to IS3 to discover that there were global **patterns [CCC-1]** where certain types of rocks experienced similar paths due to global-scale cycles. Now, students will extend their models at the molecular and organism **scale [CCC-3]** from IS2 up to ecosystems and notice **patterns [CCC-1]** in the way **energy/matter [CCC-5]** are exchanged between **components [CCC-4]** of the ecosystem.

Students return to the environment diagram of figure 5.26 and **develop a system model [SEP-2]** of the ecosystem it depicts. In systems models, students track the flow of energy and matter between components. Biological systems are complex in that food delivers both energy and matter in the same package. Biologists use the term *biomass* to describe complex carbon molecules that organisms can use as building blocks to manufacture, replace, and repair their internal structures. The biomass molecules also have significant stored chemical potential energy that organisms can use to survive and grow. In the example system model diagram in figure 5.36, a black arrow with a reddish interior signifies the transfer of that coupled matter and energy through the eating of food.

Simple black arrows 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. These black arrows include respiration of carbon dioxide out of plants and animals back into the local environment.

Figure 5.36. Ecosystem Cycles of Matter and Flows of Energy



A model of the flows of energy and matter into, within, and out of a simplified ecosystem. The wider arrows represent transfers of matter and energy coupled together in biomass. Diagram by Dr. Art Sussman, courtesy of WestEd.
Long description of Figure 5.36.

The red arrows in figure 5.36 identify different **flows of energy [CCC-5]**, with the straight arrows indicating sunlight and the red centers of the biomass arrows representing the energy portion of food. The wavy red arrows represent “waste heat” that escapes and leaves the system as heat given off during respiration and other essential chemical reactions in organisms.

A model such as figure 5.36 can become much more complex if the developer of the model chooses to increase the kinds of **flows of matter and energy [CCC-5]** and/or the number and types of organisms that are included. This complexity can pose a problem, but it can also provide great learning opportunities in situations where productive academic discourse flourishes.

Students should be **asking [SEP-1]** themselves and their peers about which features are important to display in the model and why? The CCC of **system models [CCC-4]** teaches that “[m]odels are limited in that they only represent certain aspects of the system under study.” The students get to choose what features to include, but they need to provide **evidence-based explanations [SEP-6]** for why they have included those features. A necessary part of gaining proficiency in the SEP of **developing and using models [SEP-2]** involves learning to wisely choose and omit features so that the model is powerful enough to predict and explain phenomena but not too complex so as to be overwhelming or dwell on unimportant details.

Taking time to explicitly focus on the meaning of the CCCs helps students become better scientific thinkers. Ecosystem models provide insight into why the writers of the NGSS purposely differentiated the phrasing “*cycles* of energy” and “*flows* of matter” in CCC-5. In figure 5.36, many of the energy arrows are going into and out of the system (*flow*), but the majority of the matter arrows remain within the system (*cycle*). This particular model includes two black arrows to indicate that no ecosystem is a closed system for matter. There are flows of matter, such as carbon dioxide and water in the air, that move into and out of ecosystems. Human activities can regularly disrupt the cycles of matter by adding pollution or taking away resources (EP&C IV).

With their ecosystem model in place, students can fully use it to identify what happens when one section of an ecosystem changes and there is a scarcity of energy or matter input. Students can use the model to predict which organisms will be affected first if, for example, there is a sudden decrease in sunlight or if CO_2 concentrations change in the atmosphere. Students can then **analyze and interpret [SEP-4]** population data from case studies of ecosystem change (MS-LS2-1) such as the effect of a prolonged drought on California’s forest ecosystem. How are tree survival and growth affected and how do these changes affect other organisms throughout the ecosystem? Students can develop new system models for each case study ecosystem. As they compare system models for multiple ecosystems, they begin to see and describe **patterns [CCC-1]** recurring in the relationships between organisms (MS-LS2-2). Students should be able to identify relationships common to most ecosystems such as (1) organisms that compete for resources because they both have biomass arrows originating from the same source; (2) predatory relationships where the biomass from one animal goes to another; and (3) mutually beneficial relationships where arrows of energy, mass, or other benefits point in both directions between a pair of organisms. The goal is that students should be able to use ecosystem models to predict which organisms will compete if resources become scarce (MS-LS2-2).

IS4 Integrated Grade Seven Instructional Segment 4: Sustaining Biodiversity and Ecosystem Services in a Changing World

INTEGRATED GRADE SEVEN INSTRUCTIONAL SEGMENT 4: SUSTAINING BIODIVERSITY AND ECOSYSTEMS SERVICE IN A CHANGING WORLD

Guiding Questions

- What natural processes and human activities threaten biodiversity and ecosystem services?
- How can people help sustain biodiversity and ecosystem services in a changing world?

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.]

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.]

INTEGRATED GRADE SEVEN INSTRUCTIONAL SEGMENT 4: SUSTAINING BIODIVERSITY AND ECOSYSTEMS SERVICE IN A CHANGING WORLD

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-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.*] (Assessed after being introduced in IS1 and IS3.)

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.

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

INTEGRATED GRADE SEVEN INSTRUCTIONAL SEGMENT 4: SUSTAINING BIODIVERSITY AND ECOSYSTEMS SERVICE IN A CHANGING WORLD

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) [SEP-7] Engaging in Argument from Evidence [SEP-8] Obtaining, Evaluating, and Communicating Information	LS2.C: Ecosystem Dynamics, Functioning and Resilience LS4.D: Biodiversity and Humans ESS2.A: Earth Materials and Systems ESS2.C: Roles of Water in Earth's Surface Processes ESS3.B: Natural Hazards PS1.A: Structure and Properties of Matter PS1.B: Chemical Reactions ETS1.A: Defining and Delimiting Engineering Problems 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-6] Structure and Function [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: MP.2, MP.4, 6.EE.6, 6.RP.3, 7.EE.4

CA CCSS for ELA/Literacy Connections: RI.7.8, RST.6–8.1, 7, 8, WHST.6–8.1, 2, 9, SL.7.5

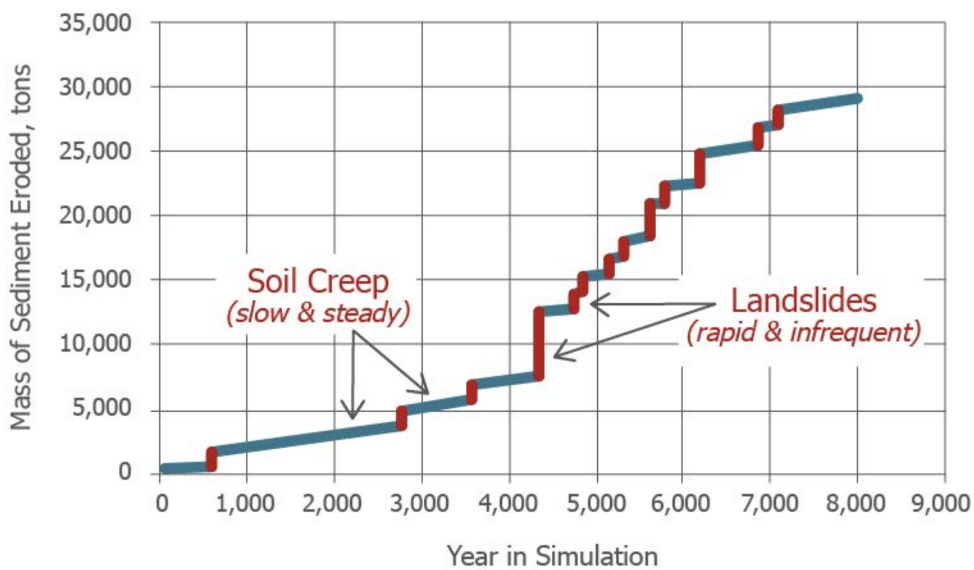
CA ELD Connections: ELD.PI.6.1, 5, 6a–b, 9, 10, 11a

Erosion is a part of everyday life in ecosystems, and plant root systems have evolved to help keep plants stable and soil in place. Every so often, erosion events become dramatic in the form of landslides. And even more rarely, a single event can trigger thousands of landslides at once. That was the case in 1994 during the Northridge Earthquake when the shaking triggered 11,000 simultaneous landslides in the mountains of Southern California (USGS 1995), each one tearing up root systems and completely transforming both the shape of the landscape and the life on it. These mega-landslide events are the anchoring phenomenon for this instructional segment, and they do not just happen during earthquakes. Over just three days in 1982, heavy rains triggered more than 18,000 landslides in the San Francisco Bay Area (USGS 1988) and landslides following wildfire are a constant concern throughout the state. After students **obtain information [SEP-8]** about these mega-landslide events, they can **ask questions [SEP-1]** about the factors that **cause [CCC-2]** landslides and how they affect the environment.

Students can examine case studies of smaller landslides, rock falls, and mud flows. While standard textbooks spend quite a bit of time discussing types of landslides, that terminology is not the focus. Instead, the emphasis is on process. What patterns do students recognize in the locations where landslides hit? They should be able to identify steep slopes, weakness of material, and often (but not always) some sort of triggering mechanism. As a preview for MS-PS2-2 in grade eight, students can review the core idea that multiple forces act on stationary objects, and those objects start moving when forces are no longer balanced (PS2.A, 3-PS2-1). Students can treat the block of soil or rock as a single object (the "landslide mass'") and identify the forces acting on it including gravity and some sort of friction or cohesion that keeps it in place. Students can use this information to begin to build a **pictorial model [SEP-2]** of what **causes [CCC-2]** landslides that will allow them to predict when and where landslides will occur. Students can also create **physical models [SEP-2]** of the situation by placing blocks on ramps and changing the angle. If they shake the ramp simulating an earthquake or add mass to the upslope side of the block, they add to the forces driving the block downslope; finding some way to lubricate the ramp reduces the force restraining the block. The added mass of rainwater and the construction of a large building are real-life examples of adding mass to a slide block. Rainwater percolating into pores can "lubricate" landslides, but far more common ways of reducing resisting forces are when material on the downhill side of a landslide block gets eroded away by rivers or cut away by people building roads or buildings. Students can use their physical model to consider general approaches that people can use to reduce landslide hazard. What would a plant root do to this situation? Vegetation predominantly reduces landslide hazard because roots spread through the soil like anchored netting, but roots also have a competing effect where they weaken material by breaking rocks apart. In some situations, the latter may become more important than the former. Students have to struggle with this apparent contradiction and add both processes into their model of landslides.

The clarification statement for MS-ESS2-2 emphasizes one of the key Earth and space science DCIs for middle grades that geologic processes can cause change that is slow, rapid, or combinations of both. Like all natural hazards, landslides happen infrequently, vary in size, and are caused by specific physical conditions that allow us to forecast where they will occur (ESS3.B). Smaller landslides are more common just like small earthquakes or smaller storms occur more frequently than destructive earthquakes and hurricanes. Since the magnitudes of hazards are important, students can look at landslides through the lens of **scale, proportion, and quantity [CCC-3]** and ask other interesting questions. For example, which form of erosion is more "important" in a landscape, the slow and steady wearing away of material or the sudden catastrophic movement of large landslides? Students can **analyze data [SEP-4]** about the amount of material eroded by each process from actual scientific observations (Swanson, Fredriksen, and McCorison 1982; Pearce and Watson 1986) or computer simulations (figure 5.37).

Figure 5.37. Landslides and Slow Processes Both Contribute to Erosion



In a computer simulation of a watershed, scientists recorded over a period of 8,000 years how much sediment moved by slow and steady processes, like soil creep, and how much by rapid and infrequent landslides. Which process caused more erosion in this simulation? Does the simulated watershed have hills or is it mostly flat? *Source:* M. d'Alessio using simulation results of Benda and Dunne 1997.
Long description of Figure 5.37.

Engineering Connection: Landslide Early-Warning System

With this model of landslide causes, students consider a small region, predict where the landslide hazards are greatest, and design a warning system to minimize their damage (MS-ESS3-2). Using computer-based map layers (such as in Google Earth) showing slope steepness, rock strength, annual rainfall, and/or expected ground shaking in an earthquake, students can identify areas that are most likely to slide. They can compare their predictions to published maps of landslide hazard for California or the locations of actual catastrophic landslides in 1982 or 1994 (USGS 1988, 1995). Students could use this information to **design [SEP-6]** a landslide warning system that works in conjunction with the National Weather Service weather forecasts (such a system actually exists, https://www.cde.ca.gov/ci/sc/cf/ch5.asp#link15). Students need to **define the problem [SEP-1]** by figuring out what information could minimize loss of life in landslides and how to get the information to the community (MS-ETS1-1).

Landslides cause major disruption to ecosystems. They can temporarily dam rivers, uproot vegetation, bury habitat, and increase the sediment in rivers so much that aquatic life “chokes.” Students can examine case studies of the effects of landslides on steelhead trout populations, including short-term concerns about the spawning habitat of local salmon (Cornwell 2014; Ruggerone 2008) or a landslide that blocked a river for hundreds of years and forced a major genetic shift in two populations of steelhead (American Geophysical Union 2011; Mackey, Roering, and Lamb 2011). On the land itself, landslides create a sudden availability of new resources in the ecosystem (such as space, sunlight, and broken up soil). Students can predict what they think will happen in the ecosystem and then obtain information about how the succession of vegetation following major ecosystem disruptions like landslides, fires, or volcanic eruptions (ecosystem change following the 1980 Mount St. Helens volcanic eruption is particularly well studied). Students should use these examples as evidence to **construct an argument [SEP-7]** that changes to physical or biological components of an ecosystem affect populations of organisms within that ecosystem (MS-LS2-4).

Human-Induced Changes to Ecosystems

Sometimes the major changes to ecosystem components are not caused by natural hazards, but by humans who now impact the environment at the scale of the planet as a whole. Students in Integrated Grade Six analyze evidence that human activities, especially combustion of fossil fuels, have caused global temperatures to increase over the past century. Students in Integrated Grade Eight explore the impacts of increasing human populations and increasing per-capita consumption of resources.

Designing and testing solutions to these kinds of environmental challenges require a different kind of engineering design. Students' prior experiences with engineering design probably focused on specific devices, such as the calorimeter highlighted in IS2. At the middle grades level, the challenges can be at a higher level of generality, and also more strongly connected with personal and societal values. In challenges involving protecting biodiversity and ecosystem services (MS-LS2-5), some of the criteria, evaluations, and decisions will inevitably be strongly influenced by ethical, economic, and cultural valuations.

California's Environmental Principles and Concepts (EP&Cs) can provide guidance in implementing these design challenges. All five of the environmental principles apply to IS4. 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 [CCC-5]** and ecosystem processes, students are primed to apply California's EP&Cs. For example, there are three concepts associated with Principle III:

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

The **systems [CCC-4]** thinking and **modeling [SEP-2]** embedded within Integrated Grade Seven provide a scientific framework evaluating design solutions. The models students made of energy **flow and matter cycles [CCC-5]** at the ecosystem scale apply to planetary scale problems as well with one significant difference: some matter (e.g., carbon dioxide and water) enters and leaves an ecosystem, but when considering the planetary scale, matter essentially does not leave or enter. All of Earth's ecosystems are linked with each other through their sharing of the atmosphere and the hydrosphere. Each of the elements vital to life on Earth exists in a closed loop of cyclical changes.

The environmental human impacts that students explore throughout the middle grades ultimately relate to the effects of human activities on Earth's cycles of matter, flows of energy, and web of life. In some challenges, such as habitat destruction or introduction of exotic species, the main direct impacts are on the local web of life. This local web of life is also often impacted by pollution. Essentially all pollution issues result from activities that contaminate or disrupt Earth's natural cycles of matter. In many cases, the pollution includes adding synthetic materials to the natural system. Even though these materials have been produced from natural resources and materials, humans altered them by chemical processes such that some of them can now harm ecosystems, and in turn harm humans (EP&Cs I–IV).

As part of the design challenge, students should gather any relevant information about how synthetic materials have affected the ecosystem and society (MS-PS1-3).

In this design challenge, students need to identify a specific problem in an ecosystem (MS-ETS1-1) that considers the relationship between people and the natural environment. This problem may be based on a large-scale investigation as described in the snapshot below. The goal is to “improve” an ecosystem by reducing human impacts, and two measures of a healthy ecosystem are biodiversity within the ecosystem and the richness of services the ecosystem provides to people. Students should choose some aspect of biodiversity or ecosystem services as measurable criteria they can track to evaluate the progress of their proposed solutions (MS-LS2-5). Students should be able to use a system model of their ecosystem to evaluate the relative merits of different solutions (MS-ETS1-2).

Integrated Grade Seven Snapshot 5.5: Planning a Large-Scale Investigation

Investigative problem: How can we restore a habitat so that it is less influenced by human activities?

Motivated by an article they read about kids making a difference, Mr. R's class decided to plan a habitat restoration project. Mr. R explained that to be effective with habitat restoration they needed to learn more about the ecosystems. He asked the class, “How would we begin a scientific study of our local ecosystems so we learn enough to work on a restoration?” Students responded that the best way to begin an investigation was to **ask scientific questions [SEP-1]**. Students began writing questions about local ecosystems at the nature center or that they had experienced in other ways. Soon the teams had numerous questions to share so they began posting them on their team flipcharts. While the teams were writing their questions, Mr. R visited and guided their discussions, as needed.

With all the questions posted, Mr. R asked the students if they noticed any **patterns [CCC-1]** among the questions. Several pointed out that some of the questions seemed to focus on the plants and animals, and others were more focused on things like the soil, rocks, water, and other parts of the physical surroundings. Mr. R asked the students to return to their flipcharts and put a big “P” next to questions that involved physical components and a big “B” next those that involved the biological components of ecosystems. Students had to provide **examples and reasoning [SEP-7]** about how these different components could **affect [CCC-2]** the population of organisms (MS-LS2-4); their reasoning referred to **models [SEP-2]** of the **flow of energy and cycling of matter [CCC-5]** in their ecosystem (MS-LS2-3) and geoscience processes that alter the physical environment (MS-ESS2-2).

Integrated Grade Seven Snapshot 5.5: Planning a Large-Scale Investigation

Returning to the students' concerns about the effect of human activities on the local ecosystems, Mr. R decided to initiate a discussion related to California Environmental Principle II: *The long-term functioning and health of terrestrial, freshwater, coastal and marine ecosystems are influenced by their relationships with human societies*. He suggested that the teams think about some additional questions that would help them learn how human activities were affecting the functioning and health of ecosystems.

The class and Mr. R had been talking about the difference between conducting an investigation that someone else had created compared with **planning and conducting your own investigation [SEP-3]**. Students reminded Mr. R about that discussion, and said they wanted to plan their ecosystem investigation. With student teams standing near their charts, each team shared one or two of their questions. He mentioned that the class would have the opportunity to vote on which questions they wanted to investigate. Mr. R then reminded students to think about the question scaffolding process they had learned about in their English language arts class, making sure that, when put all together, their questions and data should help them better understand populations and biodiversity, the physical and biological components of ecosystems, and how ecosystems are affected by human activities.

The class continued to discuss which questions would be best and soon realized that they would need data to compare the disturbed ecosystem they wanted to restore with a more natural example of that same ecosystem. The students pointed out that this process would help them plan how their restoration work might mitigate the effects of human activities at their study sites. Following much discussion, the students selected five questions for their class investigation:

- What plants and animals live in the disturbed and undisturbed ecosystem study sites?
- What are the physical and biological components of the two study sites?
- What natural processes and ecosystem services in the two study sites support the ecosystems?
- What natural processes and ecosystem services in the two study sites help humans?
- What human activities are occurring in the two study sites?

Students realized that both natural and disturbed ecosystems were changing; they hoped to be able to document how the rates of natural **change [CCC-7]** compared to the rates of human-induced changes (ESS3.C). Mr. R shared these questions with the volunteers at a local nature center who had tried to help him prepare the investigation. Mr. R couldn't make the logistics work out, but he started planning for next year. Even if it never worked out, Mr. R decided that the activity of planning the investigation was worthwhile for his students. He thought about how to frame the activity next year so that it would feel authentic but also so that the students wouldn't feel disappointed if they couldn't actually implement their project. His goal was to eventually have students propose design solutions for their habitat restoration and then evaluate the different proposals (MS-LS2-5). Their restoration plans would require attentiveness to the biosphere as well as the other Earth systems.

Grade Eight Preferred Integrated Course Model

This section is meant to be a guide for educators on how to approach the teaching of the California Next Generation Science Standards (CA NGSS) in grade eight according to the Integrated Model (see the introduction to this chapter for further details regarding different models for grades six, seven, and eight). It 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 into integrated groups that can effectively guide instruction in four sequential instructional segments (IS). There is no prescription regarding the relative amount of time to be spent on each instructional segment. As shown in figure 5.38, the overarching guiding concept for the entire year is "The processes that change Earth's systems at different spatial scales today also caused changes in the past."

