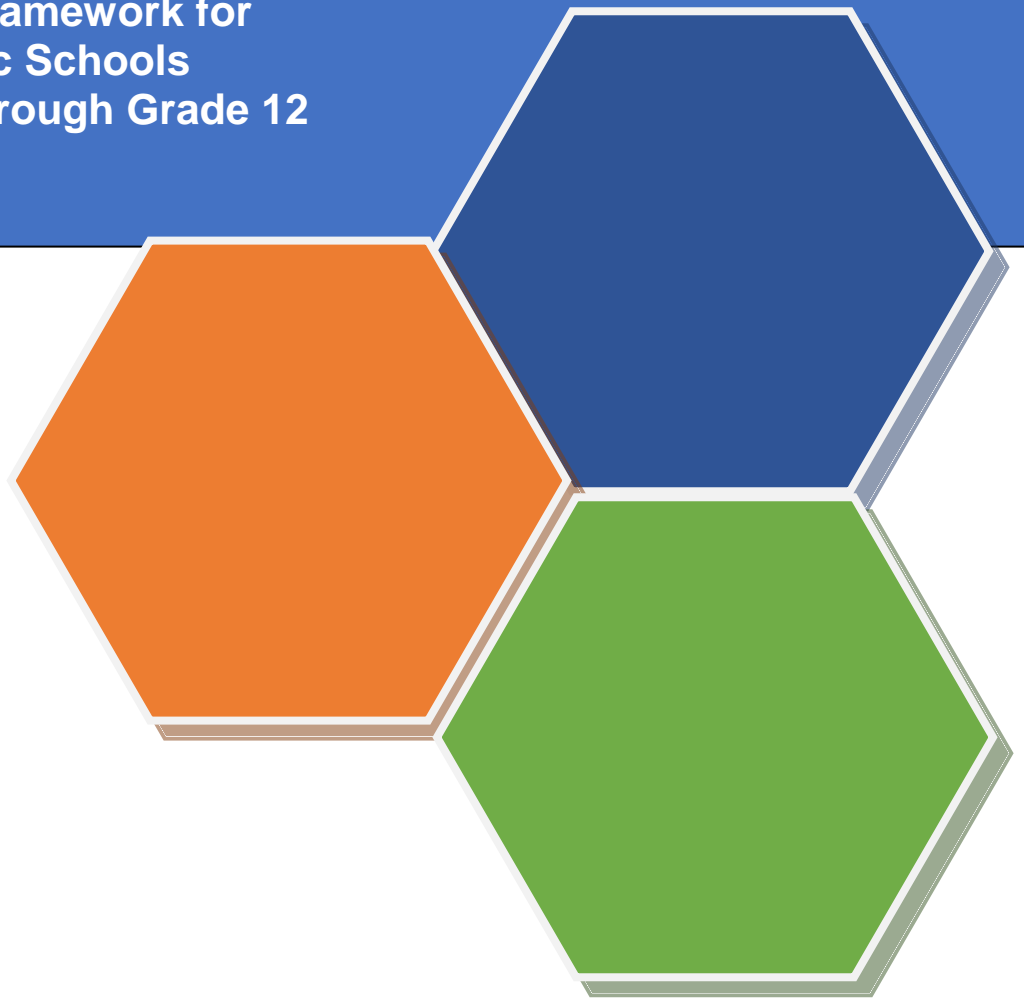


# Chapter 5

## Grades Six Through Eight

### Preferred Integrated Model

2016 Science Framework for  
California Public Schools  
Kindergarten through Grade 12



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## **Chapter 5**

### ***Grades Six Through Eight Preferred Integrated Course Model***

#### **Introduction to Grades Six Through Eight**

#### **Introduction to the Preferred Integrated Course Model for Grades Six Through Eight**

#### **Grade Six – Preferred Integrated Course Model**

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

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

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

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

#### **Grade Seven – Preferred Integrated Course Model**

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

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

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

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

## **Grade Eight – Preferred Integrated Course Model**

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

*Integrated Grade Eight Instructional Segment 2: Noncontact Forces Influence*

*Phenomena*

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

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

### **Science Literacy and English Learners**

### **References**

## **Introduction to Grades Six Through Eight**

The California Next General Science Standards (CA NGSS) defines two possible progressions for middle school: the preferred Integrated Model which interweaves science disciplines in a developmentally appropriate progression and the Discipline Specific Model where 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 school performance expectation by the end of grade. “Sequence” here refers to which course (sixth, seventh, or eighth grade) a particular Performance Expectation (PE) is mastered; this *CA Science Framework* makes no requirements about the order in which PEs are taught within a given year. (The example course sequences in this *CA Science Framework* describe possible storylines but are not the only way).

Table 5.1 shows a comparison of which Disciplinary Core Ideas (DCIs) are emphasized in the PEs required at each grade level in the two models. For both models, all eight Science and Engineering Practices (SEPs) are developed and all seven Crosscutting Concepts (CCCs) are highlighted at some point during the course of every year (though each lesson may only focus on one or two and each year may have a slight emphasis on a particular subset).

As districts consider the progression that works best for their resources and local context, they should be aware of the historical context, rationale for each 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 specific PEs for grades kindergarten through five but presented middle grade standards in a grade span of sixth through eighth grade. Because California is a kindergarten through eighth grade instructional materials adoption state, it requires that standards 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 standards for middle grades at each grade level.

The SSPI convened the Science Expert Panel comprised of kindergarten through grade twelve teachers, scientists, educators, business, industry representatives, and informal science educators. This panel evaluated a range of options for the appropriate organization and sequence of the PEs. 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 NGSS; the panel subsequently reviewed the national model that had been developed by Achieve, and adapted it to better align with CA's needs and recommended only the Preferred Integrated Model to the SBE. The full list of events that led to the adoption of the Preferred Integrated Course Model is described at the CDE Web site:

<http://www.cde.ca.gov/pd/ca/sc/ngssintrod.asp>. 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 a Discipline Specific Model of the NGSS.

The Board’s intent in their November 2013 action was for there to be 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 School Models**

	Disciplinary Core Idea		Subtopic	Preferred Integrated			Discipline Specific		
				6	7	8	6	7	8
Earth & Space	1	Earth's Place in the Universe	Universe, Stars, Solar System			X	X		
			History of Planet Earth			X	X		
	2	Earth's Systems	Water Cycle, Weather, Climate	X			X		
			Rock cycle, Plate tectonics		X		X		
	3	Earth and Human Activity	Global climate change causes	X			X		
			Resources availability		X		X		
			Natural hazards		X		X		
			Resource consumption			X	X		
Life	1	From Molecules to Organisms: Structures and Processes	Cells & Body Systems	X				X	
			Photosynthesis & Respiration		X			X	
	2	Ecosystems: Interactions, Energy, and Dynamics			X			X	
	3	Heredity: Inheritance and Variation of Traits	Sexual v. Asexual reproduction	X				X	
			Mutations			X		X	
	4	Biological Evolution: Unity and Diversity				X		X	
Physical	1	Matter and its Interactions	Atoms, Molecules, States of Matter		X				X
			Chemical Reactions		X				X

	2	Motion and Stability: Forces and Interactions				X			X
	3	Energy	Kinetic Energy & Collisions	X		X			X
			Heat & Heat Flow	X					X
			Potential Energies & Gravity			X			X
	4	Waves and Their Applications in Technologies for Information Transfer				X			X
ETS	Every course includes integrations with ETS			X	X	X	X	X	X
SEP	Every course utilizes all eight SEPs			X	X	X	X	X	X
CCC	Every course highlights all seven CCCs			X	X	X	X	X	X

## **Learning from Other Successful Countries**

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

## **Matching University Training with Middle Grades Teaching**

Many science teachers receive a university degree in a specific discipline of science within a specific university department (i.e., biology, chemistry, physics, geology), so they likely have stronger content knowledge in that field. Linda Darling-Hammond summarizes 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 middle school 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 learned from years of experience teaching a specific subject area. Some of



this PCK (pedagogical content knowledge) is discipline specific (such as awareness of specific misconceptions 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 Preferred Integrated and Discipline Specific models.

### **Sequencing in a Developmentally-Based Learning Progression**

The CA NGSS is intentionally designed so that students slowly build up knowledge and skills in all three dimensions, addressing more sophisticated challenges or revisiting simple ones at a deeper level as they progress through the grades. Achieve also noted that even in exemplary standards, most countries paid insufficient attention to developmental learning progressions. They suggest, “developers of new standards will need to tease-out the prerequisite knowledge and skills, to provide a conceptual basis for understanding (Achieve 2010).” Appendix E of the CA NGSS spells out the developmental progression of ideas within each discipline, but there is also prerequisite knowledge from one discipline that is applied in a separate discipline 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 LS DCIs appear in grade seven but core ideas about the nature of matter are not introduced until grade eight. The Preferred Integrated Course Model was arranged with this sequencing in mind, and the prerequisite knowledge is often placed within the same course so that it can be taught alongside the application. Successful implementation of the Discipline Specific Model will require some remediation of the missing prerequisite knowledge, and the specific courses in this *CA Science 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 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 Preferred Integrated Course Model also supports the Next Generation Science Standards for California Public Schools, Grades Kindergarten Through Grade Twelve (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 Preferred Integrated Course Model places the most complex phenomena at the end of the grade span when students are most ready to face them. Students undergo a lot of growth from sixth through eighth grade, and 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 are a common thread to all disciplines. 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 at the beginning of grade six and a culmination with stability and change 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 5.5.2): “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 introduces and teaches related content together to answer a single question about a phenomena within science.