Figure 5.38. Grade Eight Integrated Storyline

Guiding Concept: The processes that change Earth systems at different spatial scales today also caused changes in the past.

Instructional Segment	1 Objects move and collide.	2 Noncontact forces influence phenomena locally and in the solar system.	3 Evolution explains life's unity and diversity.	4 Human activities help sustain biodiversity and ecosystem services in a changing world.
Life Science (LS)	Living systems are affected by physical changes in the environment. Both the physical and biological changes are recorded in the fossil record.	N/A	Mutations in genes affect organisms' structures and functions. Evidence from fossils, anatomy, and embryos support the theory of biological evolution. Natural selection is the main mechanism that leads to evolution of species that are adapted to their environment.	Changes to environments can affect probabilities of survival and reproduction of individual organisms, which can result in significant changes to populations and species.
Earth and Space Sciences (ESS)	The fossil record documents the existence, diversity, extinction, and change of life forms throughout Earth's history.	Models explain lunar phases and eclipses of the Sun and Moon. Gravity plays the major role in determining motions with the solar system and galaxies.	Rock layers record Earth's history like pages in a book.	Annual cycles in the amount of sunlight absorbed cause Earth's seasons. Increases in human population and per-capita consumption impact Earth systems.
Physical Science (PS)	Newton's Laws explain the forces and motions of objects on Earth and in space. Velocity and mass determine the results of collisions between objects.	Gravitational and electromagnetic fields are the basis of noncontact forces. Changing the arrangement of objects in a system affects the potential energy stored in that system.	Chemical reactions make new substances. Mass is conserved in physical changes and chemical reactions.	Waves are reflected, absorbed, or transmitted through various materials. Wave-based digital technologies provide very reliable ways to encode and transmit information.
Engineering, Technology, and Applications to Science (ETS)	Design criteria. Evaluate solutions. Analyze data. Iteratively test and modify.	N/A	N/A	Design criteria. Evaluate solutions.

A primary goal of this section is to provide an example of how to bundle the performance expectations into four sequential instructional segments. There is no prescription regarding the relative amount of time to be spent on each instructional segment.

Integration within each instructional segment and sequentially across the year flows most naturally with the science concepts in Integrated Grade Eight. Integrated Grade Eight is somewhat less amenable to complete integration, but the concept of systems and system models plays a very strong role in connecting within and across grade eight instructional segments.

Each grade eight instructional segment tells a coherent story that generally includes two or more science disciplines that meaningfully connect with each other within that instructional segment (figure 5.38). Earth and space science content provides the conceptual "glue" by separately linking with physical science (solar system, orbital motions, and asteroid collisions) and with life science (human impacts on biodiversity and geologic time scale via fossils in rock strata). Instructional segment 1 and IS4 also feature engineering design intimately connected with the instructional segment science concepts.

Perhaps the most important perspective with respect to Integrated Grade Eight is that it serves as a capstone for the middle grades span. The vignette in IS4 provides one example of integrating across the entire year and connecting back to earlier grade levels. Many of the key concepts that have been flowing, cycling, and building in complexity in the lower grades come together to explain awesome phenomena such as the unity and diversity of Earth's life, how humans impact and can sustain biodiversity, and the beautiful dances within the solar system. These phenomena are happening within a scale of existence that extends from submicroscopic atoms to clusters of galaxies. These phenomena also occur across a scale of time that extends from instants of collisions to billions of years of stability and change. All this grandeur and wonder would be unknown to us without the powerful science and engineering practices (SEPs) and unifying concepts that students experience and apply in CA NGSS middle grades science.

IS1 Integrated Grade Eight Instructional Segment 1: Objects Move and Collide

INTEGRATED GRADE EIGHT INSTRUCTIONAL SEGMENT 1: OBJECTS MOVE AND COLLIDE

Guiding Questions

- What are forces and how do they affect the motions of objects?
- Do objects always need a force in order to keep moving?
- What happens when a moving object collides with something?
- How do fossils provide evidence of an ancient collision that wiped out the dinosaurs?

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-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-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.

INTEGRATED GRADE EIGHT INSTRUCTIONAL SEGMENT 1: OBJECTS MOVE AND COLLIDE

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-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-5] Using Mathematics and Computational Thinking [SEP-6] Constructing Explanations (for science) and Designing Solutions (for engineering) [SEP-7] Engaging in Argument from Evidence	LS4.A: Evidence of Common Ancestry and Diversity PS2.A: Forces and Motion PS3.A: Definitions of Energy ETS1.A: Defining and Delimiting Engineering Problems ETS1.B: Developing Possible Solutions ETS1.C: Optimizing the Design Solution	[CCC-1] Patterns [CCC-2] Cause and effect [CCC-3] Scale, Proportion, and Quantity [CCC-4] System and System Models [CCC-5] Energy and Matter: Flows, Cycles, and Conservation [CCC-7] Stability and Change

Highlighted California Environmental Principles and Concepts:

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

Principle V Decisions affecting resources and natural systems are complex and involve many factors.

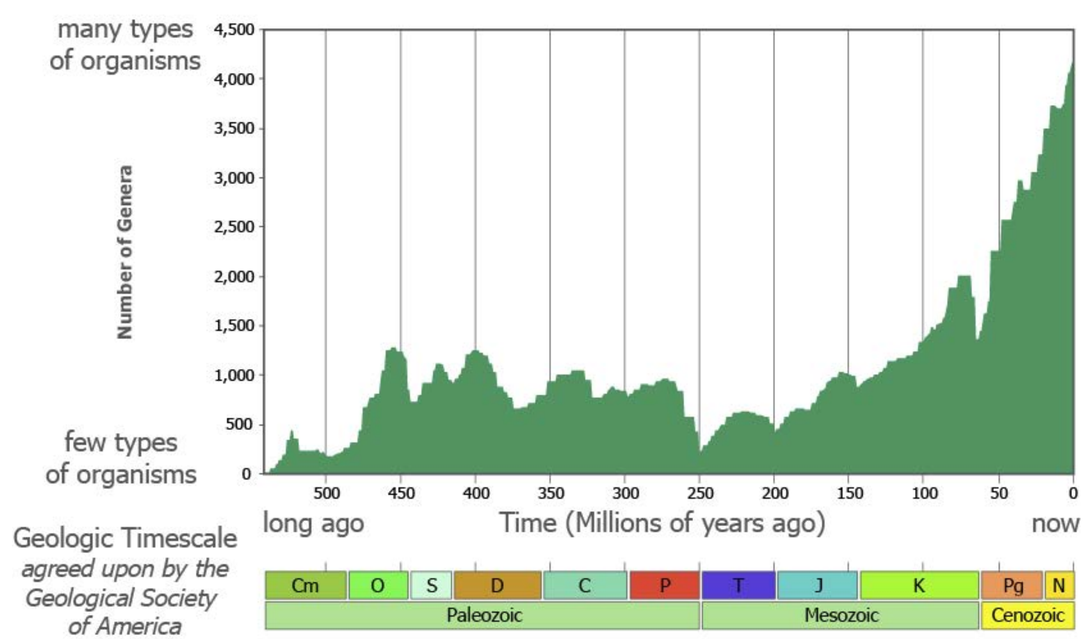
CA CCSS Math Connections: 6.EE.2, 6, 6.NS.5, 6.RP.1, 2, 7.EE.3,4, 7.RP.2, 7.SP.7, 8.EE.1,2, MP.2

CA CCSS for ELA/Literacy Connections: RST.6–8.1, 3, 7, 9, WHST.6–8, 7, 8, 9, SL.8.5

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

Integrated Grade Eight begins with a year-long mystery on planet Earth about what causes the mass extinctions and species diversification events that happen repeatedly in Earth's history. At first, this phenomenon does not appear to match the title of the instructional segment, but understanding this phenomenon requires that students understand many different aspects of science, including the physics of impacts and collisions. Students know that some types of organisms that lived in the past no longer live on Earth (LS4.A from grade three), but how often does this happen and what causes these changes? Scientists have compiled databases of every type of fossil ever discovered and how long ago those organisms lived. These databases include millions of fossils found in layers of rock deposited at thousands of sites around the world. By summarizing the data, scientists can create a single graph depicting a story of how life has diversified and gone extinct over time (figure 5.39). As students **analyze and interpret [SEP-4]** the graph, they notice a general trend as well as **ask questions [SEP-1]** about what causes the individual ups and downs. Each sudden drop on the graph represents a mass extinction event, so why are there so many of them and what **causes [CCC-2]** them?

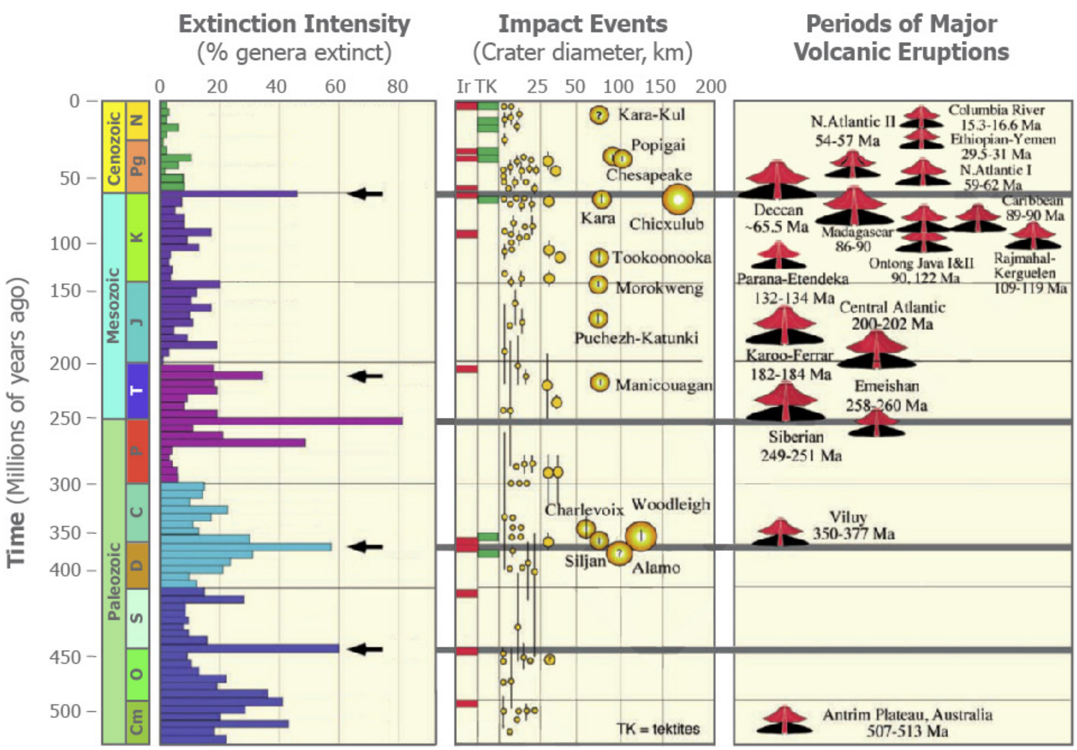
Figure 5.39. Number of Types of Marine Animals from the Last 542 Million Years



The boundaries between geologic periods that scientists have agreed upon (bottom) are often based on major extinction or diversification events when the number of genera changes quickly.
Source: M. d'Alessio with data from Rohde and Muller 2005.
Long description of Figure 5.39.

Students brainstorm possible causes of extinction events. Even if students “know” what caused the extinction of the dinosaurs from their prior knowledge, has the same process caused all extinction events? Students are assigned to different possible explanations and receive “clue cards” with evidence that supports their assigned mechanism and students use the **evidence to construct an argument [SEP-7]**. Students must **ask questions [SEP-1]** that probe and test this explanation further and then receive additional clue cards and revise their argument accordingly. While scientists have been weighing this evidence for decades, grade eight students can see that evidence supports many competing ideas (figure 5.40) and leads to multiple viable arguments that explain each extinction event; there is still disagreement even about the best-studied and most recent event that wiped out the dinosaurs (Keller 2011).

Figure 5.40. The Timing of Major Extinction Events and Possible Causes



Note that the time on the vertical axis is not at a uniform scale because of the data set used to make this figure. Each bar in the extinction intensity data set corresponds to rocks deposited during a different sub stage of geologic time. These sub stages were decided before techniques for determining the absolute age of a rock had been developed. At that time, scientists divided geologic time into different time periods based on the systematic changes they observed in the layers of rocks and fossils contained in those layers. Scientists continue to refer to these geologic time periods even though they can now describe geologic time in absolute terms (i.e., millions of years ago).
Source: Modified from Keller 2011.
[Long description of Figure 5.40.]

One likely mechanism that explains some mass extinctions is the impact of a large asteroid that caused a major disruption to Earth's climate. To motivate students and provide context, students can obtain information about the specific impacts of the Chicxulub Crater that might be responsible for the extinction of the dinosaurs. In addition to introducing one of the year's major topics (the history of life on Earth), this anchoring phenomenon of an asteroid impact also leads into many key concepts related to forces, motion, and gravity. How does science **describe and explain [SEP-6]** the motions of objects such as an asteroid or our planet? How big an asteroid would be needed to cause an extinction? What effects would such an impact have? How can we investigate phenomena related to motions and collisions? These questions mark the transition to a section of the instructional segment that focuses on physical science DCIs.

Motions and collisions provide many engaging ways for learners to **design experiments [SEP-6]**, manipulate variables, and **collect useful data [SEP-8]** over the course of a single or multiple succeeding class periods. Few topics in other science disciplines provide this abundance of laboratory experiences that ignite enthusiasm and quickly provide meaningful data.

Every day we push or pull many things. An object begins to move after we exert a force on it, and then it stops moving shortly after we stop pushing or pulling it. We conclude that forces cause temporary motions in objects. In complete contrast, Newton's First Law of Motion teaches that a force can **cause [CCC-2]** an object to move, and that the object should keep moving at exactly the same speed until another force slows it down, speeds it up, or causes it to change direction. As illustrated in the snapshot below, students need to **investigate [SEP-3]**, **model [SEP-2]**, and **analyze observations [SEP-4]** of many phenomena in order to develop an understanding of the ways in which objects move in scientifically accurate ways, and to correctly use motion concepts to explain the **cause and effect [CCC-2]** relationships that result in observed phenomena.

Integrated Grade Eight Snapshot 5.6: Learning About Motion

After having engaged students in the Earth and space science phenomena of an asteroid impact and asking questions about the speed of the impactor, Ms. Z focused on the physical science DCIs about motion. Ms. Z's students had just finished activities where they described motion in terms of speed. She decided to use the free Forces and Motion education animations (see https://www.cde.ca.gov/ci/sc/cf/ch5.asp#link16) to transition from a focus on constant velocity to acceleration.

Anchoring phenomenon: A toy car doesn't move unless you push on it.

Sometimes, even a mundane observation can lead to great insight. She began by showing students a toy car and asking them to explain in words why the car is not moving. Some students had good ideas, but many struggled to find the right words to express the answer to this seemingly obvious question. She connected to students' investigations from grade three with balanced forces (3-PS2-1). Using an example of a toy car, she wrote up the statement on the board, "When the total force on an object is zero its motion does not change at that instant" (Newton's First Law). She asked students why she emphasized the phrase "at that instant."

Investigative phenomenon: (Students explore various phenomena related to the cases in each computer simulation).

Having established some background, she instructed the students to work individually or with a partner to explore their assigned animation, such that one-third of the class each explored one of the three animations (Motion; Friction; Acceleration). They recorded in their notebooks what they did, any conclusions they reached, and any questions the animation raised.

In the succeeding days, class sessions focused on the animations in the order of Motion, then Friction, and finally Acceleration. As the students presented, they or Ms. Z used the projector to manipulate the animation to support and extend what the students recorded in their notebooks. After reviewing the three animations as a whole class, the students collaboratively agreed on specific questions or concepts to explore further within the animations, such as **analyzing data [SEP-4]** about the **effects [CCC-2]** of mass and velocity on acceleration. These investigations and subsequent **analyses [SEP-4]** resulted in a consensus statement of Newton's Second Law, "When the total force on an object is not zero, its motion changes with an acceleration in the direction of the total force at that instant."

Students were surprised that the scientific meaning of the term *acceleration* includes speeding up, slowing down or changing direction. Some of the students enjoy telling people that vehicles actually have three accelerators: the gas pedal, the brake, and the steering wheel.

Resources:

The physical science narrative in this snapshot and instructional segment uses materials from Daehler, Shinohara, and Folsom 2011b.

The word *motion* in the CA NGSS implies both the object's speed and its direction of travel. The assessment boundaries of performance expectations for grade eight state that students will only be assessed on forces that are aligned, and deal with changes in speed that occur when the net force is aligned to the motion (i.e., only one-dimensional motion).

Speed is a ratio of distance divided by time. Students can **investigate [SEP-3]** speed by conducting experiments in which they measure both distance and time. 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 at https://www.cde.ca.gov/ci/sc/cf/ch5.asp#link17), use a motion sensor probe, or use computer simulations.

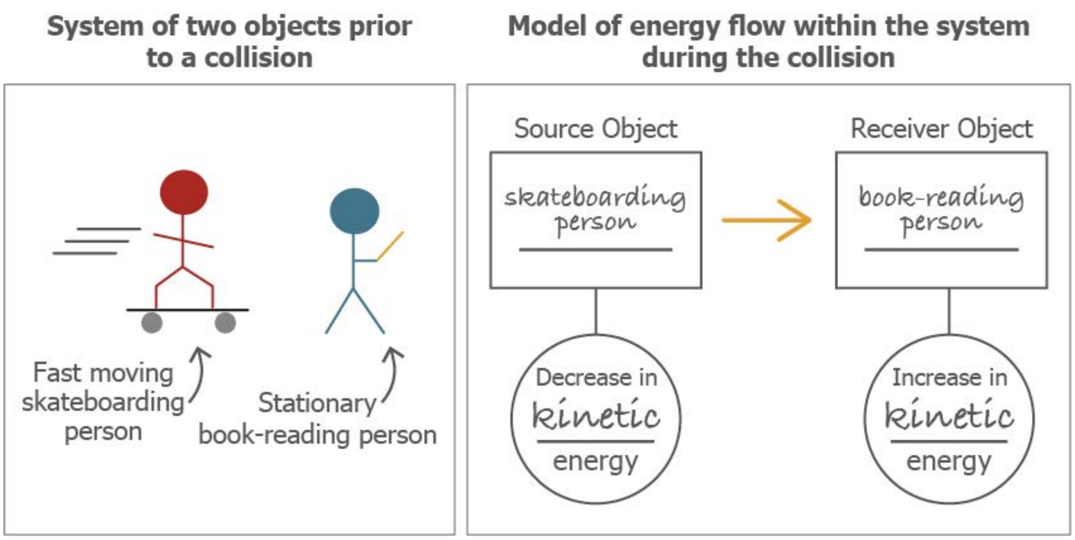
From a mathematical point of view, speed is the ratio of two very disparate quantities (distance such as meters and time such as seconds). Speed itself, the ratio, is also qualitatively different from the distance component and from the time component. This situation is typical in science where ratios are used in specific contexts to analyze phenomena. In order for these science ratios to make sense, students need to specify the units of measure for each component of the ratio and also of the resulting number, such as a speed or a density. This situation is very different from learning about ratios as an abstract relationship of two numbers that do not have units associated with them.

Students often harbor the preconception that a moving object will naturally stop rather than keep moving. If you kick a soccer ball, it will roll along the ground, slow down, and then stop. From a force point of view, the kick initiated the ball's movement and then friction, a very different force, opposed that movement. It requires a lot of experimentation and discussion before students internalize the understanding that without an opposing force, the ball would actually keep moving forever at the same speed in the same direction. Even after extended investigations and discussions, students may still retain preconceptions, for example, that the initiating force somehow remains associated with the moving object and keeps propelling it. Modeling the forces at different instants of time (before, during and after motion) can help address this kind of preconception. Another very powerful way to deepen understanding of motion is to provide an **energy [CCC-5]** perspective in addition to the force perspective.

The **energy [CCC-5]** perspective can help students understand why objects slow down. The kick transferred kinetic energy from the foot to the soccer ball. If no interactions remove kinetic energy from the soccer ball, it makes sense that the ball will keep moving at the same speed in the same direction. The interaction with the ground transfers some of that kinetic energy to the ground (the grass moves and also becomes a little warmer because of being rubbed by the ball). Since the soccer ball has lost some of its kinetic energy to the grass and the air surrounding, it naturally slows down and eventually stops.