**Table 5.2. Integrated vs. Coordinated Science**

<b>Integrated</b>	<b>Coordinated</b>
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
<p>A few examples:</p> <ul style="list-style-type: none"> <li>• Astronomy is taught in conjunction with gravity and forces. The connections and applications of physics is applied to astronomy.</li> <li>• Heat (physics) is taught at the same time with climate and weather as the applied examples.</li> <li>• Light and the chemistry of photosynthesis are all taught interconnected.</li> </ul>	<p>A few examples:</p> <ul style="list-style-type: none"> <li>• Astronomy is taught conceptually with gravity and forces taught in separate units that may not connect to astronomy.</li> <li>• Heat is taught as a separate physics unit. Climate and weather are taught as a separate unit.</li> <li>• Light is taught as a separate unit as strictly physics with no connections to life science needed.</li> </ul>

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 IS should take a different fraction of the school year. As students achieve the PEs within each IS, they uncover Disciplinary Core Ideas (DCIs) from the different fields of science (Physical Science, Life Science, and Earth & Space Science) and engineering. Students engage in multiple practices in each IS, not only those explicitly indicated in the PEs. Students also focus on one or two 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 PE 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 disciplines. 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 school 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 opportunities to apply knowledge. These details are not missing from the CA NGSS, but they have just been moved from middle school to the more developmentally appropriate position in high school. The level of detail builds up slowly. As teachers, we often complain that our students do not remember concepts from year-to-year, but perhaps this forgetting is a consequence of our desire to provide self-contained instruction 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 will likely have to make major modifications to some of their favorite lessons or even leave them behind because those lessons focus on providing all the ‘answers’ where 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

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and schools will need to invest in significant resources for professional development to help teachers make these modifications in supportive, collaborative environments.

### **Grade Six – Preferred Integrated Course Model**

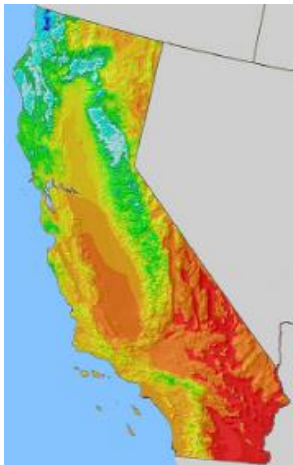

This section is meant to be a guide for educators on how to approach the teaching of the CA NGSS in grade six according to the Preferred Integrated Course Model (see the introduction to this chapter for further details regarding different models for grades six, seven, and eight). It is not meant to be 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 PEs into integrated groups that can effectively guide instruction in four sequential IS. There is no prescription regarding the relative amount of time to be spent on each IS. 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. Grade Six Integrated Storyline****Guiding Concept:** Systems within organisms and between them are adapted to Earth's climate systems.

IS		Life Science (LS)	Earth & Space Sciences (ESS)	Physical Science (PS)	Engineering, Technology, and Applications to Science (ETS)
1	<b><i>A cell, a person, and planet Earth are each a system made up of subsystems.</i></b>				
	 <p>Source: NASA/Goddard Space Flight Center 2008</p>	<p>All living things are made of cells.</p> <p>The body is a system made of interacting subsystems.</p>	<p>Water cycles among the land, ocean, and atmosphere.</p> <p>Weather and climate involve interactions among Earth's subsystems</p>		<p>Design Criteria</p> <p>Evaluate Solutions</p>
2	<b><i>Weather conditions result from the interactions among different Earth subsystems.</i></b>				
	 <p>Source: University of Wisconsin 2010</p>		<p>The movement of water and interacting air masses helps determine local weather patterns and conditions.</p> <p>The ocean has a strong influence on weather and climate.</p>	<p>Temperature measures the average kinetic energy of the particles that make up matter.</p> <p>Energy transfers from hot materials to cold materials.</p> <p>The type and amount of matter affects how much an object's temperature will change.</p>	<p>Design Criteria</p> <p>Evaluate Solutions</p> <p>Analyze data</p> <p>Iteratively test and modify</p>

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IS		Life Science (LS)	Earth & Space Sciences (ESS)	Physical Science (PS)	Engineering, Technology, and Applications to Science (ETS)
3	<b>Regional climates strongly influence regional plant and animal structures and behaviors.</b>				
	 <p>Source: Geology Cafe 2012</p>	<p>Variations of inherited traits arise from genetic differences.</p> <p>Genetic traits and local conditions affect the growth of organisms.</p> <p>Organisms rely on their body structures and behavior to survive long enough to reproduce.</p>	<p>Energy input from the Sun varies with latitude, creating patterns in climate.</p> <p>Energy flow through the atmosphere, hydrosphere, geosphere, and biosphere affect local climate.</p> <p>Density variations drive global patterns of air and ocean currents.</p>	<p>The type and amount of matter affects how much an object's temperature will change.</p>	
4	<b>Human activities can change the amount of global warming, which impacts plants and animals.</b>				
	 <p>Source: Chau 2016</p>	<p>Local conditions affect the growth of organisms.</p> <p>Organisms rely on their body structures and behavior to survive, but these adaptations may not be enough to survive as the climate changes.</p>	<p>Human changes to Earth's environment can have dramatic impacts on different organisms.</p> <p>Burning fossil fuels is a major cause of global warming. Strategic choices can reduce the amounts and impacts of climate change.</p>		<p>Design Criteria</p> <p>Evaluate Solutions</p> <p>Analyze data</p>



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 very 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.

IS3 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]**.

IS4 concludes the year by **scaling [CCC-3]** from the regional climate level to the level of global warming. In previous IS, 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.

## 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 very useful tool that can help learners to connect ideas within a topic and also across science disciplines. The Overview chapter of this *CA Science 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 IS, 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
<p><i>Guiding Questions:</i></p> <ul style="list-style-type: none"> <li>• How are living systems and Earth systems similar and different?</li> <li>• What is the value of creating a systems model?</li> </ul>
Performance Expectations
<p><i>Students who demonstrate understanding can:</i></p> <p><b>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.]</b></p>

**MS-LS1-2. Develop and use a model to describe the function of a cell as a whole and ways parts of cells contribute to the function.**

[Clarification Statement: Emphasis is on the cell functioning as a whole system and the primary role of identified parts of the cell, specifically the nucleus, chloroplasts, mitochondria, cell membrane, and cell wall.] [Assessment Boundary: Assessment of organelle structure/function relationships is limited to the cell wall and cell membrane. Assessment of the function of the other organelles is limited to their relationship to the whole cell. Assessment does not include the biochemical function of cells or cell parts.]

**MS-LS1-3. Use argument supported by evidence for how the body is a system of interacting subsystems composed of groups of cells.**

[Clarification Statement: Emphasis is on the conceptual understanding that cells form tissues and tissues form organs specialized for particular body functions. Examples could include the interaction of subsystems within a system and the normal functioning of those systems.] [Assessment Boundary: Assessment does not include the mechanism of one body system independent of others. Assessment is limited to the circulatory, excretory, digestive, respiratory, muscular, and nervous systems.]

**MS-LS1-8. Gather and synthesize information that sensory receptors respond to stimuli by sending messages to the brain for immediate behavior or storage as memories.** [Assessment Boundary: Assessment does not include mechanisms for the transmission of this information.]

**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 <i>A Framework for K–12 Science Education</i> :		
Highlighted Science and Engineering Practices	Highlighted Disciplinary Core Ideas	Highlighted Crosscutting Concepts
[SEP-1] Asking Questions and Defining Problems	LS1.A: Structure and Function	[CCC-2] Cause and Effect
[SEP-2] Developing and Using Models	ESS2.C: The Role of Water in Earth's Surface Processes	[CCC-4] System and System Models
[SEP-6] Constructing Explanations (for science) and Designing Solutions (for engineering)	ESS2.D: Weather and Climate	
[SEP-7] Engaging in Argument from Evidence	ETS1.A: Defining and Delimiting Engineering Problems	
[SEP-8] Obtaining, Evaluating, and Communicating Information	ETS1.B: Developing Possible Solutions	

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*Highlighted California Environmental Principles & Concepts:*

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

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

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

CA CCSS Math Connections: 6.EE.9

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

CA CCSS ELA/Literacy Connections: RST.6-8.1, R.I.6.8, WHST.6-8.1,7,8,9, SL.6.5

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 circles like the solar system. Rather than focusing initially on terminology and definitions, students can begin this IS by exploring a situation that exemplifies the key features of systems. Students **obtain information [SEP-8]** about the massive experiment called Biosphere2 where scientists placed plants, animals, and people in an air-tight 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 some animals died and oxygen levels were unsafe. 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 reason they identified it is 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 to report the information they gathered. Next, have them read appropriate science text and identify the five features of systems within the text. Using evidence from text and language frames, have them discuss the connections between their classroom example and textual evidence, including a definition, gathered that either confirm or refute it as a system. Ask students in their groups to revisit their classroom examples and reach consensus on whether or not each meets the criteria of a system based on the five important features [CCC-4]: boundaries, components, interactions, inputs/outputs, and one or more system properties.