Students can create a diagrammatic **model [SEP-2]** of the **flow of energy [CCC-5]** within **systems [CCC-4]** as shown in figure 5.41. This simple diagram of a collision 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 is 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 transfers of energy.

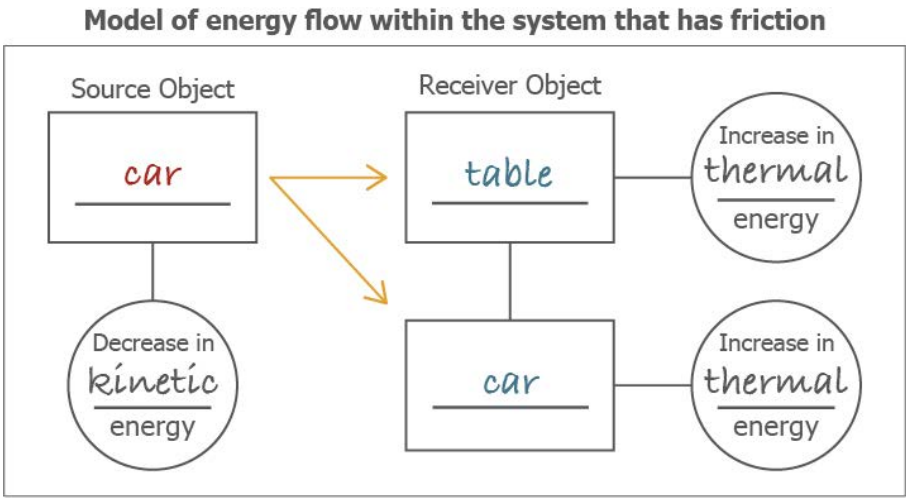
Figure 5.41. Energy Transfer in a Collision



Model of energy flow within a system during a collision. Diagram by M. d'Alessio.
Long description of Figure 5.41.

The force of friction is an interaction in which **energy [CCC-5]** is transferred. Students must **plan investigations [SEP-3]** to explore the **effects [CCC-2]** of balanced and unbalanced forces on the motion of objects (MS-PS2-2). One such investigation could involve measuring the velocity 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 (figure 5.42) 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 all of the energy must be accounted for. The car clearly decreases in energy but that means another component of the system [CCC-4] must increase in energy.

Figure 5.42. Energy Transfer 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 5.42.

Using simple analogies such as friction of hands rubbing together, students can conclude that the energy is likely converted into thermal energy. When rubbing hands together, both hands warm up even if one hand remains stationary during the rubbing. This observation gives rise to two related modifications to the previous simpler energy source/receiver diagram: (1) there can be multiple energy receivers in a system [CCC-4] from a single energy source; and (2) an object (e.g., the car) can be both the source and the receiver of energy if that energy converts from one form (kinetic energy) to another form (thermal energy).

During an interaction when a force acts on an object, that object will gain kinetic energy. How much will the object's motion change during this interaction? Students asked similar questions [SEP-1] in fourth grade (4-PS3-3), and now they will begin to answer them. The answer depends strongly on the target object's mass. This principle becomes easily apparent in collisions. Students can perform investigations [SEP-3] by colliding the same moving object with target objects of different masses that are otherwise identical in shape (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 (by rolling down a ramp of a fixed distance, for example). This procedure will ensure that the initial kinetic energy is constant and will lead to a consistent force initiating 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 that 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. Instead this performance expectation focuses on the **proportional [CCC-3]** relationship of motion changes and force.

When the source and target objects have equal masses and collisions transfer all of the **energy [CCC-5]** from source to receiver, the speed of the target object should be similar to the speed of the source object. This phenomenon 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 (revisiting MS-PS3-5 from Integrated Grade Six).

In each trial collision so far, the amount of **energy [CCC-5]** transferred to the target object has been held constant. While the amount of energy is constant, changes in the target object's mass can change how the energy transfer affects the object's speed. The motion of smaller target masses changes more (greater acceleration) than the change in motion of larger target masses. This kind of inverse relationship (bigger mass resulting in smaller change) can be confusing for students, so it can help to make that aspect of Newton's Second Law very explicit. Students can explore this idea further by changing the kinetic energy of the source object. In that case, the relationship is direct rather than inverse. Keeping the target object constant, groups of students can predict and demonstrate that increasing the mass or the speed of the source object increases the change in motion of the target object. From the energy perspective, a faster moving or more massive source object can transfer more kinetic energy to the target object. From the force perspective, a faster moving or more massive source exerts a greater force on the target object. Animation investigations can complement these tabletop investigations very nicely, and the dual perspectives of force and energy can help **explain [SEP-6]** the results of changing variables within the animations.

Engineering Connection: Landslide Early-Warning System

MS-PS2-1 provides a capstone goal for IS1. Students **design a solution [SEP-6]** to a problem involving the motion of two colliding objects. The clarification statement for the performance expectation offers examples of collisions between two cars, between a car and a stationary object, or between a meteor and a space vehicle. In order for this challenge to extend deeper into the design process, the suggestion here is to restrict the projects to situations for which students can physically model and obtain data that can be used in iterative testing and refinement of their design solution.

The classic egg drop could be used but many of the solutions to that problem involve slowing the falling egg before the collision. The emphasis for the performance expectation is on applying Newton's Third Law that objects experience equal and opposite forces during a collision. For example, a variation where students attach eggs to model cars and design bumpers will follow naturally from their prior tabletop experiments. At the conclusion of their testing and refinement, students should be able to use their models of **energy transfer [CCC-5]** and kinetic energy to make an **argument [SEP-7]** about how their design solution works. Bumpers tend to reduce the effects of collisions by two processes: (1) they absorb some of the source kinetic energy so that less of it gets transferred to kinetic energy in the target object and more of it gets converted to thermal energy; and (2) they make the collision last longer so that the transfer of energy occurs over a longer time interval.

No matter what type of collisions students **investigate [SEP-3]**, they will need to identify the constraints that affect their design as well as the criteria for identifying success (MS-ETS1-1). As student teams evaluate competing design solutions (MS ETS1 2) and identify common features of successful models (MS ETS1 3), they can identify and model the physical processes that are involved, using the dual perspectives of forces and energy transfers. Students should be able to discuss their bumper solution in terms of energy source/receiver diagrams such as figure 5.41. Towards the end of their design challenge, students need to **explain [SEP-6]** why certain choices they made actually work, and then use their more detailed **models [SEP-2]** of their system to further refine their design.

Now students return to the anchoring phenomenon of an asteroid impact and can use models of energy transfer to explain various observations of rock layers that formed at the time the dinosaurs went extinct. First, Earth's motion appeared largely unaffected by the asteroid impact. What does this say about the size of the asteroid relative to Earth? Small chunks, however, were thrown into the air at high speed. Could they fly up faster than the original asteroid? Lastly, impact sites like Chicxulub Crater show evidence of rock that melted at the impact site, and many of the distant deposits include solidified droplets of formerly molten rock. Where did the energy come from to melt this rock?

The CCC of **energy and matter: flows, cycles and conservation [CCC-5]** is applied in many different contexts throughout the middle grades. One of the middle grade bullets used to describe this CCC states that "the transfer of energy drives the motion and/or cycling of matter." In Integrated Grade Six and Integrated Grade Seven, the emphasis is on the role of energy transfer in driving the cycling of matter (water cycle, rock cycle, and cycling of matter in food webs). In Integrated Grade Eight IS1, the emphasis is on the role of energy transfer in driving the motion of matter.

Using this CCC throughout the middle grades serves at least three complementary purposes. As students gain experience in applying the CCC, it helps them connect with different DCIs and understand these DCIs and the related phenomena in greater depth. As students apply the CCC in different contexts, they get to understand the CCC itself in greater depth (e.g., transfers of energy can drive cycles of matter and motion of objects). Thirdly, students experience science as a unified endeavor rather than separate and isolated topics. Ultimately all of science works together as a unified whole system.

Now that students understand more about the physical science effects of a giant impact, they can return to the anchoring phenomenon to consider how such an impact would affect the biosphere. They will need to draw on their understanding of Earth's interacting systems from earlier grades (ESS2.A). Students also know that dinosaurs went extinct, while other species survived and then thrived following the impact. Why? Can we use this information about how living systems were affected to determine more details about the physical changes to Earth's climate following the impact? A goal of the Integrated Model is that students see how understanding one domain can enhance understanding in others.

To transition to the next instructional segment, students might wonder more about these asteroids and how they move in space. This turns their attention to the sky.

IS2

Integrated Grade Eight Instructional Segment 2: Noncontact Forces Influence Phenomena

Many phenomena are controlled by forces that do not touch the affected object. In IS2, students explore gravity and electromagnetism in the context of observable features of the Sun, Moon, stars, and galaxies. After years of noticing patterns in the movement of these objects in earlier grades, they finally develop a model that explains these celestial motions. This model does appear until grade eight because it requires students to visualize complex motions from multiple frames of reference (both as observers on Earth and out in space). What makes this unit "integrated" is that the motions are considered in tandem with the gravitational forces that cause them.

INTEGRATED GRADE EIGHT INSTRUCTIONAL SEGMENT 2: NONCONTACT FORCES INFLUENCE PHENOMENA

Guiding Questions

- What causes the cyclical changes in the appearance of the Moon?
- How can an object influence the motion of another object without touching it?
- Does Earth's force of gravity attract other objects equally?

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.] (Introduced, but seasons are not assessed until IS4)

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*.]

MS-PS2-3. Ask questions about data to determine the factors that affect the strength of electrical and magnetic forces. [Clarification Statement: Examples of devices that use electrical 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 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-PS2-4. 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*.]

INTEGRATED GRADE EIGHT INSTRUCTIONAL SEGMENT 2: NONCONTACT FORCES INFLUENCE PHENOMENA

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.]

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*.]

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-7] Engaging in Argument from Evidence	ESS1.A: The Universe and Its Stars ESS1.B: Earth and the Solar System PS2.B: Types of Interactions PS3.A: Definitions of Energy PS3.C: Relationship Between Energy and Forces	[CCC-1] Patterns [CCC-2] Cause and Effect [CCC-3] Scale, Proportion, and Quantity [CCC-4] Systems and System Models

CA CCSS Math Connections: 6.RP.1, 6.EE.2, 6, 7.RP.2, 7.EE.3, 4, MP.2, MP.4

CA CCSS for ELA/Literacy Connections: RST.6–8.1, 3, 7, WHST.6–8.1, 7, SL.8.5

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

One of the biggest challenges of studying noncontact forces is that it is difficult to visualize them. How do you see the invisible? In fact, one of the challenges that students must meet in the CA NGSS is to **plan investigations [SEP-3]** that provide evidence that fields exist between objects interacting through noncontact forces (MS-PS2-5). Nature provides demonstrations of these interactions on a massive scale as galaxies interact (figure 5.43). As an anchoring phenomenon for this instructional segment, students will consider how galaxies have unique shapes, and some galaxies have long "tails" or diffuse clouds that appear to connect or interact with nearby galaxies. Students examine images of different interacting galaxies and record patterns they see. While they can begin to link these structures to gravity, it is not clear how a force that draws things together causes round, swirling shapes. Over the course of IS2, they will develop models of attractions between different objects in the solar system and universe and use them to explain observations.

Figure 5.43. Interacting Galaxies Demonstrate Attraction

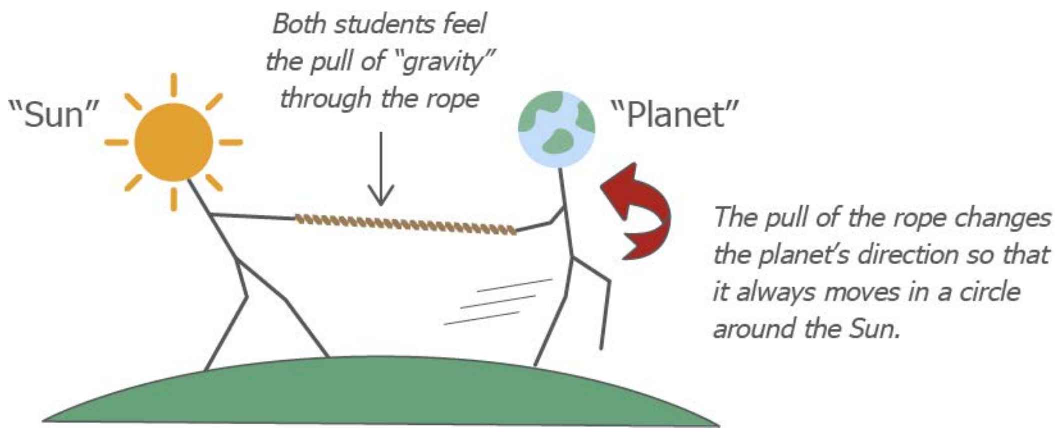
Galaxy pair Ar271. *Source:* Gemini Observatory 2008

In this instructional segment, students use the concept of gravity to **explain [SEP-6]** motions within solar systems and galaxies (MS-ESS1-2). Essential components of the explanation are (1) gravity is a force that pulls massive objects toward one another; (2) objects in the solar system move in circular patterns around the Sun; and (3) stars in galaxies move in circular patterns around the center of the galaxy.

Students can illustrate the forces in these circular motions with a rope (figure 5.44). 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 they move only in a circular motion around the other person. A significant limitation of this **model [SEP-2]** is that it gives the impression that the central mass must rotate as part of the motion.

Figure 5.44. Kinesthetic Model of an Orbit



Two people can use a rope to model Earth's orbit around the Sun. Diagram by M. d'Alessio.
Long description of Figure 5.44.

Isaac Newton was the first person to develop and **mathematically [SEP-5]** prove the idea of gravity as the **cause [CCC-2]** of orbital motions in the solar system. As part of his thinking process, Newton **developed a conceptual model [SEP-2]** of orbits based on shooting cannon balls at different speeds from a very tall mountain. 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 and enjoy Newton's cannonball model (see https://www.cde.ca.gov/ci/sc/cf/ch5.asp#link18).

One of the most Earth-shaking aspects of Newton's theory of gravity is that he showed that the same force that **causes [CCC-2]** apples to fall from trees also causes the Moon to travel around Earth. The same scientific principles that **explain [SEP-6]** what is happening on planet Earth can also explain what is happening throughout the solar system and in very distant galaxies. More specifically, Newton helped us understand that every object attracts every other object via gravity. One factor affecting the strength of the force depends on how much mass each of the objects has, with larger masses causing stronger pulls. Because planets, stars and, galaxies have huge masses, gravity plays a major role in the structures and motions observed in solar systems and galaxies.

Explaining Motion in the Solar System

Students **develop and use models [SEP-2]** of the Earth-Sun-Moon system (MS ESS1 1). This system involves a variety of effects **caused [CCC-2]** by three different solar system objects, two different orbits, and Earth's rotation on its axis. Associated phenomena include Moon phases, eclipses, and the lengths of a day, a month, and a year. In the course of their exploration, students can practice **using and developing models [SEP-2]** (physical, kinesthetic using their bodies, computer-based) and directly experience that different kinds of models inherently have advantages and limitations.

Typically in educational settings, students have been presented with established models that resulted from decades or centuries of observations and investigations. Over those long periods of time scientists developed, argued about, and revised models to explain observed phenomena, and they made predictions that could be tested based on different models. In CA NGSS classrooms, the pedagogic philosophy is to have students engage more in the SEPs involved with *building* models rather than simply showing them the completed models that are currently supported by a consensus among scientists. Instructional materials and teachers can choose the relative amount of emphases to place on developing models and on using established models.

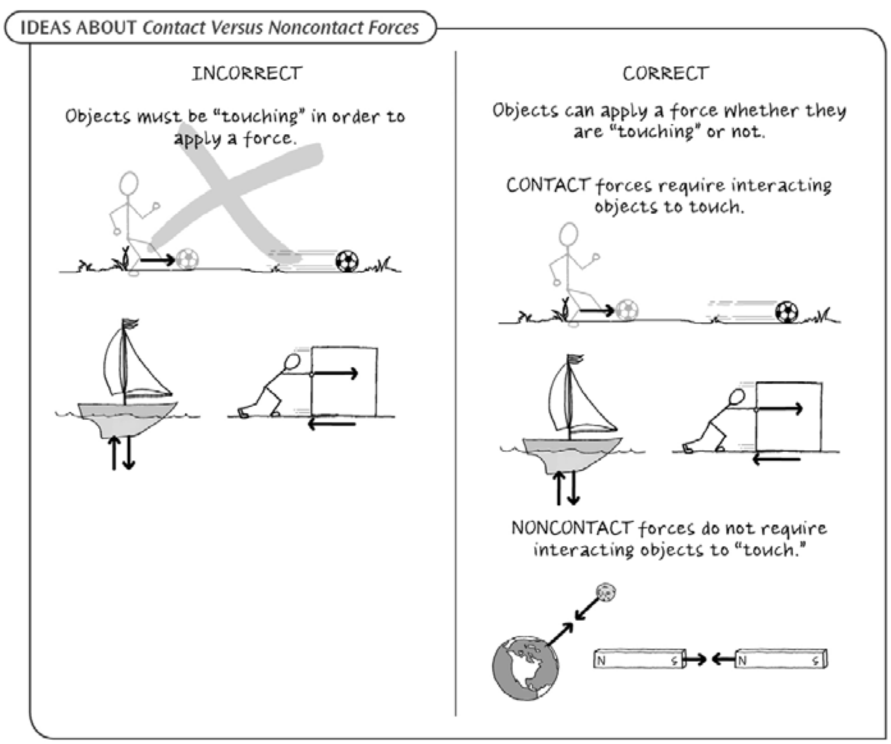
Factors Controlling the Effects of Gravity

Before grade eight, students in the middle grades were hearing and talking about gravity. However, if they are asked to compare how strongly Earth pulls on a bowling ball and on a baseball, they are very likely to say that Earth pulls equally hard on each. Based on all our earthly experiences of falling objects, it is very logical to think that gravity is a special property of Earth similar to other properties like density or color. But gravity is the property of a **system [CCC-4]** caused by an interaction between the components of that system. This example provides a strong connection to IS1 where students learned that two objects involved in a force have an "equal and opposite" relationship. No single object exerts a force just by itself.

Gravity also illustrates another feature of forces, a puzzling feature that even Isaac Newton could not explain. How can an object exert a force on or with an object that it is not even touching? Gravity is an example of a noncontact force (figure 5.45). The Golden Gate Bridge in San Francisco and Dodger Stadium in Los Angeles pull on each other and also pull on every person in California. The reason we do not notice these pulls is that they are so weak compared with the attraction the planet itself exerts on us. Since all mass is attracted to all other mass in the universe, it is also true that the Sun itself pulls on every student. Why don't students fly up in the sky towards the hugely massive Sun?

The answer is that the strength of the gravitational force also depends on the relative positions of the interacting objects (i.e., the distance between them). Gravity on Earth is usually thought of as pulling objects toward 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 ground directly beneath his or her feet exerting the strongest pull and the ground on the opposite side of the planet exerting a much weaker force because of its distance away. Because these secondary forces are so weak, it is difficult to experiment directly with the factors that affect gravity, but students can **investigate [SEP-3]** using free computer simulations that visualize these forces with two bodies (PhET, https://www.cde.ca.gov/ci/sc/cf/ch5.asp#link19). Students can apply their knowledge of gravitational forces to simulations of much more complex planetary systems (Test Tube Games, https://www.cde.ca.gov/ci/sc/cf/ch5.asp#link20) where they get to create different size planets and place them in different positions. They can design experiments, predict how different configurations will end up looking, and be challenged to create their own solar system.

Figure 5.45. Contact Forces and Noncontact Forces



Objects can apply a force even if they are not "touching." *Source:* From Making Sense of SCIENCE: Force and Motion (WestEd.org/mss) by Daehler, Shinohara, and Folsom. Copyright © 2011b WestEd. Reproduced with permission.
Long description of Figure 5.45.

Just as students investigated the sum of forces when objects are touching in IS1 (MS-PS2-2), changes in motion are **caused [CCC-2]** by the sum of all forces acting on an object. Earth is a sphere, so there is approximately the same amount of ground level mass to the north, south, west, and east of a person, so these pulls counteract each other. The overall gravitational effect is a downward pull towards the center of the planet. With very special devices, scientists can precisely measure differences in the direction and pull of gravity at different locations on Earth. For example, if an underground aquifer is full of water or an underground volcano 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 difference in pull can be measured using satellites orbiting the planet that provide valuable data for monitoring water supplies and volcanic hazards (see GRACE Watches Earth's Water at https://www.cde.ca.gov/ci/sc/cf/ch5.asp#link21).

Opportunities for ELA/ELD Connections

Have students create a visual and explain, using evidence and scientific principles, how an object influences the motion of another object without touching it. Ask students to list the scientific terms they will be using. As students present, coach and encourage them to use all the listed terms correctly.