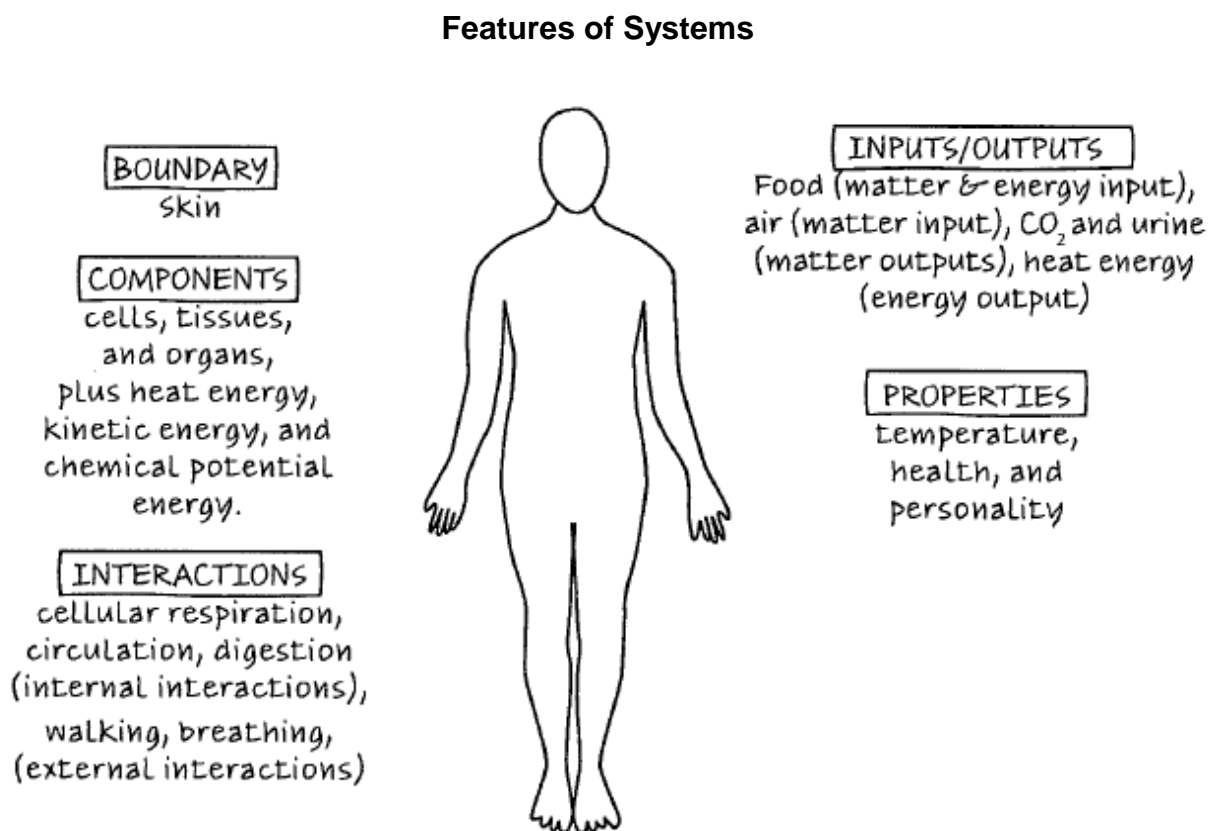
CA CCSS ELA/Literacy Standards: RST.6–8.1, 2, 4; SL.6–8.1

CA ELD Standards: ELD.PI.6–8.1, 2

### Human Body Systems

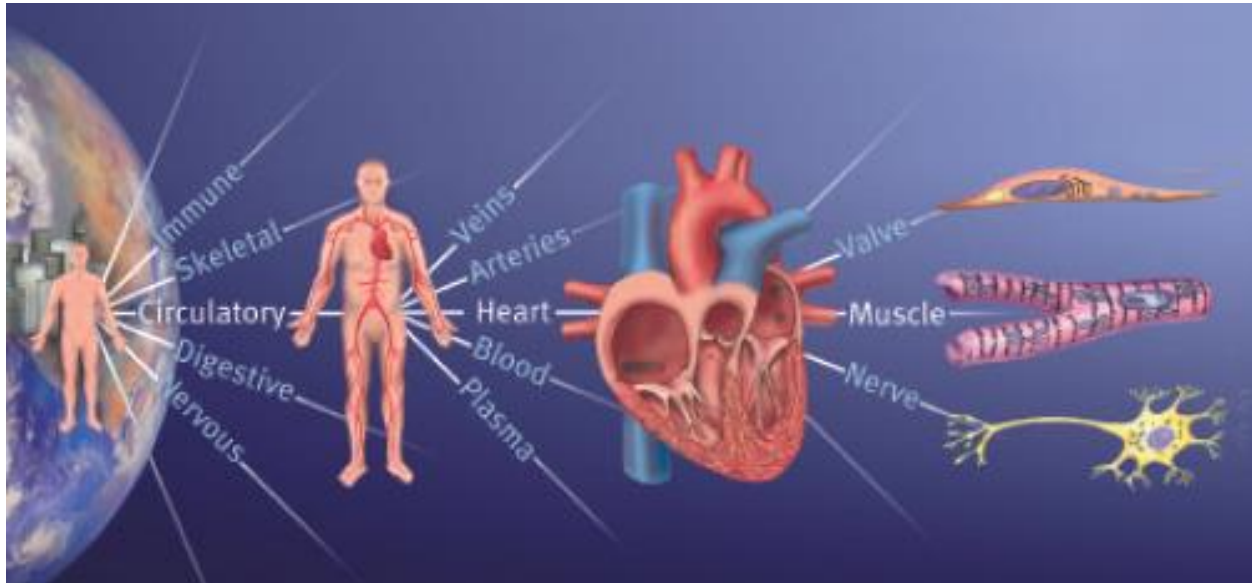
Next students focus on their own body system (figure 5.2). Explicitly discussing the features of a **system** [CCC-4] is just the first step in creating a system **model** [SEP-2] that can explain different phenomena in a human body. For example, “Why does my heart race when I get scared?” requires that 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).