CA CCSS for ELA/Literacy Standards: WHST.6–8.7; SL.6–8.4, 5; L.6–8.6

CA ELD Standards: ELD.PI.6–8.9

Similarities Between Gravity and Magnetism

Figure 5.45 includes magnetism as an example of a force that acts at a distance (noncontact forces). Static electricity is another example of a noncontact force that students can readily **investigate [SEP-3]**. The modern explanation of the puzzling phenomenon of noncontact forces is that fields exist between objects that exert noncontact forces on each other. Students probably have ideas about force fields based on science fiction movies. Students at the middle grades level are not expected to understand the physics concept of fields, but they can begin to approach a more scientific understanding of force fields by **measuring [CCC-3]** the strength of these fields under a variety of conditions.

Noncontact Forces and Energy

MS-PS3-2 connects **investigations [SEP-3]** of fields with the concept of potential energy. Students are expected to describe that changing the arrangement of objects interacting at a distance **causes [CCC-2]** different amounts of potential energy to be stored in the system. During IS1 of Integrated Grade Eight, students applied energy considerations to complement and deepen their understanding of phenomena involving forces and motion. Without necessarily using the term gravitational potential energy, students investigated situations that involved the back-and-forth transfers of gravitational potential energy and kinetic energy (e.g., in the motion of a pendulum or a roller coaster).

In Integrated Grade Seven, students also encountered the concept of potential energy with respect to the chemical energy stored in molecules. In food-web models of ecosystem **energy flows [CCC-5]**, they illustrated that this chemical potential energy transferred to motion energy and thermal energy. Students may have created or analyzed graphic organizers comparing forms of kinetic and potential energy, such as table 5.10.

Table 5.10. Forms of Energy

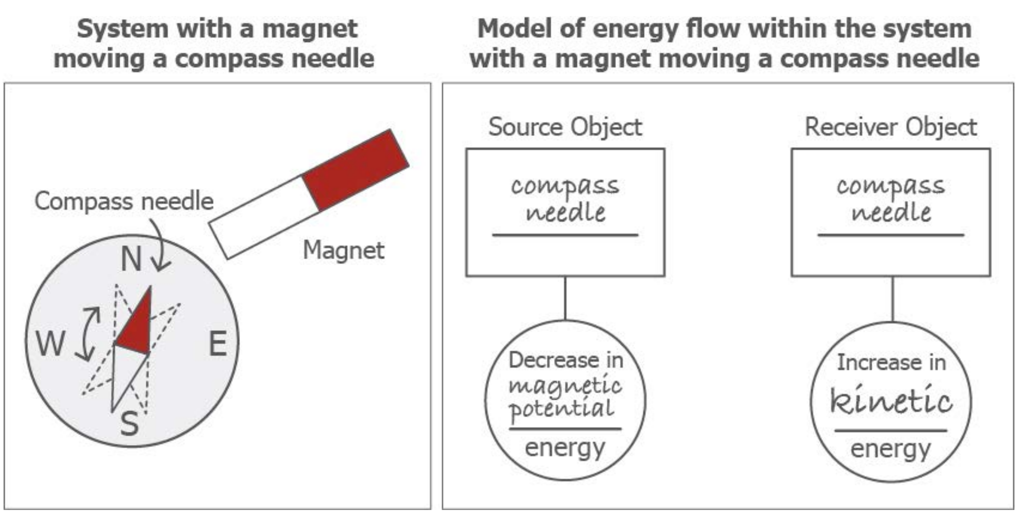
ENERGY OF MOTION **Energy due to the motion of matter**	**ENERGY OF POSITION** **Energy due to the relative positions of matter**
Kinetic Energy	Gravitational Potential Energy
Thermal Energy (often called Heat Energy)	Elastic Potential Energy
Light Energy	Chemical Potential Energy
Sound Energy	Magnetic Potential Energy
Electrical Energy	Electrostatic Potential Energy

Source: From Making Sense of SCIENCE: Energy (WestEd.org/mss) by Daehler, Shinohara, and Folsom. Copyright © 2011a WestEd. Reproduced with permission.

Unlike gravitational fields around stars and planets that are hard to visualize, students can easily **collect data [SEP-8]** about the position and orientation of iron filings contained within a clear plastic box as they move a bar magnet nearby (MS-PS2-5). They can then predict and record the resulting **patterns [CCC-1]** that they observe as they introduce different magnets and magnetic objects nearby. Students should begin to **ask questions [SEP-1]** about the spatial **patterns [CCC-1]** that they observe (MS-PS2-3). For example, what happens if two magnets are placed end to end versus side by side? Does the pattern change with the addition or movements of a magnetic object? Since iron filings tend to concentrate in areas where the magnetic force is strongest, students can use their observations to describe the relative strength of the invisible magnetic field at different locations. They can also relate the lines of iron filings to the spiral arms in interacting galaxies. Both structures form because of interactions at two different scales: the small scale attractions between individual particles cause the clustering, and the large-scale attractions due to the broader field cause these clusters to align in systematic shapes (galaxy shapes are further complicated by the initial movements and rotations of the galaxies). Students can design and conduct similar **investigations [SEP-3]** based on electrostatic forces of attraction and repulsion.

Magnetic fields provide a way to visualize the potential energy of magnets. Magnetic potential energy has some similarities with gravitational potential energy where the relative position of the objects determines the strength of the force. Because magnets have two poles, orientation also becomes important. Changing the relative position and orientation of magnets can store potential energy that can be converted into kinetic energy. By **analyzing data [SEP-4]** from frame-by-frame video analysis of a compass needle, students can determine the conditions that **cause [CCC-2]** the needle to gain the most kinetic energy. They can use these observations to support their **model [SEP 2]** that the arrangement of objects **determines [CCC-2]** the amount of potential energy stored in the **system [CCC-4]** (figure 5.46).

Figure 5.46. A Magnet Moving a Compass Needle



Schematic diagram and model of energy flow within a system of a magnet moving a compass needle. Diagram by M. d'Alessio.
Long description of Figure 5.46.

Students can also use iron filings to **investigate [SEP-3]** electromagnets and gather evidence about the spatial **patterns [CCC-1]** of the magnetic fields created by electromagnets. Students can try 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).

Notice that the text and figure 5.46 describe the potential energy of the system. Some textbooks and curricular materials may refer to "the potential energy of the object," but this language should be avoided. The potential energy is a property of a **system [CCC-4]** based on the objects within the system and their spatial and other relationships to each other. Keeping this systems approach helps elucidate the nature of gravitational, electrostatic, and magnetic fields.

The end of grade eight IS2 provides an opportunity to reflect on the progression of major physical science concepts, particularly **flows of energy [CCC-5]**, throughout the integrated science middle grades span. In grade six, students explored many transformations of energy, especially those that involved thermal energy, such as in the water cycle and weather conditions. In grade seven, they modeled flows of energy into and out of organisms and ecosystems, and experienced the concept of potential energy in the context of chemical reactions, food chains, and food webs. In the first two grade eight instructional segments, students again **investigated [SEP-3]**, **collected evidence [SEP-8]**, **made arguments [SEP-7]**, **developed models [SEP-2]**, and **constructed explanations [SEP-6]** involving major energy concepts. Although the CA NGSS middle grades physical science performance expectations and DCIs do not explicitly mention or require the Law of Conservation of Energy, this key concept actually is implicit in many of their models and explanations. Calling attention to this concept during or after IS1 and IS2 could help solidify student understanding and better prepare to apply this concept as they continue to encounter and wonder about phenomena.

Integrated Grade Eight Snapshot 5.7: Causes of Io's Volcanism

Anchoring phenomenon: Io, a moon of Jupiter, has massive volcanic eruptions.

Mr. J developed a unit around Io, one of four moons of Jupiter discovered by Galileo using his telescope. However, students benefited from the far better images captured by satellites. They investigated images of its surface features and snapshots of eruption plumes and discovered evidence for Io's active volcanism. They collected and **compared data [SEP-4]** contrasting the size of volcanoes and eruptions on Io to those on Earth (MS-ESS1-3). They used their findings to support the claim that Io is the most volcanically active body in the solar system. Students looked at thermal infrared images of Io and saw how the surface is dotted with hot regions that correspond to the volcanoes seen in visible light. Where does all this **energy [CCC-5]** come from? Students read an article to **obtain information [SEP-8]** about three different possible sources of heating, including energy generated by interactions with Jupiter's magnetic field, tidal friction caused by gravity, and internal heat from radioactivity. All three of these mechanisms are complex, so Mr. J worked hard to find an article that provided just the right level of detail to introduce the ideas at the middle grades level. It focused on the idea of energy transfer without dwelling on the complex details. After reading the article, Mr. J instructed students to draw diagrams that modeled the **flow of energy [CCC-5]** in these **systems [CCC-4]**.

Over the next several days, they explored each of these possible mechanisms. The article emphasized that all three mechanisms **cause [CCC-2]** some heating of Io. In the middle grades, students begin to consider processes that are influenced by multiple causes and to **ask questions [SEP-1]** about the relative importance of each cause.

Investigative phenomenon: A satellite orbiting Jupiter recorded different magnetic field strengths as it moved to different locations around the planet at different distances away.

The class doesn't spend much time on internal radioactivity, which is discussed more in high school when students have a model of the internal structure of atoms (the article indicates that this source is small compared to the others). Magnetic heating is an energy transfer mechanism that is more complex than even the high school level, but students in the middle grades are expected to explore magnetic fields in the CA NGSS. The students **analyzed [SEP-4]** the magnetic field strength recorded by a satellite as it passed close to the Jupiter and **asked questions [SEP-1]** about the factors that affected the strength (MS-PS2-3).

Integrated Grade Eight Snapshot 5.7: Causes of Io's Volcanism

Investigative phenomenon: The orbital period of Io is exactly half that of Europa and one-fourth that of Ganymede.

The article described how Io receives energy from constant pulling by Jupiter and its other moons. Students used a virtual telescope simulator to examine the orbits of Io and the other moons of Jupiter and discovered that Io's orbital period is exactly half that of Europa and one-fourth that of Ganymede. Students **used this evidence to support the claim [SEP-7]** that the planets interact with one another through gravity (MS-PS2-4). They drew diagrams with arrows that indicated the direction of gravitational attraction between the moons at different snapshots in time where they have different relative positions. They used these **models [SEP-2]** to describe how the moons affect one another's motion (MS-ESS1-2). Students also used these diagrams to demonstrate how the gravitational potential energy of the system changes (when the planets get closer together, they have less potential energy; MS-PS3-2). As potential energy in a system decreases, there must be an increase in some other form of energy (or a flow of energy out of the system)—in this case, the potential energy is converted to heat energy.

Investigative phenomenon: Loki volcano erupts on a cycle that repeats about once every 1.5 Earth years.

They ended the unit by examining the eruptive history of Io's largest volcano, Loki. Could it provide clues about the relative importance of each heating mechanism? The volcano alternates between high activity and low activity, and Mr. J asked them to predict what the time interval might be for each of the mechanisms. He scaffolded the discussion and directed students to tie their thinking to Io's orbit around Jupiter (about 42 hours) and its interactions with the other moons (multiples of two and four times longer). Then, students **analyzed data [SEP-4]** to determine the actual time interval between eruptive peaks (Rathbun et al. 2002). They found that the cycle repeats about every 1.5 Earth years, much longer than the cycles they were expecting. Mr. J knew that his students would be disappointed and confused, but he intentionally chose this data set because he wanted to highlight an authentic scientific experience for his students where they did not find any answer at all. He explicitly drew attention to the importance of time **scale [CCC-3]**, noting that students were able to rule out certain **cause and effect mechanisms [CCC-2]** because the time scale of the possible cause is radically different than the time scale of the effect. The actual cause of the 1.5-year cycle remained a mystery to the students!

IS3

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

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

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

Guiding Questions

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

Performance Expectations

Students who demonstrate understanding can do the following:

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

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

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

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

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

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

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

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

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

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

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

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

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

Highlighted Science and Engineering Practices	Highlighted Disciplinary Core Ideas	Highlighted Crosscutting Concepts
[SEP-2] Developing and Using Models [SEP-4] Analyzing and Interpreting Data [SEP-5] Using Mathematics and Computational Thinking [SEP-6] Constructing Explanations (for science) and Designing Solutions (for engineering) [SEP-7] Engaging in Argument from Evidence [SEP-8] Obtaining, Evaluating, and Communicating Information	LS3.A: Inheritance of Traits LS3.B: Variation of Traits LS4.A: Evidence of Common Ancestry and Diversity LS4.B: Natural Selection LS4.C: Adaptation ESS1.C: The History of Planet Earth	[CCC-1] Patterns [CCC-2] Cause and Effect [CCC-6] Structure and Function [CCC-7] Stability and Change

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

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

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

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

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

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

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

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

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

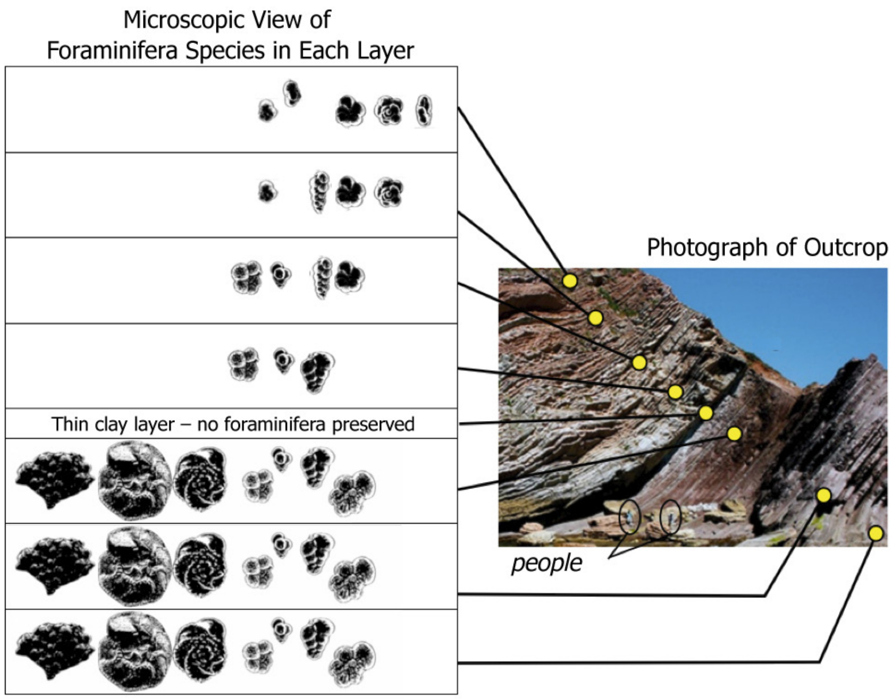
Source: Information from Sussman 2006.

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

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

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

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



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

Long description of Figure 5.47.

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

Opportunities for ELA/ELD Connections

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

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

CA ELD Standards: ELD.PI.8.6, 7

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

Integrated Grade Eight Snapshot 5.8: Making Sense of Natural Selection

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

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

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

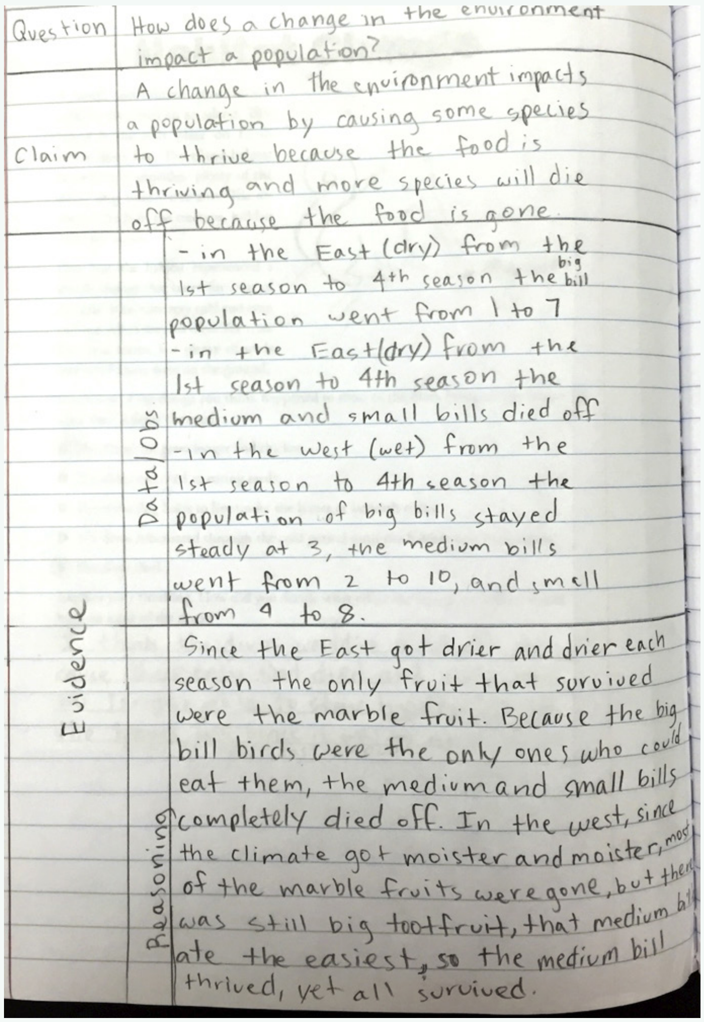
Investigative phenomenon: In a simulation, birds with different size beaks die off when the climate changes and causes a change in food supply.

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

Integrated Grade Eight Snapshot 5.8: Making Sense of Natural Selection

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

Figure 5.48. Preliminary Student Explanation of the Clipbird Scenario



Question: How does a change in the environment impact a population?

Claim: A change in the environment impacts a population by causing some species to thrive because the food is thriving and more species will die off because the food is gone.

Evidence – Data/Obs: - in the East (dry) from the 1st season to 4th season the big bill population went from 1 to 7 - in the East (dry) from the 1st season to 4th season the medium and small bills died off - in the west (wet) from the 1st season to 4th season the population of big bills stayed steady at 3, the medium bills went from 2 to 10, and small from 4 to 8.

Evidence – Reasoning: Since the East got drier and drier each season the only fruit that survived were the marble fruit. Because the big bill birds were the only ones who could eat them, the medium and small bills completely died off. In the west, since the climate got moister and moister, most of the marble fruits were gone, but there was still big tootfruit, that medium bill ate the easiest, so the medium bill thrived, yet all survived.

Source: Photo provided by Jill Grace.
Long description of Figure 5.48.

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

Integrated Grade Eight Snapshot 5.8: Making Sense of Natural Selection

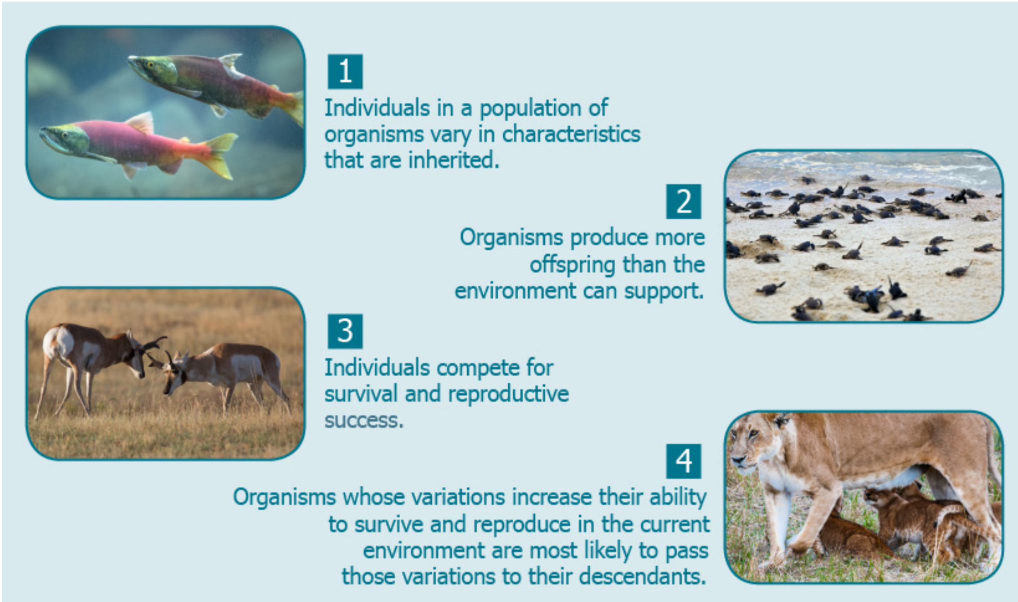
to better understand it, and students agreed they should combine and then graph the data. **Organizing and presenting the data [SEP-4]** in a visual form (graph) helped students make sense of the information and enabled them to discuss and work with their team to **review and revise their explanations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

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

Natural Selection Based on Four Scientific Concepts

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

Figure 5.49. Four Key Ideas in Natural Selection



Source: Adapted from Sussman 2006.
Long description of Figure 5.49.