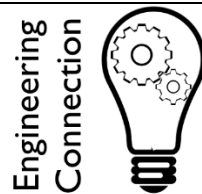
**Figure 5.2. Features of a Human Person System**

Source: Illustration adapted from Folsom and Daehler 2012.

When tracing out these interactions within the body system, students uncover the middle school understanding that, “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.



### **Engineering Connection: Systems Models of Organ and Tissue Donation**

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 website that includes educator resources, notably an Interactive Body Tour (see Donate Life California at <http://www.donatelifecalifornia.org/education/how-donation-works>).

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 that 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 non-living things are not (MS-LS1-1). Comparing microscope images of non-living 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 (student 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 do we get thirsty when we 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 the 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 utilize 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 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 bring 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.). 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's Systems**

<b>Earth's System</b>	<b>Earth's Materials</b>
Geosphere	<i>Rocks, minerals, and landforms</i> at Earth's surface and in its interior, including soil, sediment, and molten rocks.
Hydrosphere	<i>Water</i> , including ocean water, groundwater, glaciers and ice caps, rivers, lakes, etc.
Atmosphere	Gases surrounding the Earth (i.e., our air)
Biosphere	<i>Living organisms</i> , including humans.

While in fifth grade, they focused on the functioning of each individual system, they progress to understanding the Earth as a singular system where each of the Earth

systems they learned in fifth grade are now viewed as a component or subsystem of the larger scale planet system is now viewed as a component or subsystem of the larger scale planet system. Learners of all ages generally expect that definitions, especially in science, should be precise and either/or – that the geosphere, for example, is *either* its own system *or* a component of a larger system, but not both at the same time. Older grade levels in science often mark an 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 flows into soft sands 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. In studying water on Earth, Table 5.4. Different System Boundaries for Investigating Water on Earth Table 5. indicates the boundaries that different people might choose 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 disciplines 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**

<b>Investigation Topic</b>	<b>System Boundary</b>	<b>Matter Input/Output</b>
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 ocean 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 facility	Sewage in, clean water and waste out.

Table by Dr. Art Sussman, courtesy of WestEd.

Much like the boundary 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. IS2 then goes into the details of system models of the water cycle and weather systems.

## 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
<p><i>Guiding Questions:</i></p> <ul style="list-style-type: none"> <li>• Why is the weather so different in different parts of California?</li> <li>• How is weather related to the transfer of energy?</li> <li>• How do models help us understand the different kinds of weather in California?</li> </ul>
Performance Expectations
<p><i>Students who demonstrate understanding can:</i></p> <p><b>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.</b> [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.]</p> <p><b>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.</b></p>



[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 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*:

<div> <b>Highlighted</b>  <b>Science and Engineering Practices</b> </div> <div> <b>[SEP-1] Asking Questions and Defining Problems</b> </div>	<div> <b>Highlighted</b>  <b>Disciplinary Core Ideas</b> </div> <div> <b>ESS2.C: The Roles of Water in Earth's Surface Processes</b> </div>	<div> <b>Highlighted</b>  <b>Crosscutting Concepts</b> </div> <div> <b>[CCC-1] Patterns</b>   <b>[CCC-2] Cause and</b> </div>
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<p><b>[SEP-2] Developing and Using Models</b></p> <p><b>[SEP-3] Planning and Carrying Out Investigations</b></p> <p><b>[SEP-6] Constructing Explanations (for science) and Designing Solutions (for engineering)</b></p> <p><b>[SEP-7] Engaging in Argument from Evidence</b></p> <p><b>[SEP-8] Obtaining, Evaluating, and Communicating Information</b></p>	<p><b>ESS2.D: Weather and Climate</b></p> <p><b>PS3.A: Definitions of Energy</b></p> <p><b>PS3.B: Conservation of Energy and Energy Transfer</b></p> <p><b>ETS1.A: Defining and Delimiting Engineering Problems</b></p> <p><b>ETS1.B: Developing Possible Solutions</b></p>	<p><b>Effect</b></p> <p><b>[CCC-3] Scale, Proportion, and Quantity</b></p> <p><b>[CCC-4] System and System Models</b></p> <p><b>[CCC-5] Energy and Matter: Flows, Cycles, and Conservation</b></p>
<p><i>Highlighted California Environmental Principles &amp; Concepts:</i></p> <p>Principle III Natural systems proceed through cycles that humans depend upon, benefit from and can alter.</p> <p>Principle IV The exchange of matter between natural systems and human societies affects the long term functioning of both.</p> <p>Principle V Decisions affecting resources and natural systems are based on a wide range of considerations and decision-making processes.</p>		
<p><i>CA CCSS Math Connections:</i> MP.2, 6.RP.1, 6.SP.5</p>		
<p><i>CA ELD Connections:</i> ELD.PI.6.6a-b,9,10,11a,</p>		

CA CCSS ELA/Literacy Connections: SL.6.5, RST.6-8.1,3,7,9 WHST.6-8.1,7,8
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Different parts of California experience dramatically different weather. As an anchoring phenomenon for this IS, students will consider how some parts of California are dry with desert vegetation while others are green and wetter. When students examine a true color satellite image of California (Figure 5.4 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 sequence that focuses on explaining the phenomenon of California's climate zones drawing in DCIs from an ESS and PS. Students will integrate LS in IS3 and IS4.