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

Linking Natural Selection and Evolution

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

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

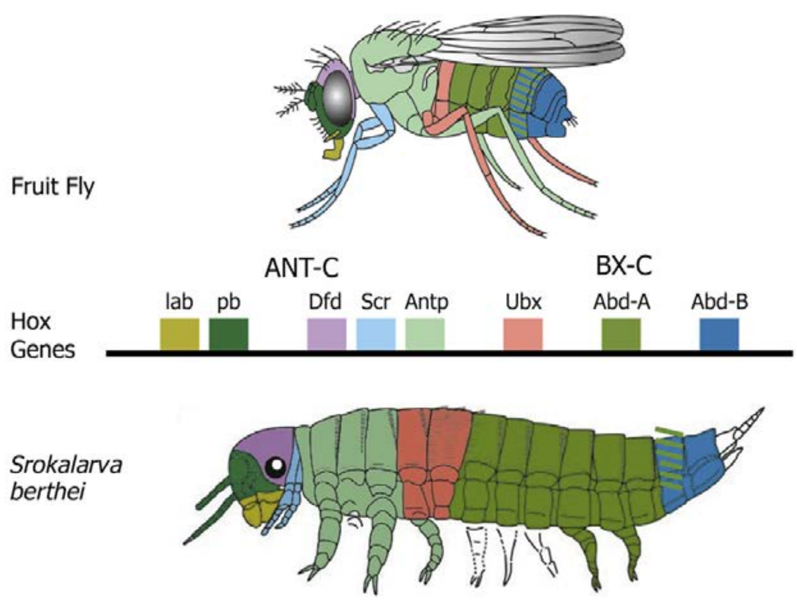
Students can compare and contrast the processes of artificial selection and natural selection. By selecting for specific characteristics over many generations, humans consciously take advantage of naturally occurring variations, and they keep increasing the quantity and quality of a particular trait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

What Causes Variation?

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

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

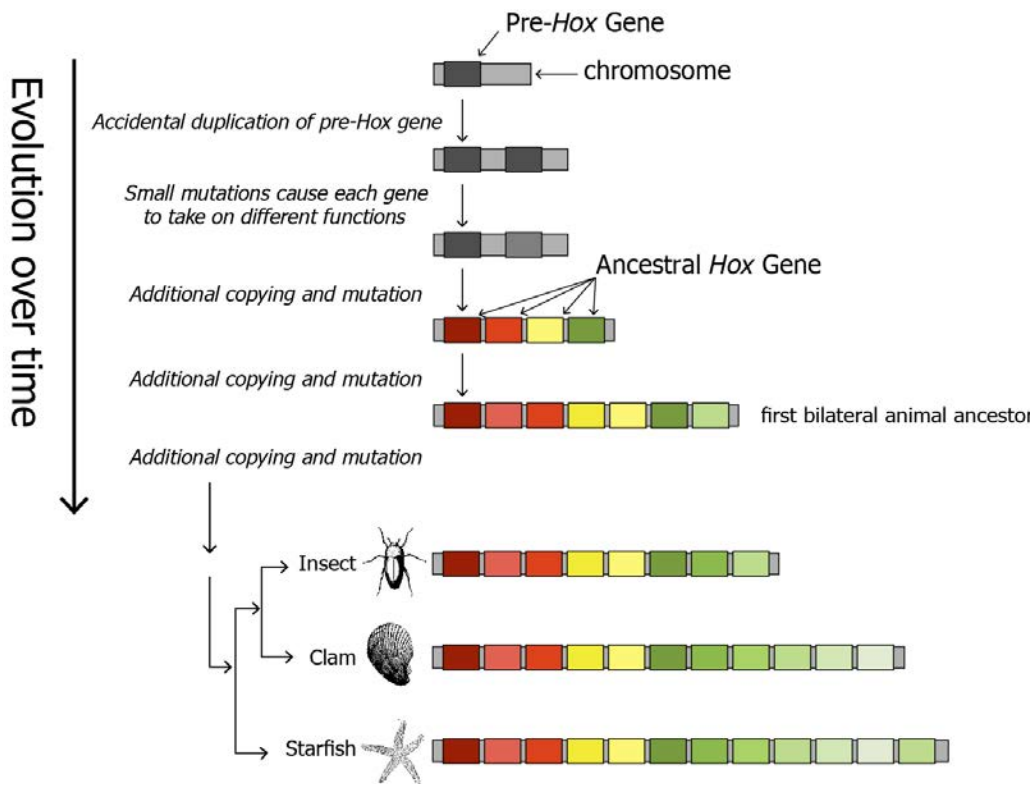
Figure 5.50. Arthropod Bodies Have Similar Structures



Source: M. d'Alessio with image from PhiLip 2007; adapted image from Haug et al. 2015, Fig. 4; and data from Haug et al. 2015.
Long description of Figure 5.50.

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

Figure 5.51. Animals Share Similar Genetic Code for Body Segments



Source: M. d'Alessio
Long description of Figure 5.51.

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

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

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

Table 5.12. Possible Results of a Mutation

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

Source: Dr. Art Sussman, courtesy of WestEd

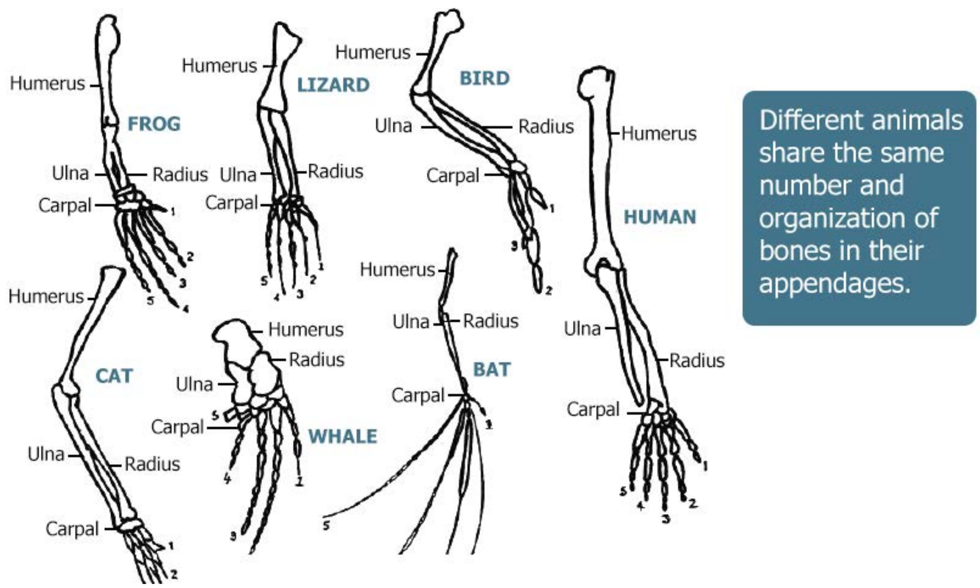
Just like artificial selection parallels natural selection, humans have developed technology to artificially introduce mutations. Students can return to their case study of corn and maize and **obtain information [SEP-8]** about how seed manufacturers have genetically modified some maize traits by inserting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

Unity and Diversity of Life

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

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

Figure 5.52. Comparing Limb Bone Structures in Different Animals



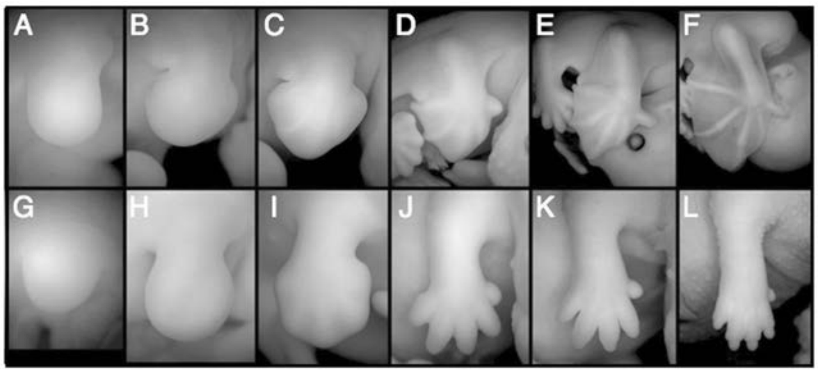
Anatomy reveals both the unity of basic bone structures and the diversity of organisms. *Source:* Lawson 2007

Long description of Figure 5.52.

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

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

Figure 5.53. View of Embryo Development in Bats and Mice



(Top Row, A-F): Bat; (Bottom Row, G-L): Mouse. *Source:* Cretekos et al. 2008, © Cold Spring Harbor Laboratory Press
Long description of Figure 5.53.

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

Integrated Grade Eight Snapshot 5.9: Simulating Mutant Hands

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

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

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

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

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

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

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

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

Bringing the Unit Together

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

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

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

IS4

Integrated Grade Eight Instructional Segment 4: Sustaining Local and Global Biodiversity

This instructional segment features a very important concept related to the CA NGSS Earth and Space Science domain: Earth and Human Activity. Increases in human population and in per-capita consumption of natural resources impact Earth's systems (MS-ESS3-4). In this instructional segment, students revisit life science concepts that they explored in IS3: *changes in environmental conditions alter populations of organisms and can cause extinction* (MS LS4 4 and MS-LS4-6). Fortunately, modern technologies, such as using digitized signals to encode and transmit information (MS-PS4-3), can help us monitor, understand and reduce these impacts.

INTEGRATED GRADE EIGHT INSTRUCTIONAL SEGMENT 4: SUSTAINING LOCAL AND GLOBAL BIODIVERSITY

Guiding Questions

- What are the characteristic properties and behaviors of waves?
- What human activities harm Earth's biodiversity and what human activities help sustain local and global biodiversity?
- How does communication technology encode information and how can digital technologies be used to help sustain biodiversity?

Performance Expectations

Students who demonstrate understanding can do the following:

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.]

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-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.]

INTEGRATED GRADE EIGHT INSTRUCTIONAL SEGMENT 4: SUSTAINING LOCAL AND GLOBAL BIODIVERSITY

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 sign. [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*.]

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.

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

INTEGRATED GRADE EIGHT INSTRUCTIONAL SEGMENT 4: SUSTAINING LOCAL AND GLOBAL BIODIVERSITY

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 [SEP-8] Obtaining, Evaluating, and Communicating Information	LS4.B: Natural Selection LS4.C: Adaptation ESS1.A: The Universe and Its Stars ESS1.B: Earth and the Solar System ESS3.C: Human Impacts on Earth Systems PS4.A: Waves Properties PS4.B: Electromagnetic Radiation PS4.C: Information Technologies and Instrumentation ETS1.A: Defining and Delimiting Engineering Problems ETS1.B: Developing Possible Solutions	[CCC-1] Patterns [CCC-2] Cause and Effect [CCC-6] Structure and Function [CCC-7] Stability and Change

Highlighted California Environmental Principles and Concepts:

Principle 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: 6.RP.1, 3, 6.SP.5, 6.EE.6, 7.EE.3,4, 7.RP.2, 8.F.3, MP.2, MP.4

CA CCSS for ELA/Literacy Connections: RST.6–8.1, 9, WHST.6–8.1, 2, 9, SL.8.1, 4, 5

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

Students begin by watching an animation of net primary productivity, a quantity related to the amount of photosynthesis occurring at different locations around the world (NASA, https://www.cde.ca.gov/ci/sc/cf/ch5.asp#link26). Students can recognize the obvious cycles of the seasons, but they can also notice the effects of deforestation, desertification, and climate change. For this instructional segment, the anchoring phenomenon is that plants go through seasonal cycles where productivity peaks in the Northern Hemisphere around July and the Southern Hemisphere around January. During the instructional segment, students will explain the large seasonal signal and zoom in to design solutions for problems causing some of the smaller scale changes. This video is remarkable not only because of the Earth system interactions captured, but also in the technology involved in making the observations. Net primary productivity is actually a measure of the amount of carbon dioxide released into an area. How can scientists measure the concentration of a gas at every point around the planet? The answer is that the carbon dioxide gas interacts with light in certain ways that enable scientists to detect the amount of the gas in the air using a satellite with a sophisticated camera.

Students **obtain information [SEP-8]** about the Moderate Resolution Imaging Spectroradiometer (MODIS) on NASA's Terra satellite and how it observes photosynthesis across the entire planet each month while orbiting 700 km above the surface. The details of the sensor and the frequency of light it uses are outside the assessment boundaries for the middle grades, but one of the major reasons that DCI PS4 is so prominent in the CA NGSS is that we want our students to understand how different wave-based technologies have completely transformed the way we do science, communicate, and live. Before students can explain the features in the anchoring phenomenon, they need to further develop their models of wave properties and behavior. The vignette below uses scientific monitoring of a different life science phenomena to introduce sound waves and other waves such as radio waves.

INTEGRATED GRADE EIGHT VIGNETTE 5.3: WAVES AS A TOOL IN BIOLOGY

Performance Expectations

Students who demonstrate understanding can do the following:

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).] (revisited from grade six)

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.]

INTEGRATED GRADE EIGHT VIGNETTE 5.3: WAVES AS A TOOL IN BIOLOGY

MS-PS4-2. 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: 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-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 performance expectations marked with an asterisk integrate traditional science content with engineering through a practice or Disciplinary Core Idea.*

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

Highlighted Science and Engineering Practices	Highlighted Disciplinary Core Ideas	Highlighted Crosscutting Concepts
[SEP-1] Asking Questions and Defining Problems [SEP-2] Developing and Using Models [SEP-5] Using Mathematics and Computational Thinking	ESS3.C: Human Impacts on Earth Systems PS4.A: Waves Properties PS4.B: Electromagnetic Radiation ETS1.A: Defining and Delimiting Engineering Problems	[CCC-1] Patterns [CCC-6] Structure and Function

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: 7.SP.1-3, 8.SP.4

CA CCSS for ELA/Literacy Connections: ELD.PI.8.1, 2, 4, 6a–b, 9

CA ELD Connections: RI.8.2, RI.8.8, SL.8.1, 4, 6

Introduction

This vignette flows from IS3, in which students explored the evolutionary history of several species. Sharks are one of the most ancient vertebrate species with approximately 400 million years of history.

Mrs. G transitioned her students to the next unit on waves, being mindful that she wanted to build in a strong nature of science connection to this part of the unit (Science is a Human Endeavor: *advances in technology influence the progress of science*, and Science Addresses Questions About the Natural and Material World: *science knowledge can describe consequences of actions but does not necessarily prescribe the decisions that society takes*). She decided to help her students see the application of understanding waves in answering some of the biggest questions beach visitors, beach city leaders, and biologists are asking today about sharks: Why

INTEGRATED GRADE EIGHT VIGNETTE 5.3: WAVES AS A TOOL IN BIOLOGY

are we seeing so many white sharks, *Carcharodon carcharias*, off the coast of California?

5E Lesson Design—This sequence is based on an iterative 5E model. See the "Instructional Strategies" chapter for tips on implementing 5E lessons.

Day 1: Questioning Claims about Shark Encounters

Students read an article about a string of recent shark sightings and then shared their own tales about sharks. They asked questions about how they could distinguish fact from fiction.

Day 2: Data with More Questions than Answers

Students tried to interpret a graph of the number of reported shark captures, but found that many factors influenced the data set itself.

Day 3: Locating with Sound

Students watched a video about an autonomous underwater vehicle that tracks and films sharks. They used models to reverse-engineer how the device locates the sharks using sound waves.

Day 4: Obtaining Information about Tags

Students researched about how different types of electronic tags and receivers use wave technology to collect and transmit information to scientists.

Days 5–6: Light and Sound

Students obtained information about light and sound and then planned an investigation to explore the differences in how they travel through salt water.

Days 7–8: Interpreting Shark Data

Students explored new understandings from this technology.

Days 9–10: Applying Understanding to a Different Population

Students applied new understandings and predicted possible trends in shark populations on the East Coast.

Days 11–12: Educating Different Audiences

Students considered the question, Now that we have better information on white sharks, what type of information is important for the public to know? to probe thinking as to why sharks are important and human actions that affect the population and created a public service announcement to target a specific audience.

Day 1: Questioning Claims about Shark Encounters (Engage)

Everyday phenomenon: Sharks have been seen at California beaches recently.

To pique interest and provide all students with background on a real-world phenomenon, students read a short article on recent shark sightings (Rocha 2015). Students excitedly shared stories they have heard about white sharks, many of which were outlandish and eventually led to rumors about sharks attacking or eating humans. Mrs. G simply solicited

INTEGRATED GRADE EIGHT VIGNETTE 5.3: WAVES AS A TOOL IN BIOLOGY

information from the students and let the excitement in the room build. Mrs. G then began to direct the conversation. After everyone agreed that sometimes people embellish stories and some things may not be true, Mrs. G asked how students could distinguish accurate information on sharks from the fantastical stories friends and families share. How could they tell if there were more shark encounters this year than in the past? After several months in Mrs. G's class, they all called out, "We need data!"

In groups, students discussed how they could build an accurate record of information on white sharks that had visited the coast in recent history (for the past 100 years). At the middle grades level, students should be able to **ask questions [SEP-1]** that help them identify evidence that can support an argument. Students struggled with this question once they realized that Google didn't exist 100 years ago. As she visited teams, Mrs. G asked students to think if there was anyone who would have had consistent access to the coast and might have documented information on sharks. Students continued to stumble, but came up with ideas such as lifeguards or someone who lives at the beach—but they acknowledged that they probably couldn't see sharks very well from the shore.

In one team, Minh had a different idea. She often went to the pier to fish with her family and sometimes caught small "sand sharks." She explained that even her grandfather told stories of catching sharks when he was a small boy in Vietnam. Mrs. G asked if Minh would mind sharing with the class. As Minh began, José's eyes lit up and he began frantically waving his hand. He, too, went fishing with his uncle, who owned a sport fishing charter boat. His uncle kept a log of what everyone caught. When the boat returned to the dock, they had to report what they caught on the trip, and sometimes there was someone at the dock who inspected their buckets. The class quickly began to realize that fisher logbooks might be a good source of information.

Day 2: Data with More Questions than Answers (Explore)

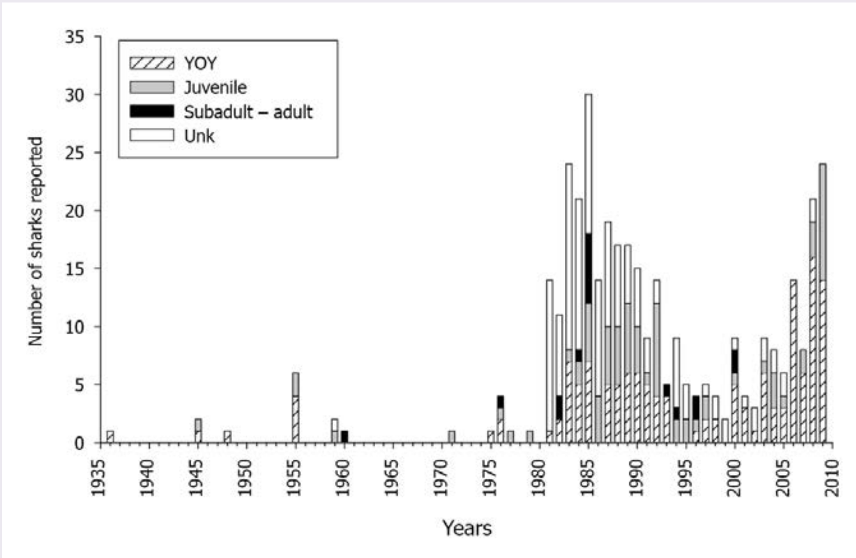
Anchoring phenomenon: The number of shark sightings increased dramatically in 1980 and goes up and down over time.

Mrs. G provided students a graph with observations of reported shark catches over the last 100 years (figure 5.54). Once students had a chance to examine and discuss it with their team. Mrs. G asked the class where the title was and students realize it was at the bottom. "Does anyone have any idea what 'temporal trends' means?" she asked. One student suggested temperature and several agreed. Mrs. G continued, "What if I told you the word came from a Latin word, *tempus*?" Kim, a music student, replied, "Is that like tempo? We use that word in music, it like, deals with time or something." "Oh, good connection, Kim," said Mrs. G. "It does have to do with time, so here we are looking at temporal trends, or trends over time." She asked students to share what they think *YOY*, *Juvenile*, *Subadult-adult*, and *Unk* represented on the graph. She asked students to discuss if they should focus on the height of each bar, or the height of the overall total. "I would be afraid of a white shark no matter what age it is,"

INTEGRATED GRADE EIGHT VIGNETTE 5.3: WAVES AS A TOOL IN BIOLOGY

offered José. Mrs. G emphasized that students need to focus in on the information in the data that would help them answer their questions about whether or not sharks are becoming more common along the California coastline and they could ignore the extra details for now.