**Figure 5.4. Satellite View of California**



Source: NASA 2014

**Integrated Grade Six**  
**Vignette 5.1. Interactions of Earth Systems Cause Weather**  
**Performance Expectations**

*Students who demonstrate understanding can:*

**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 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-1] Asking Questions and Defining Problems	ESS2.C The Roles of Water in Earth’s Surface Processes	[[CCC-1] Patterns
[SEP-2] Developing and Using Models	PS3.A Definitions of Energy	[CCC-2] Cause and Effect
[SEP-3] Planning and Carrying Out Investigations	PS3.B Conservation of Energy and Energy Transfer	[CCC-4] System and System Models
[SEP-6] Constructing Explanations (for science) and Designing Solutions (for engineering)		

<p><b>[SEP-7] Engaging in Argument from Evidence</b></p> <p><b>[SEP-8] Obtaining, Evaluating, and Communicating Information</b></p>		
<p><b>Connections to the CA CCSSM:</b> 6.NS.7b, 6.NS.8, 6.EE.9, 6.SP.4</p>		
<p><b>Connections to CA CCSS for ELA/Literacy:</b> RST.6–8.1, 4; WHST. 6–8.1, 7; SL.6.1, 2, 3</p>		
<p><b>Connections to CA ELD Standards:</b> ELD.PI.6-8.1, 9, 10b</p>		
<p><b>Introduction</b></p> <p>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 that helps inform other scientists (especially satellite imagery).</p>		
<p><b>Days 1-2: What is Smoke/Fog/Steam</b></p> <p>Students make observations and ask questions about a mystery material.</p>	<p><b>Days 3-4: A Watched Pot Never Boils</b></p> <p>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.</p>	<p><b>Days 5-9: Questions about California’s Climate Zones</b></p> <p>Groups of students research individual climate zones in California and report back to the class. Students ask questions about what they hear.</p>

The *CA Science Framework* was adopted by the California State Board of Education on November 3, 2016. The *CA Science Framework* has not been edited for publication. © by the California Department of Education.

<b>Days 10-11: Planning an Investigation</b>  Students plan and conduct an investigation to compare the effects of heat on water versus air.	<b>Day 12: Crafting an Explanation</b>  Students create, critique, and revise a scientific explanation that explains their observations from the previous day's investigation.	<b>Days 13-14: Analyzing Rainfall Data</b>  Students make graphs showing the relationship between elevation and precipitation in California and relate these findings to changes of state from previous days.
<b>Day 15: Explaining California Climate</b>  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 review the reservoirs of the water cycle that they had learned in fifth grade. They describe the physical state of water (solid, liquid, gas) in each of the reservoirs. However, even when they include the atmosphere as a reservoir of the water cycle, students tend to emphasize liquid water in clouds rather than the invisible water vapor gas in air.



Ms. L then gets their excited attention by bringing out an insulated container that has dry ice in it. She pours 91 percent isopropyl alcohol into the container to create an extremely cold bath that bubbles. Something visible forms and flows around the insulated container. Students describe it as smoke or fog or steam. Ms. L challenges 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,” or SFS as they start calling it for short. She points out that while they are discussing, she will put some small pieces of dry ice into a latex-free surgical glove, and tie off the end of the glove. That way they can capture some of the mystery SFS material to investigate its properties.

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

When Ms. L lifts the hugely expanded glove, students laugh about its shape, and want to know more about the properties of SFS. When Ms. L is about to cut one of the glove ‘fingers to release the material,” she asks students to predict what they expect to see. Ms. L never lets her students make a prediction without explaining what influences their expectation. She prompts students to describe what similar situation, background knowledge, and/or observations they base this prediction upon. Ms. L cuts the glove and releases the trapped material in a controlled manner. While they can see the glove deflating, students are surprised that nothing appears to come out. After Ms. L extinguishes a lit candle by “pouring” some of the invisible gas over it, they reach the **conclusion** that this material must be a gas denser than regular air. What is the relationship between the invisible gas and SFS? Has it somehow changed when inside the glove?