Figure 5.54. White Shark Captures in Southern California from 1935–2009



Source: Lowe et al. 2012
Long description of Figure 5.54.

Mrs. G asked students to view the data through the lens of **cause and effect [CCC 2]** and record questions in their science notebooks. Using protocols they established earlier in the year, students in each team helped each other generate ideas. Students invited each other to share an idea before any one person shared more than one idea, and they often invited someone who is reluctant to share or to be the first one to speak. Mrs. G overheard Minh's group. Minh restated the question for Maria, an English language learner who was often reluctant to speak, "Maria, what is your question about this?" Pointing to the data in the figure, she said, "This is the effect. What was the cause?"

Students began working and charting questions: Why were there so few sharks reported before 1980? Why do the numbers of sharks reported go down in the late 1990s through the early 2000s? Why were there so many young sharks and so few adults? Students were then asked to narrow down to one question, and consider possible causes or factors that could

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have led to that result. Mrs. G selected one group's chart to share with the class because it allowed her to focus on a key issue:

Question: Why were there so few sharks reported before 1980?

Possible causes:

- There weren't very many white sharks.
- People didn't fish as much.
- Fewer people lived in California so there weren't as many fishermen.
- There wasn't good fishing technology before 1980 so it was harder to catch a white shark.
- There wasn't someone to track information and computers were not common before 1980.
- Some people caught white sharks to sell them.
- Once people learned about sharks they were scared and they wanted to kill sharks.

Mrs. G asked students to look at this team's list of possible causes and divide them into two categories: inconsistency in the data set and an actual change in the number of sharks. Both were possible, so students needed more information about their data set.

Students read an article Mrs. G adapted from a paper written by researchers at California State University, Long Beach and the Monterey Bay Aquarium reviewing the history of white sharks in California (Lowe et al. 2012). Each team was asked to read a part and then **report a key finding [SEP-8]** on the class white board. From this, students commented on how messy and confusing the data can be and how there was a lot of information they had to take into account to make sense of it without misinterpreting it. For example, in some cases it might have looked like the white shark population was increasing, yet at the same time the population of humans living and playing at the coast increased, which could have resulted in increased reports. They were shocked to learn that a movie had an impact on the data. The release of the movie *Jaws* resulted in an increase in white shark reporting in the early 1980s, as people set out to kill white sharks. Some of this increase was due to more sharks tangled in commercial fishing nets as demand for human consumption and updated fishing technology increased (EP&C II). Students acknowledged that relying on fishing data was helpful because we could start to build some understanding, but it did not give them a very clear sense of what is actually going on with respect to white shark behavior.

Day 3: Locating with Sound (Explain)

Investigative problem: Sharks are hard to track and identify.

Mrs. G asked, "Can you think of a way we might get some more reliable data? We can't go back in time, but we can collect better data in the future."

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Students began sharing ideas and Victor suggested using drones to track sharks, and the class erupted in laughter. Mrs. G smiled and said, "Victor is on to something! Drones work in the air, and some lifeguards have tried using a drone rather than sending a lifeguard out on a jet ski just to see where they are. Even with a drone, however, we can't see the sharks if they aren't near the surface. Can you think of something that could work in the water?" Victor then suggested an underwater robot.

Investigative phenomenon: An underwater robot can track sharks using sound waves.

Mrs. G showed a short video clip about the Woods Hole Oceanographic Institution's robotic shark tracker (underwater autonomous vehicle), REMUS (Woods Hole Oceanographic Institution 2014). Students recorded "aha moments" and questions in their notebooks as they watched the video.

Mrs. G asked students what information about sharks they think REMUS could provide. The excited students began listing things like sharks are awesome, sharks can bite hard, and sharks don't like the robot. Mrs. G asked students to turn their list of into specific **questions [SEP-1]** about sharks that they could investigate. They returned to these questions on day 6.

Mrs. G returned to the original question of finding and tracking sharks. It is true that sometimes the shark came to attack the robot, but most of the time the robot sought out the sharks. The video briefly mentioned that the robot had a sensor for locating sharks based on acoustic technology (sound waves). Students were surprised that sound can travel through water, but Mrs. G challenged them to try it out next time they are in a swimming pool or bathtub by submerging their head and then tapping on the wall with a metal spoon. Her students complained that they want her to prove it right then, so Mrs. G filled up a tub of water and clinked together two metal spoons in the middle of the tub so that students can put their ear up against the wall of the tub to hear it. Mrs. G introduced the concept that "sound waves are *transmitted* through water" to explain this phenomenon?

Mrs. G asked students to draw a **model [SEP-2]** on their white board of how they think that the robot could use sound to locate the shark. Students were pretty confused, but Mrs. G helped prompt students to think creatively. Different groups had different models, with some "listening" for the shark with a microphone and others showing a sonar-style device. Mrs. G told students that the devices could only detect sharks from a limited distance away and she had them use their model to write an explanation in their notebook about why. She told them that their explanation should use an energy diagram like the one they learned about earlier in the year. Most students recognized that the sound waves are a form of energy and that this energy must "die out." In groups, students discussed how to represent "die out" in terms of energy and decided that the energy must be absorbed by some other object (probably the water molecules). What could they do to their **system [CCC-4]** to detect sharks from further away? Mrs. G was trying to get students to consider the amplitude of the sound waves and how

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they relate to energy (MS-PS4-1). For a sonar system, for example, they could increase the amplitude of the pulse they send out. Mrs. G asked students to add representations of the sound waves to their diagram where they indicate how the amplitude changes at different points along its path. What would be some challenges the robot would need to overcome in order to send out higher amplitude waves? Students offered good ideas about possibly disturbing the sharks or other marine wildlife with the loud noises, but she directed them towards the idea that the robot would need to use more energy (higher amplitude = higher energy) and would run out of batteries.

Mrs. G showed a quote from a Web page that says REMUS relies on an electronic device, a "transmitter tag," attached to the shark (but her quote provides no other details). Mrs. G asked students what they think this tag does and had them modify their diagram to show a tag transmitting a signal that the REMUS receives. Mrs. G reminded students how quickly cell phones run out of charge when someone talks on them constantly and asked for students to think about how they could extend the battery life on the tag even further. Mrs. G then shared another quote from the REMUS Web page that described how the tags attached to the shark did not send out a constant signal, but instead waited to receive a signal from the REMUS robot. That way, they used much less energy in "standby" mode than they would transmitting constant pulses. The sensor on the robot recorded how long it takes for the sound energy to return after sending its initial pulse and from which direction the return pulse arrives in order to determine the sharks distance and direction. The direction sensing worked a lot like the two human ears spaced a short distance apart (**structure and function [CCC-6]**); the REMUS robot referred to this distance as an "ultra-short baseline." Mrs. G had students act out the direction sensing process by making a physical **model [SEP-2]** with one student blindfolded playing the part of the robot and another playing the part of the shark. When the robot claps, the shark claps back.

Day 4: Obtaining Information about Tags (Explore)

Investigative phenomenon: Some tags use radio waves to transmit information.

Now that students knew that tags existed, Mrs. G told them that these devices attached to a shark's fin could actually record all sorts of information and send it back to scientists. She asked them to record ideas in their notebook about what sort of data the tag could collect. She partnered students who had mobile devices with those who didn't to **obtain information [SEP-8]** about what shark tags actually measured, and suggested they look up SPOT and PAT tags as these were commonly used on white sharks. The students developed a list of things the tags could measure such as temperature, depth, and light intensity. On one team, Trinh wondered aloud how this would tell them anything about what was going on with the shark and how they would get the information from the tag. Her teammate, Oscar, reading from his phone, said, "The SPOT tags transmit using radio waves and so the shark would have to be at the surface to transmit to a satellite. When it swam up to the surface, we would know where

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the shark was, but the PAT tags were designed to pop off and float to the surface." Trinh commented, "That's strange, why does it have to transmit at the surface? Don't waves travel underwater?"

Days 5–6: Light and Sound (Explore/Explain)

Investigative phenomenon: You can hear the buzz of an electronic timer that is under water, but a radio receiver cannot detect radio waves when it is submerged in salt water.

Although her students had heard of radios before, the idea of thinking of these as waves was new for them. They studied waves in grade four, but assessment was limited to mechanical waves (4-PS4-1). For the rest of the period, Mrs. G gave the class time to dig deeper into radio waves and sound waves and explore the phenomenon of what happens to waves in water. She asked them to think of objects in the classroom that used radio waves and those that used sound waves. A student thought of a radio and grabbed a small hand-held AM/FM radio. One student questioned if radio was the same as sound. Acknowledging this, Mrs. G asked him to think of something that had sound that wasn't a radio. He grabbed the class digital timer. Mrs. G had a large saltwater tank set up that had been donated to the class, already filled with a saltwater solution she made that morning. She set out zip-top bags and asked students to **investigate [SEP-3]** the differences between radio waves and sound in water. As they worked, she asked them to record procedures, predictions of what would happen when they submerged devices, and give a rationale for their thinking. After each team confirmed that everyone had supported the predictions with rationale, students held the devices in the center of the tank, surrounded by about a foot of water on all sides. To their delight, they could no longer hear the radio after submerging, but could hear a faint buzzer of the timer. Mrs. G had students document the differences in how radio waves and sound waves traveled through salt water versus air by filling in a table in their science notebooks using the terms *absorbed* and *transmitted*. Their investigations and this video (https://www.cde.ca.gov/ci/sc/cf/ch5.asp#link27) helped give students ideas for revising the models they started on day 3. Some of the students remembered from grade four that light is a wave and wondered if it was absorbed or transmitted in the water.

After a laser safety reminder, Mrs. G encouraged students to shine a laser through the saltwater tank. They didn't notice anything unusual, but Mrs. G told them that there are some important effects of light that shark taggers must consider. Mrs. G called students back to their teams and showed the class a photo of a researcher on a boat trying to tag a shark in the water. She asked them to consider the challenges the researcher had in this task. Students commented that they would be afraid to be so close to a shark and it would be hard because the boat is moving. Mrs. G hinted that there is one more challenge they might not have thought of. She had a student from each group pick up a clear cup of water with a penny at the bottom and bring it back to their table. She then passes out a straw to each team and instructs

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the students to stand directly over the cup and quickly thrust it in to spear the "shark" right on Abraham Lincoln's eye. The students were surprised that they all missed. Mrs. G asked them to view the straw at eye level and Victor shouted, "It's crooked!" Mrs. G confirmed his observation and said, "What you are calling *crooked*, scientists call refraction." Mrs. G then had her students use the PhET simulation "Bending Light" (https://www.cde.ca.gov/ci/sc/cf/ch5.asp#link28) and asked students to make a model in their notebooks of what happens when light goes from air to air, from air to water, from air to glass. She then asked students to make three separate **models [SEP-2]** in their notebooks that **predict [CCC-2]** what would happen if light goes from air to an acrylic block, from air to a wood block, and from air to an aluminum block. Once all of the students in a team had made their predictions, they got a laser and set of blocks, tried it out, and updated their models in their notebook.

Bringing students back to the challenge of tagging a shark from the surface of a boat, she passed out an index card to each team and asked them to compose a tweet to the @CSULBSharkLab. She promised to really tweet the one in the class that best demonstrates an understanding of how light's behavior made it hard to tag sharks.

Days 7–8: Interpreting Shark Data (Explore/Explain)

Investigative phenomenon: White sharks spend lots of time near the shore where fishing regulations prevent the use of entanglement nets.

What have scientists learned from tracking sharks? Is the shark population actually increasing? How does this information help protect the sharks? Mrs. G designs a jigsaw activity where teams divide up into groups of experts that **obtain information [SEP-8]** to answer one the following four questions (with key highlights of what they might find in parentheses):

- As California has grown, has commercial fishing grown, too? (Fishing expanded greatly in the 1970s but was so successful that many fish populations crashed, leading to increased regulations. The commercial halibut catch in California in 2015 was less than half of what it was in the 1990s.)
- How do the commercial entangling nets work? (Large nets left out for as long as several days entangle hundreds of fish at a time and sometimes catch white sharks as well.)
- What laws govern commercial fishing? (In 1994, laws passed that prohibit entangling nets in the shallow water within three miles of the coast.)
- What happens to a white shark when it gets caught by a fishing net? (Some die before the net is brought back to the boat and some get released back into the water.)

Back in their home teams, expert students taught each other about their assigned topics. Together, students made important connections to ideas that related to consumer demand and certain fishing techniques impacting the food source of young great whites. Mrs. G then

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passed out copies of an article from a newspaper that described a study conducted by a graduate student at the CSULB Shark Lab that looked at geo-positioning data from tagged juvenile white sharks (Dulaney 2013). Mrs. G carefully selected figures from the source article (Lyons et al. 2013) and had her students **analyze and interpret [SEP-4]** some of the original tracking data. They found that young sharks spend a surprising amount of time swimming in the shallow water where boats are prohibited from casting nets (within 3 miles of shore). Students constructed an **argument from this evidence [SEP-7]** that the shark population was increasing, and that the increase was a direct result of the laws that have created protected "shark nurseries."

The tracking data also allowed scientists to monitor the fate of sharks that were accidentally caught and released (if the tracker kept going, the shark must have survived). **Interpreting the data [SEP-4]**, students found that sharks had a high chance of survival, and that sharks were more likely to die when nets were left out for longer periods (like 1–2 days) than when the nets were pulled in after just a few hours. They would revisit this finding on day 11.

Days 9–10: Applying Understanding to a Different Population (Elaborate)

Investigative phenomenon: Shark populations in Cape Cod have also changed in recent decades.

Mrs. G told students that as newly minted shark experts, they had been hired to study sharks in Cape Cod, Massachusetts, where there had been frequent sightings of great white sharks in recent years. Were the same factors **causing [CCC-2]** a similar **trend [CCC-1]** as in Southern California? What information would they want to know about the Cape Cod population? Given information about abiotic factors of Cape Cod, could they predict details about the Cape Cod population? Knowing more about the Cape Cod population, what type of tracking device (including details about type of wave and why) would they design to best study them (**planning an investigation [SEP-3]**, **engaging in argument from evidence [SEP-7]**)?

Days 11–12: Educating Different Audiences (Evaluate)

On the final days of the lesson sequence, Mrs. G reminded her students that there were many misunderstanding about sharks at the beginning of their studies. She posed a question, "Now that we have better information on white sharks, what type of information is important for the public to know?" Students in the class had a few moments to record their thinking in their notebooks and the class discussed. Mrs. G asked the teams to think about what they had learned and introduced them to their challenge: Create a public service announcement (PSA) to help educate different audiences in the community. Students decided which audiences would be important to target for this message, created a storyboard to organize their message, and got to work. Groups targeted the fishing industry, lawmakers, and other beach visitors. Mrs. G provided a rubric to help students focus as they worked and provided

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check-in opportunities where teams updated her on their progress and got feedback. The students then proudly shared their PSAs at the school's family science night later that month.

Vignette Debrief

The overall structure of this vignette used a real-world phenomenon in life science to motivate a technological solution using principles of physical science. In the vignette as written, students did not get to answer all the questions introduced by the anchoring phenomenon because changing shark populations and behavior are more closely aligned with performance expectations in grades six (MS-LS1-4) and seven (MS-LS2-1; MS-LS2-4). Teachers could easily extend the lesson to interpret actual data from shark populations to resolve some of the initial questions raised on days 1–2.

This vignette illustrates the CA NGSS vision of blending SEPs, DCIs, and CCCs. While the lesson narrative describes this blend, the sections below focus on relevant aspects of each dimension in isolation, along with ties to the CA CCSS and the EP&Cs.

SEPs. The students in the vignette engaged in many SEPs, thereby building a comprehensive understanding of what it means to do science. The initial focus of the vignette was to identify data that could help students answer a scientific question (**planning investigations [SEP-3]**) and to select the appropriate technology for a device that can provide that information (days 1–2 and 6–7). After learning about a puzzling phenomenon about shark populations, students **asked questions [SEP-1]** on day 2 about the shark siting data they had **analyzed [SEP-4]** and again on day 3 as they were motivated to learn about sharks. On day 4, they **developed models [SEP-2]** of how the REMUS robot transmitted and received information from the sharks. They **conducted simple investigations [SEP-3]** on days 5–6 about light, sound, and radio waves in water. They ended with a **communication product [SEP-8]** that presented both their model and their investigation plan in one authentic public service announcement.

CCCs. The initial motivation for the sequence involved asking questions about **stability and change [CCC-7]** on day 2 when students examined data about shark populations. Students eventually used the tracking data to infer the **cause [CCC-2]** of these changes. In addition to this scientific problem, the vignette focused a lot on understanding the science and engineering aspects of the tracking devices, highlighting how technology facilitates scientific observation as part of the Nature of Science CCC, **Influence of Science, Engineering, and Technology on Society and the Natural World**. The vignette treated shark-tracking technology as a **system [CCC-4]** and students traced out the **flow of energy [CCC-5]** (by sound and radio waves) on days 3–4 when they explained how REMUS and other shark tags work. The foundation box for MS-PS4-2 attributed **structure and function [CCC-6]** to MS-PS4-2 because the structure of materials determined how they would interact with light and sound, though this CCC was not a major theme emphasized throughout the vignette.

DCIs. Shark tags sent information via mechanical (sound) or electromagnetic waves (light and radio), introducing students to basic wave properties (PS4.A). These waves interacted with objects and the media through which they travel, being transmitted, absorbed, or reflected

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(PS4.B). On day 3, students explored the tag transmissions in terms of energy. They identified that higher amplitude waves contain more energy (PS4.A; MS-PS4-1) by discussing how higher amplitude signals would drain batteries more quickly because they require more energy. Students also represented how amplitude decreases with distance as the water absorbs some energy.

In helping students develop models of wave behavior, this vignette went beyond the assessment boundary of MS-PS4-2. That performance expectation stated that wave behavior will only be addressed for light and mechanical waves—introducing the electromagnetic spectrum was beyond the middle grades level. Mrs. G decided that this phenomenon was compelling and included many important aspects of the Evidence Statement for MS-PS4-2. In days 5–6 when students explored sound and light waves, Mrs. G specifically avoided the discussion of the electromagnetic spectrum because the details are complex and more appropriate for high school.

Physical science DCIs about waves are strongly tied to specific life science questions about shark behavior. Shark tags provided data about shark behaviors that increase their odds of survival and reproduction such as migration over large areas, giving birth in warmer waters that influence growth rate, predatory strategies of hiding and attacking, and cooperative hunting (LS1.B Growth and Development of Organisms). In Integrated Grade Six, students constructed arguments about how such behaviors help animals survive (MS-LS1-4), and this vignette focused on **planning an investigation [SEP-3]** using shark tags that would provide evidence for such arguments.

By confronting the environmental impact of fishing on shark populations through monitoring (tags) and mitigation (public service announcement), students achieve MS ESS3-2 (revisited from grade six) and gain a better idea of human impacts on the Earth system. This vignette's focus on the biosphere is outside the recommendations and intent of the clarification statement that focus on the physical aspects of Earth systems, but this application of the Earth and space science principles to a life science realm is an excellent way to revisit this grade six performance expectation and the human impacts of ESS3.C.

On days 9–10, students performed some engineering design thinking where they had to select the appropriate technology (radio or sound waves) that best met the criteria for investigating the Cape Cod sharks (ETS1.B). In this case, students defined these criteria based on whether or not the device could transmit measurements that supported the scientific investigation (ETS1.A).

EP&Cs. Humans influence shark populations directly through fishing and indirectly through pollution, climate change, and alterations to marine habitat (EP&C II). Students discussed the effects of fishing on shark populations from days 7–8, and then reconsidered specific actions that could minimize human impacts on days 11–12 when they created their final communications product.

CA CCSS Connections to English Language Arts and Mathematics. Throughout the lesson sequence, students read informational articles to obtain information about shark populations (RI.8.2,8). They analyzed data to infer possible causes of the rise and fall of shark populations in Southern California at various points in time (7.SP.1-3). Students engaged in

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structured discourse with teams, including the jigsaw activity on days 6–7 (SL.8.1). Students also crafted a persuasive public service announcement targeting a specific audience based on robust evidence (SL.8.4, 6).

Reference:
Developed by Jill Grace.

Resources:

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Lyons, Kady, Erica T. Jarvis, Salvador J. Jorgensen, Kevin Weng, John O'Sullivan, Chuck Winkler, and Christopher G. Lowe. 2013. "The Degree and Result of Gillnet Fishery Interactions with Juvenile White Sharks in Southern California Assessed by Fishery-Independent and –Dependent Methods." *Fisheries Research* 147 (October 2013): 370–380.

Rocha, Veronica. 2015. "13 Young Great White Sharks Spotted off Huntington Beach." *Los Angeles Times*. https://www.cde.ca.gov/ci/sc/cf/ch5.asp#link30

Woods Hole Oceanographic Institution. 2014. "REMUS SharkCam: The Hunter and the Hunted." Posted at *Vimeo*, https://www.cde.ca.gov/ci/sc/cf/ch5.asp#link31

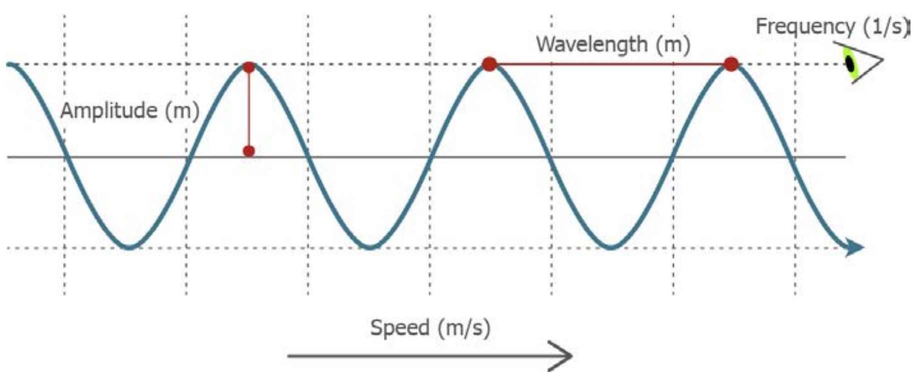
Water Waves

Over the course of this instructional segment, modeling activities should begin with mechanical waves propagating in a matter medium that is visible (such as water waves), then waves that propagate through a matter 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 (see https://www.cde.ca.gov/ci/sc/cf/ch5.asp#link32), ripple tanks (Falstad n.d.) 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 **investigate [SEP-3]** a variety of waves they can generate and observe in a flat-bottomed water container (ripple tank). Students observe and discuss general wave properties that they observe including absorption, reflection, transmission of one wave through another, and even make observations that prepare them for the high school understanding of waves by observing how the simultaneous production of multiple waves produces complex waveforms. Placing floating objects at the surface and drops of colored dye below the surface allows students to track the motion of particles within the tank. These observations of phenomena should provoke students to **ask questions [SEP-1]** about 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 these questions and the emerging explanations.

Waves are part of many different physical processes, but they all share some common aspects related to shape, direction of motion, and how the motion changes over time. By generating simple waves on a stretched rope or spring, students should be able to describe some of these features of waves. Discussions within and among groups can help elicit common observations about the height, speed, and spacing of waves. Similar features were probably observed in ripple-tank investigations. Student teams can then **develop a model [SEP-2]** of a typical wave and compare the ones they developed with the standard diagrammatic representation of wave shape as a regularly spaced series of peaks and valleys (figure 5.55). Students compare terms they used with the vocabulary that is commonly used to describe the shape of a wave and how it changes over time.

Figure 5.55. Model of a Typical Wave



Some properties that distinguish waves from each other include wavelength, amplitude, frequency, and speed of wave movement. Diagram by M. d'Alessio.
Long description of Figure 5.55.

Having become familiar with the properties of waves and having developed ways to represent and describe travelling waves, students are ready to think about and to model waves and/or wave pulses as carriers of **energy [CCC-5]**. 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). They can also see that more of this up-and-down motion results from 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 quantify this representation by dropping different size objects 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).

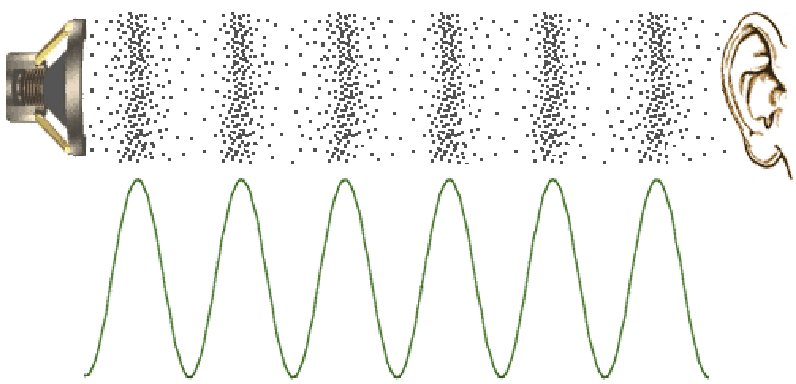
Students' **models [SEP-2]** of wave motion, amplitude, and **energy [CCC-5]** can help them **explain [SEP-6]** why waves break at the beach (enabling California's famous surfing and other beach play). Surfers know that the water in a breaking wave is moving toward the beach (which pushes their surfboard forward), but that out beyond the breakers, the water is not moving toward the beach! Surfers 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, and it begins to interact with the sand below. The wave can no longer have all its kinetic energy continue as up-and-down motion, and some of the energy gets transferred into forward motion that begins to "tip the wave over" and cause it to "break."

Students can **investigate [SEP-3]** this phenomenon in a ripple tank by introducing a sloping bottom spanning about a third of the tank length and creating waves by moving a flat object up and down at the other end of the tank. They can observe the relationship between the locations where the sloped bottom begins and where waves begin to break, and vary the slope angle to measure its effect on the waves. These discussions and investigations are necessary since most students need help understanding that the wave movement transfers the wave energy, but the medium of the wave (in this case, water) can move in a different direction than the energy flow. In a water wave, the water moves up and down perpendicular to the energy flow. Students can gather **evidence [SEP-7]** to show that the medium doesn't move far by watching floating corks bob up and down as waves travel across the ripple tank. Students may cite evidence of objects washing ashore at the beach that contradicts this statement. These objects are evidence of other processes such as ocean currents and waves breaking (it turns out that what we call waves at the beach do not meet the standard physical science definition of a wave—they are more complex because they interact with the seafloor and beach itself).

Sound Waves

Sound waves introduce a different kind of wave that students can **investigate [SEP-3]**. While water waves are easily recognizable as waves, students need evidence to believe that sound transfers energy as a wave. Since students' models of waves include motion, they may wonder what is moving in the sound wave. Students can readily feel the movement as sound passes through a solid. Students can also observe the driving energy of sound by using slow-motion video clips to observe the vibrations of speakers or by simply placing paper scraps on top of a large speaker. Students can use these observations to **develop a model [SEP-2]** of sound traveling as the back-and-forth motion within a solid material (figure 5.56). Students can then readily generalize this **model [SEP-2]** to **explain [SEP-6]** how sound travels through a gas, where the movement of air must be happening but cannot be seen.

Figure 5.56. Model of a Sound Wave in Air



Two representations of how sound travels as a wave in air. Source: Pluke 2012
Long description of Figure 5.56.

We can think of sound as a traveling wave of pressure differences in the air. The black dots in figure 5.56 represent air molecules packed together very tightly or less tightly. **Because of [CCC-2]** the vibrations in the speaker, the air varies in density in a wave-like **pattern [CCC-1]**. The dots and the wave-line provide two complementary ways to **model [SEP-2]** the fluctuations in the density of the air molecules. This wave pattern of density fluctuations of air molecules causes vibrations within the ear that **result in [CCC-2]** our conscious perception of sound (Integrated Grade Six MS-LS1-8). Note that the air molecules do not travel from the source of the sound to the ear.

Students can compare similarities and differences between water waves and sound waves. They should be able to **communicate [SEP-8]** using words or diagrams that both of these wave patterns transfer energy through a medium across a distance, and that the individual particles move only a very small distance. In both cases, waves reflect or are absorbed at various surfaces or interfaces, and two waves can pass through one another and emerge undisturbed. In the case of a water wave, the particles move perpendicular to the wave direction. In the case of a sound wave, the particles move parallel to the wave direction.

A surprising phenomenon related to the transmission of **energy [CCC-5]** by sound waves is the event in which a singer is able to break a glass using the sound of his/her voice. In order to **explain [SEP-6]** how the glass breaks, 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 vocal cords 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 molecule density that reaches the glass. Finally, the students' models will represent the transfer of energy from the vibrating air molecules to the molecules in the glass.

Light Waves

The idea that light is also a wave phenomenon can best be developed by the fact that it shows all the behaviors of waves (reflection, absorption, transmission through a medium such as glass, and carrying **energy [CCC-5]** from place to place; MS-PS4-2). 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 know that these fields are related to energy after their investigations in IS2, but the assessment boundaries for the middle grades MS-PS4-1 and MS-PS4-2 explicitly state that electromagnetic radiation (including a discussion of the electromagnetic spectrum) is not assessed in the middle grades. For grade eight students, visible light serves as a familiar form of energy and an example of how electromagnetic radiation can transfer energy very quickly across huge distances.

Light travels in straight lines, until it encounters an object where its energy can be absorbed, reflected back, or be transmitted through the material. Students can perform **investigations [SEP-3]** to compare the different effect 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). In fourth grade, students already began developing a model of how light allows objects to be seen (4-PS4-2), and teachers should connect to that earlier learning experience to emphasize that reflection is crucial because we only see objects after they reflect light back to our eyes. Eyes perceive waves with different frequencies as different colors, and each wave's amplitude is observed as light's brightness.

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 develop effective vocabulary-learning 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

A Model of Seasons

Knowing that light is energy that travels in straight lines, students can **develop a model [SEP-2]** of how differences in the distribution of **energy flow [CCC-5]** cause seasons. Students combine models of Earth's climate from grade six with models of the Earth-Sun system from IS1. We know that Earth is tilted a fixed amount of 23.5° relative to the plane of its orbit (figure 5.57) because one star in the sky barely ever moves as the Earth rotates each night—the North Star. Students will hopefully ask, Why is Earth's rotation axis tilted? and teachers can turn this around and tell them to **ask more specific questions [SEP-1]** through the lens of individual CCCs: What could **cause [CCC-2]** the Earth to tilt (impact, gravitational attraction, etc.)? Do other planets exhibit a similar tilt establishing a solar-system wide **pattern [CCC-1]**? Is the tilt stable, or does it **change [CCC-7]**—and does the timing of this change give clues to the cause of the tilt in the first place?

Figure 5.57. 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 5.57.

Students can make these connections using a physical model where their own body represents the motion of the planet (Space Science Institute, Kinesthetic Astronomy at https://www.cde.ca.gov/ci/sc/cf/ch5.asp#link33). They tilt their bodies toward or away from the Sun at the same 23.5° tilt as the Earth and move around Earth's orbit, making sure that their tilt axes always point 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° while it makes the angle smaller in the Southern Hemisphere. Computer simulations allow students another way to visualize these changes (NOAA, Seasons and Ecliptic Simulator, https://www.cde.ca.gov/ci/sc/cf/ch5.asp#link34).

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, at https://www.cde.ca.gov/ci/sc/cf/ch5.asp#link35 and in review articles at https://www.cde.ca.gov/ci/sc/cf/ch5.asp#link36). 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 in order 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.[2] In these virtual worlds, students view the Sun–Moon–Earth **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 more hours during the day (causing longer duration sunlight) and from higher angles in the sky (causing more sunlight to appear more intense in a given patch of the surface). Together, these give rise to warmer summers and cooler winters.

Students return to the anchoring phenomenon and **explain [SEP-6]** the dramatic seasonal shifts in primary productivity in the two hemispheres during a year. By using simple

2. Interactive 3D simulations can be found on the Internet and are described in Bakas and Mikropoulos 2003.

computer applets, they can determine the total amount of solar energy per square meter that different cities receive during each month of the year. They use these **quantitative [CCC-3]** data as evidence to support their **explanation [SEP-6]** of why the primary productivity remains high year round near the equator. They continue to **ask questions [SEP-1]** about some of the specific features they observe in the movie, many of which remain unanswered but could inspire further investigation in the capstone project at the end of the instructional segment.

Integrated Grade Eight Snapshot 5.10: School Solar Energy Project

Anchoring phenomenon: How much energy will solar panels on our school rooftop provide?

Mr. S invited a rooftop solar panel installer to visit his classes. In the days before their visit, the students prepared a list of **questions [SEP-1]** about the factors that affect the amount of energy the panels can generate. When they arrived, they gave a short presentation about solar energy and then went onto the roof to make measurements. The installer emphasized the importance of the angle of the Sun and that buildings with a flat roof like the school need a special platform that tilts the solar panels towards the Sun. A few days later, the solar installer sent the results from computer calculations to Mr. S with graphs of the amount of energy the panels would collect at different times during the year based on the position of the Sun and nearby trees that shade the panels (EP&C III). Students drew **models [SEP-2]** of light traveling in straight lines from the Sun to the rooftop (PS4.B), indicating how trees would absorb the solar energy when the Sun is in some positions but not in others based on its predictable movement throughout the day and year (ESS1.A). In essence, students were repeating the investigations of shadows from grade one (1-ESS1-1) with a more sophisticated level of understanding.

Investigative phenomenon: Solar panels produce different amounts of energy at different times of year.

The class worked to **interpret [SEP-4]** the graphs so that they could **explain [SEP-6]** the systematic variations during the year (ESS1.A) using their **models [SEP-2]** of the Earth–Sun system (MS-ESS1-1) and the paths of light (PS4.B) from the Sun to the Earth (MS-PS4-2). They drew **models [SEP-2]** that illustrated how the angle of the Sun’s rays affects the amount of energy converted to electricity much like this angle affects Earth’s temperature throughout the seasons and at different latitudes (MS-ESS2-6). Their models also showed how trees absorb light energy when the Sun is in some positions but not in others based on its predictable movement throughout the day and year. In essence, students were repeating their investigations of shadows from grade one (1 PS4-3; 1-ESS1-1) with a more sophisticated level of understanding.

Mr. S had arranged for the students to present the information to the local school board that makes decisions about how money is spent (EP&C V). Different groups set to work on an executive summary, a presentation, and a poster that **communicated [SEP-8]** the report's findings. Through a peer review and feedback process, the class revised each product and selected a team of students to make the formal presentation. The school board voted unanimously to allocate funds to install solar panels and the students tracked the installation progress. The following year, the students analyzed the actual energy production from their panels from day to day and month to month to recognize the **patterns [CCC-1]** in solar energy input.

Waves Can Encode and Transmit Information

How exactly does the MODIS satellite detect the amount of CO_2 in the air and transmit this information back to Earth? After having researched water waves, sound, light and electromagnetic radiation (EM), students can be challenged to summarize the characteristics of each of these with respect to wavelength/frequency, amplitude, and wave speed.

The students work in groups, share their drafts across groups, critique each other based on evidence, and compare finished drafts with respect to advantages and disadvantages. Table 5.13 illustrates one kind of summary.

Table 5.13. Characteristics of Waves

TYPE OF WAVE	WAVELENGTH / FREQUENCY ASSOCIATED WITH	AMPLITUDE ASSOCIATED WITH
Water wave	Physical distance between top of water waves	Height of the physical wave
Sound wave	Pitch of the sound	Loudness of the sound the sound
Light wave	Color of the light	Brightness of the light
All EM waves	Type of EM wave (x-ray, UV, light, IR, microwave)	Intensity of that EM wave

Table by Dr. Art Sussman, courtesy of WestEd.

A different summary might highlight other features of waves: (1) waves are repeating quantities; (2) waves interact with materials by being transmitted, absorbed, or reflected; (3) waves can transfer **energy [CCC-5]** over long distances without long-distance movement of matter; and (4) waves can be used to encode and transmit information.

Once students recognize that light and sound are waves, they can **communicate [SEP-8]** that even in the absence of modern technologies, each of us is constantly interacting with invisible waves of energy. All the information and experiences that we get through sight or hearing come to us as waves that our senses and nervous systems enable us to detect and experience. A string-and-tin-can "telephone" or a stringed instrument can provide a quick and very direct experience that waves can communicate information.

Students can research and report on how early technological devices captured sounds, images, and other information in mechanical ways. For example, an early clock had an inside pendulum whose movements resulted in the hour and minute hands that moved around on the face of the clock. Thomas Edison captured words and music by using a needle to convert the waves of air vibrations into bumps and valleys that he engraved into wax or tin. Then a needle on a sound player could respond to the engraved bumps and valleys, and create vibrations that he amplified back into the original sound. Photographers reproduced images by capturing and focusing light on material embedded with chemicals that reacted to the presence of light.

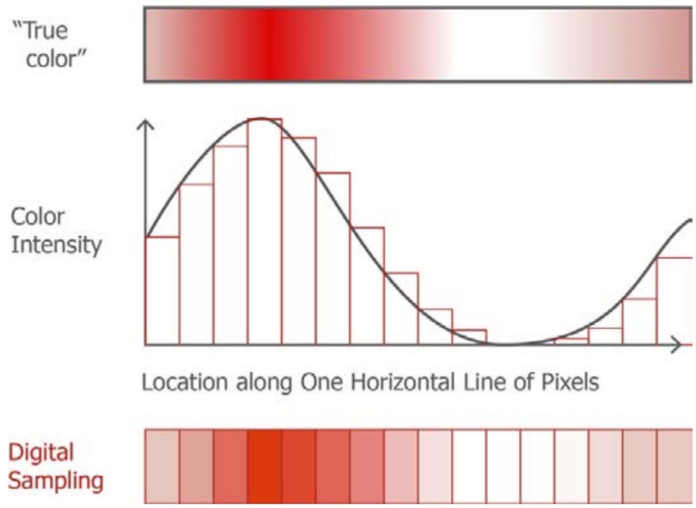
Students can compare the advantages and disadvantages of the earliest mechanisms of transmitting information to the beginning ages of radio to today's wireless cell phones and tablets. Historical examples of encoded information in wave pulses (e.g., drum or smoke signals, the invention of Morse code and early telegraph systems) can be helpful to develop both the idea of information in a waveform and the idea of encoding information. Finding out about and understanding the difference between AM and FM radio signals may serve as an activity. Students should be able to **model [SEP-2]** the conversions starting with the vocal chords of a singer in a studio to sound waves to electromagnetic radio waves being transmitted through antennas or wires to a radio device that converts those electromagnetic waves back to vibrations in a mechanical speaker eventually resulting in people hearing the song in the comfort of their home.

Today's advanced technologies such as cell phones and tablets use digital means to encode and transmit sound and images. Students are probably aware that pictures they see on a screen are encoded in pixels. Each pixel is a very tiny colored dot that is so close to its neighbors that the viewer sees what looks like a sharp, perfectly smooth image. A typical medium-quality photo on a screen may consist of 400 vertical rows of pixels, and each row may have 300 pixels located horizontally next to each other (a total of 120,000 pixels).

Figure 5.58 shows a wave line that corresponds to the color of 300 pixels in one horizontal line of a photo. The height of that line at any point specifies the color intensity at a point along the line. The horizontal position specifies where that point is horizontally located on the line. The rectangular boxes sample the average value of the color at

13 different locations, and summarize the color at each of those 13 locations as a number. Specifying the color of only 16 pixels along a horizontal line would result in a very fuzzy image. For a medium-quality photo image, the wave would be averaged at 300 different locations to obtain 300 numbers that specify the color of each pixel on that horizontal line. That process would be repeated vertically 400 times to have a specific color designation for each of the 120,000 pixels that make up a beautiful screen image.

Figure 5.58. Digitizing a Screen Picture



The features of an electromagnetic wave can be converted into numbers that change over a spatial location. These numbers can then be converted into computer-friendly digital formats so a very clear image can be displayed on a screen. Diagram by M. d'Alessio and A. Sussman.
Long description of Figure 5.58.

When an image or a sound has been entirely represented by numbers, we say that it has been digitized. Computers store data as a sequence of zeros and ones. The zeros and ones are called digits, which is why the files of information are called digital files. These digital files can hold an incredible amount of information in a very small space. For example, one tablet can store in its memory a large number of books, audio CDs, and even movie files. In addition, each of these digital files can be copied, edited (changed), and transmitted.

Digital technologies enable people today to obtain and manipulate information in previously unimaginable ways. Students should be able to **evaluate the claim [SEP-7]** that digitized signals offer significant advantages with respect to encoding and transmitting information (MS-PS4-3). In the vignette that concludes the middle grades progression, student groups engage with a design challenge focused on sustaining Earth's systems in which they use and **evaluate information [SEP-8]** at least one digital technology in researching their challenge and **designing their solution [SEP-6]**.

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Performance Expectations

Students who demonstrate understanding can do the following:

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-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.] (Revisited from grade six)

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*.]

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.

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-6] Constructing Explanations (for science) and Designing Solutions (for engineering) [SEP-7] Engaging in Argument from Evidence [SEP-8] Obtaining, Evaluating, and Communicating Information	LS4.B: Natural Selection ESS3.C: Human Impacts on Earth Systems PS4.C: Information Technologies and Instrumentation ETS1.A: Defining and Delimiting Engineering Problems	[CCC-1] Patterns [CCC-2] Cause and Effect [CCC-6] Structure and Function [CCC-7] Stability and Change

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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 complex and involve many factors.

CA CCSS Math Connections: 8.SP.2, 4

CA CCSS for ELA/Literacy Connections: RST.6–8.1, 2, 7, 9; RI.8.3; SL.8.1, 4, 6; WHST.6–8.2, 7-9

CA ELD Connections: ELD.PI.6–8.1, 9

INTEGRATED GRADE EIGHT VIGNETTE 5.4: STUDENT CAPSTONE PROJECTS

Introduction

By the end of grade eight, students can approach new phenomena, recognize how different parts of the Earth system are interacting in the situation, draw on DCIs from all disciplines of science and engineering to explain the mechanisms driving these interactions, and design solutions to problems that they identify and constrain. This capstone project puts them to work at using all their understanding from grades K–8.

Day 1: Analyzing Per-Capita Consumption

Students calculate per-capita consumption of different countries, develop and critique different ways of communicating these data, and ask questions about trends they see.

Day 2: Introducing Capstone Projects

Ms. D provides the background about the capstone project and students read and discuss five environmental case studies.

Day 3: Focus on Solutions

Students read about five case studies of communities that have developed solutions to environmental problems. Students brainstorm ideas for their capstone projects.

Days 4–8: Collaborative Work Sessions

Teams work collaboratively and the teacher helps focus and guide students.

Day 9: Project Presentations

Students prepare final presentations for a school science night.

Day 10: Synthesis

Students from different project groups combine together to identify common elements in the projects and identify how the projects relate to the EP&Cs.

Day 1: Analyzing Per-Capita Consumption

Anchoring phenomenon: Different countries consume radically different amounts of energy per capita.

How many people live on planet Earth? Where in the world do they live? Ms. D facilitated the discussions and appropriately guided them towards information about specific countries (e.g., the United States, China, Mexico) and also about parts of the world (e.g., Africa, Pacific Islands, Europe). She charted their comments, and then asked students if they had any ideas about which areas consumed the most resources and why. After a while, students concluded that for each country or continental area, they should probably get **quantitative [CCC-3]** data about total consumption and per-capita consumption.

Ms. D provided each group of students with information about world populations (available at Data from the Population Reference Bureau report accessed at https://www.cde.ca.gov/ci/sc/cf/ch5.asp#link37) and about consumption of natural resources in the year 2013. In both

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cases, the datasets included information at the country level (e.g., Brazil) and at a regional level (e.g., South America). The consumption data were reported as the number of millions of metric tons of carbon dioxide emitted from the consumption of energy resources (see Data from the U.S. Energy Information Administration accessed at https://www.cde.ca.gov/ci/sc/cf/ch5.asp#link38). Because the total amount of data from the sources was somewhat overwhelming and also not 100 percent consistent with respect to country/region designations, Ms. D had compiled the data to cover seven distinct regions, and had highlighted within each region significant representative countries.

Student groups **analyzed the data [SEP-4]** that Ms. D had provided, **calculated [SEP-5]** per-capita consumption as the ratio of the emissions and population, and then developed a poster to **communicate [SEP-8]** the differences to their classmates. Some student groups chose color-coding maps to compare per-capita consumption. Other groups superimposed on global maps pictorial ways to represent total consumption by a country or region. This representation helped them compare geographic size with consumption total. A less visually oriented group created a summary table (table 5.14).

Table 5.14. Per-Capita Consumption

Region, *[An example country]*	Population in 2013 *(number of people)*	Total CO_2 Emitted in 2013 *(tons)*	Per-Capita Emission of CO_2 *(tons/person/year)*
Africa *[Nigeria]*	1,100 million *(174 million)*	1,268 million *(96 million)*	1 *(0.5)*
Asia *[China]*	4,302 million *(1,357 million)*	18,909 million *(10,246 million)*	4 *(8)*
East Europe *[Russia]*	295 million *(144 million)*	2,713 million *(1,789 million)*	9 *(12)*
West Europe *[Germany]*	190 million *(81 million)*	1,466 million *(759 million)*	8 *(9)*
South America *[Brazil]*	401 million *(196 million)*	1,188 million *(502 million)*	3 *(3)*
Middle East *[Saudi Arabia]*	251 million *(30 million)*	1,716 million *(543 million)*	7 *(18)*
North America *[USA]*	352 million *(316 million)*	5,660 million *(5,184 million)*	16 *(16)*

Table by Dr. Art Sussman, courtesy of WestEd with data from the Population Reference Bureau 2013 and Population Reference Bureau 2016.

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The whole class then did a gallery walk where they examined each of the posters and listened to the group's presentation about their chart. The students discussed the benefits and disadvantages of each representation of the data. Students asked questions, and wrote down notes about specific pieces of the data that they noticed in each representation. After the gallery walk and while the charts were still visible, the whole class discussed the most important **patterns [CCC-1]** of per-capita consumption, and Ms. D invited students to propose **evidence-based claims [SEP-7]**. Some students noticed a **pattern [CCC-1]** that some small countries, particularly in the Middle East, had the highest levels of per-capita emission. For example, Kuwait had a per-capita emission rate of 37 tons of CO_2 per person per year. They made a claim that this extremely high rate resulted from Kuwait's large role as a producer, refiner and exporter of fossil fuel resources, and cited as **evidence [SEP-7]** correlations with other countries that produce and export large amounts of fossil fuels.

Throughout the year, Ms. D had posters along her wall with illustrations of California's Environmental Principles and Concepts and she asked students to refer to them now. She asked her students which EP&Cs might apply to the data set they analyzed. One student suggested EP&C II (*The long-term functioning and health of terrestrial, freshwater, coastal and marine ecosystems are influenced by their relationships with human societies*). She facilitated a brief class discussion about the concepts associated with that principle. Several students observed that their data seemed to support the idea that the growth of human populations is directly related to the amount of resources humans consume (EP&C II, concept a).

Day 2: Introducing Capstone Projects

Motivated by these observations about human consumption and questions about the possible impacts this consumption has on the rest of Earth systems, Ms. D introduced student group projects that concluded their immersion in the middle grades science. Student teams chose a specific human activity that has an environmental impact and explored it using all three dimensions of the CA NGSS as they experienced them throughout all three middle grades. She organized her expectations around the SEPs:

- **obtain and evaluate information [SEP-8]** about a specific phenomenon in which human activities are impacting one or more Earth systems;
- **analyze data [SEP-4]** related to the impacts on Earth systems, and identify how they demonstrate the California EP&Cs;
- **construct explanations and design solutions [SEP-6]** related to those human activities and impacts;
- **analyze design solutions [SEP-4]** with respect to their criteria and constraints associated with successful implementation;
- **model [SEP-2]** how digital technologies can assist with gathering data, implementing solutions, and/or communicating results;
- **argue using evidence [SEP-7]** to evaluate and refine their solutions; and
- **communicate the scientific and/or technical information [SEP-8]** related to their project and their proposed solution.

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To help establish a shared background within and across the student groups, Ms. D provided five different illustrated readings that she had made based on the *Living Planet Report 2014* from the World Wildlife Fund (World Wildlife Fund 2014). Students worked in teams of two to initially process the information in one of the readings and then combined into larger groups focused on that reading. These groups then made presentations to the whole class, followed by discussions about the individual topics and how those topics connected with each other around the theme of human impacts on Earth systems. The five readings focused on **cause and effect [CCC-2]** and **stability and change [CCC-7]** as they related to

- an overall decline in biodiversity of 52 percent between 1970 and 2010 resulting from habitat modification, over-exploitation, pollution, and invasive species;
- the ways that climate change can magnify the negative impacts on biodiversity;
- how humans are currently converting more nitrogen from the atmosphere into "reactive forms" than all terrestrial processes combined;
- the claim that humanity's demand for natural resources currently exceeds the capacity of land and sea areas to regenerate those resources; and
- **analyzing data [SEP-4]** comparing the "ecological footprints" of high-income countries and low-income countries.

Day 3: Focus on Solutions

Ms. D transitioned to a focus on solutions by sharing seven brief readings from the *Living Planet Report 2014*. Each reading described positive strategies that a specific community had implemented to preserve natural resources, have more efficient production, and consume more wisely. While they **evaluated information [SEP-8]** in these readings in teams and as a whole class, students began brainstorming potential solutions related to the impacts in the first set of readings. Student facilitators helped summarize and display notes on these potential solutions.

Students then started meeting in groups to develop projects. Groups shared their initial ideas with each other and with the teacher. These ideas and the partnering of students were in flux for a while until they solidified into specific project teams. Four teams focused on climate change but with different geographical contexts (the Arctic, Pacific Atolls, and two in California). Another team focused on protecting the California freshwater shrimp, an endangered species living in a stream near the school, while another team focused on reducing the school's energy consumption. After Ms. D approved the request of students to broaden the topics to include other concepts they had covered in grade eight, two groups chose asteroid-impact deflection to protect the planet, and a third group chose genetic engineering as a general way to increase food supplies.

Days 4–8: Collaborative Work Sessions

The schedule for the work on student projects included designated dates when groups shared their current status with each other. This sharing greatly broadened the learning from the projects about the topics and expanded the feedback to the student groups. During these

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sessions, each group focused on reporting about their project through the lens of one or two CCCs. The CCCs helped guide student thinking and lead them to ask specific types of questions (see chapter 1 of this framework for examples).

Day 9: Poster Presentations

At the end of the projects, student groups across the different grade eight classes presented posters of their projects at a school science evening program.

Some highlights from the projects included public outreach and monitoring water quality in a local stream to help protect the California freshwater shrimp. Students shared that this organism was an example of the four main HIPPO (**H**abitat loss, **I**nvasive species, **P**ollution, **P**opulation growth, **O**verexploitation) categories of activities that threaten biodiversity. People have altered its habitat by building dams, and also overharvesting timber and gravel along the stream banks. In addition, people have stocked streams with invasive nonnative fish species and polluted the water. The students proposed plans to increase public awareness related to stream overharvesting and pollution practices, and identified constraints that need to be addressed to reduce these practices. (EP&C II; See the EEI unit "Extinction: Past and Present" https://www.cde.ca.gov/ci/sc/cf/ch5.asp#link39 for more information and a lesson on HIPPO.)

The genetic engineering group made an analogy between genetic code and the encoding involved in digital files. They claimed that genetic code is neither analog nor digital, but instead is uniquely biological and provides the evidence that the language of DNA includes four "digits" instead of just the two options in the binary codes of digital communication. In addition, they provided **evidence for claims [SEP-7]** that genetic engineering of food crops does not significantly endanger personal health (e.g., cancer) but a key design constraint in genetic engineering is that solutions must not endanger the health of ecosystems (EP&C V).

The school energy group visited a school in a different district that had been recognized as a green school. They **analyzed and compared energy consumption data [SEP-4]** from their school and the green school, and made recommendations based on those analyses. In addition, they **shared information [SEP-8]** about digital tools that schools use to monitor and reduce energy consumption by improving the efficiency of lighting and heating. The team identified specific reduction goals as their criteria for success as well as detailed plans to achieve those goals. They identified a constraint that energy budgets and decisions are made at the district level rather than the school level (EP&C V).

One of the asteroid-impact teams changed projects. They remembered that the HHMI BioInteractive Web site about the impact crater included remote digital data that originally identified the crater in the Yucatan. While checking other links, they discovered that the HHMI BioInteractive Web site included conservation efforts at the Gorongosa National Park in Mozambique (https://www.cde.ca.gov/ci/sc/cf/ch5.asp#link40). The students explained that this park provided a case study in ecology and conservation science. They were particularly excited when they learned that park scientists used GPS satellite collars and motion-sensitive cameras to gather data about the recovery of the park's lion population. In addition to sharing pictures and video, the students used educational resources from the Web site to **explain [SEP-6]**

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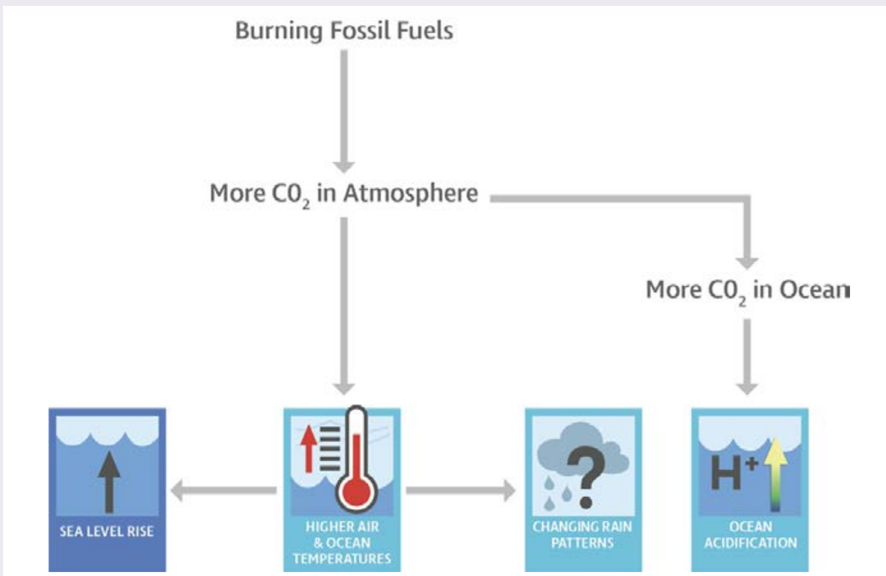
factors that influenced the park ecology, the conservation recovery plans, and significant constraints that need to be addressed to promote successful restoration (EP&C V).

The different student groups working on climate change issues jointly identified as a constraint that many people were confused about global warming and climate change. They consulted with their grade six science teacher who had taught them that global warming is the increase in air and ocean temperatures due to the increased greenhouse effect (MS-ESS3-5). She referred them to a PBS LearningMedia Web site (https://www.cde.ca.gov/ci/sc/cf/ch5.asp#link41) that has a computer interactive explaining four main impacts of climate change (figure 5.59). Higher concentrations of atmospheric CO_2 directly result in global warming and ocean acidification. The increased thermal energy trapped in the Earth system **causes [CCC-2]** other changes such as sea-level rise and changing precipitation patterns (EP&C IV).

Figure 5.59. Effects of Burning Fossil Fuels



Increased emissions of carbon dioxide cause global warming (higher air and ocean temperatures) and three other climate change impacts. *Sources:* Illustration by Dr. Art Sussman, WestEd, and Lisa Rosenthal, WGBH.
Long description of Figure 5.59.

Since their school is located relatively near the major Lake County 2015 Valley Fire that burned 76,000 acres and destroyed almost 2,000 structures, several student groups researched predictions related to climate change and wildfires. They learned that average temperatures in California are projected to generally keep increasing throughout this century (figure 5.60). They noted that reductions in emissions of greenhouse gases could reduce the amount of heating. They also learned that communities could engage in individual and collective actions that would increase the fire safety of homes.

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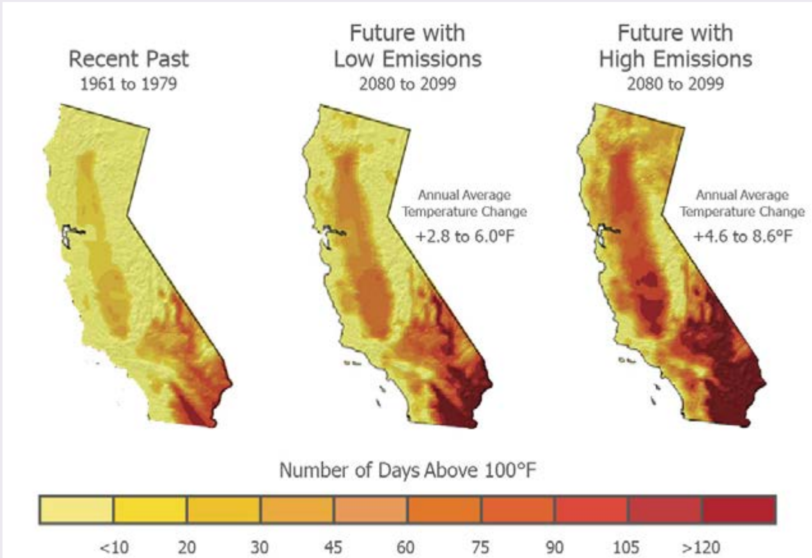
Figure 5.60. Projected Changes to California's Average Temperature



Projected increases in statewide annual temperatures during this century. *Source:* M. d'Alessio with images from U.S. Global Change Research Program 2009 and data from Moser, Ekstrom, and Franco 2012.
Long description of Figure 5.60.

The Pacific Atoll climate change group reported about the Marshall Islands, which had been a territory of the United States. They shared information about its geography and used digital tools to video conference with a school on the island of Majuro. The group explained that the approximately 60,000 Marshall Islanders were severely threatened by sea-level rise. The highest natural points on the islands are generally just 3 meters (10 feet) above sea level. During the period the schools communicated with each other, a King Tide caused serious flooding in the area of the Majuro School. The group presentation included **explanations [SEP-6]** of how climate change **caused [CCC-2]** sea levels to rise, and how scientists remotely measure sea level around the globe via satellites equipped with digital tools. Their engineering design challenge focused on ways communities can protect beaches and homes from rising sea levels. Like the other student groups, they wanted to learn more about ways to reduce the amount of climate change caused by human activities. (EEI Curriculum unit *The Greenhouse Effect on Natural Systems* https://www.cde.ca.gov/ci/sc/cf/ch5.asp#link42 provide additional resource materials on climate change and greenhouse gases.)

Day 10: Synthesis

In each of the three middle grades, students learned about the EP&Cs that were approved by the California State Board of Education. For the final lesson related to the student projects, students formed groups that consisted of students who had worked on at least three of the different projects. Each of these new groups then discussed what they had done or heard

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about that related to each of the EP&Cs. Students then shared their ideas in a whole-class discussion. They were surprised how many of them identified Principle V as something they had seen but not really understood until they had to think about engineering criteria and constraints related to reducing their specific environmental impact. They concluded that decisions affecting resources and natural systems are definitely based on a wide range of considerations and decision-making processes.

Vignette Debrief

This vignette illustrated the CA NGSS vision of blending SEPs, DCIs, and CCCs. While the lesson description described this blend, the sections below focus on relevant aspects of each dimension in isolation, along with ties CA CCSS and the EP&Cs.

SEPs. Scientists typically use all SEPs to fully understand new phenomenon, though they may focus on one practice at a time during the course of a project. Typical educational settings mirror this focus by isolating certain tasks to focus on building specific skills. In a capstone project where students confront an entirely new phenomenon and have the time to fully pursue it, students should fully employ all SEPs. For this reason, Ms. D explicitly organized her project criteria around all the SEPs.

CCCs. The CCC's are a series of big, overarching issues that scientists consider when they approach a new phenomenon. Since the students were engaging in a big science and engineering problem that was new to them, the CCCs provide a critical scaffold. Presentations during the collaborative work sessions on days 4–8 focused on viewing the projects through individual CCCs.

DCIs. The vignette integrated major concepts in Earth science (human impacts and Earth systems), physical science (information technologies and instrumentation), life science (natural selection), and engineering technology and applications of science (engineering design: defining and delimiting engineering problems). Different project groups focused on problems that were more closely related to DCIs in one or two domains, though the project criteria required that students consider human impacts (ESS3) and include digital technology (PS4.C) and engineering design (ETS).

CA CCSS Connections to English Language Arts and Mathematics. The capstone projects and surrounding structure in the vignette were heavily focused on gathering and synthesizing information from informational texts about environmental problems (RST.6–8.1, 2, 7, 9; RI.8.3). Student groups analyzed data, calculating the per-capita consumption as the ratio of the emissions and population. They looked for patterns in the data and made evidence-based claims about what they observed (8.SP.2, 4). The entire project was structured to promote student discourse in small groups and in formal presentations (SL.8.1, 4, 6). Students then created written and visual communications products that summarized their process and findings (WHST.6–8.2, 7-9).

EP&Cs. By the end of grade eight, students are able to focus on much broader issues than they did back in kindergarten. The entire capstone project was designed to draw together all of the EP&Cs. Even though this framing was intentional, Ms. D still devoted specific time on day 1 and again on day 10 to identifying which EP&Cs apply to the situations.

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