Students return to their small groups to make a list of the most important observations, and try again to make **claims supported by evidence [SEP-7]** about the nature of the SFS. All the student groups realize that its visibility means that SFS could not be water vapor or carbon dioxide. Gradually, discussions within the groups and then

between them result in the conclusion that SFS must be water drops that condense from water vapor in the air. One team shares a **model drawing [SEP-2]** that they made that illustrates 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<sub>2</sub> gas contacted it; and
- 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 concludes the lesson by putting a test tube of water with an inserted temperature probe into the dry ice/isopropyl alcohol bath. She shows how quickly the water freezes. She calls on students to read the temperature on the probe, and they note that it was in minus degrees Celsius, meaning that it was colder than the freezing point of water. She takes the test tube and carefully suspends it in warm water. Students record 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 review their observations of the super-cooled ice. Students then work in teams to slowly and steadily heat a mixture of ice and water. They record the temperature every minute and also write a description about how much the ice was melting at each time. The handout that she provides includes a data table for recording temperature, elapsed time, and whether melting is happening. For safety

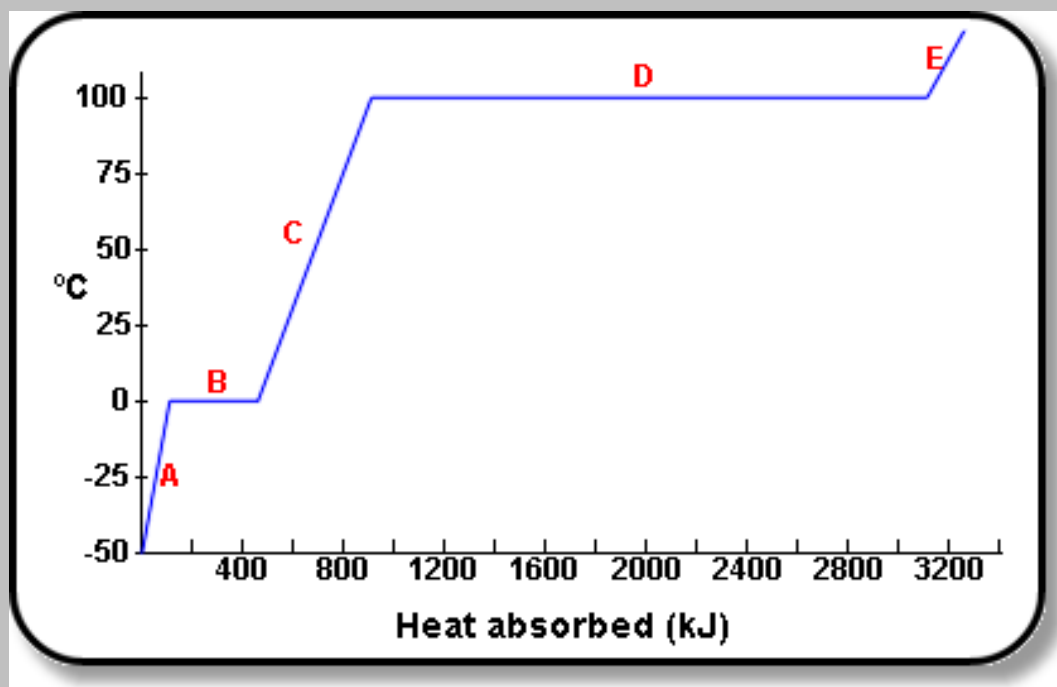
reasons, the students stop their experiments when the temperature of their water reaches 45°C.

Using graph paper, each student team creates a labeled graph and enters their data on the graph. The students generally obtain graphs that show a mostly flat temperature line near 0°C during the time of melting, and then a steady rise in temperature after all the ice melts.

Ms. L then asks the teams to predict on their graph what it will look like the next day when she demonstrates heating the water until it boils and while it keeps boiling. They also need to note on their prediction when the boiling is happening just as they had noted when the ice was melting.

The following day the teams share their predictions and their reasoning. Then Ms. L demonstrates the heating of water to the boiling stage and for a period of continued boiling. Students record the observed temperatures on their graphs, and compare the observations with their predictions. At the end of the demonstration, students discuss the results as a whole class.

The next day, Ms. L projects a graph of changes in the state of water that is posted on the web by a chemistry teacher. Students discuss this graph in small groups, and write 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**

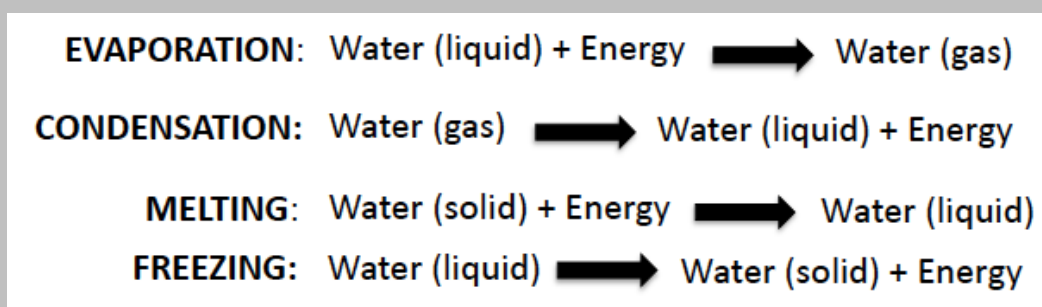
Continuously adding thermal energy increases the temperature from super-cooled ice to superheated steam. Heating does not cause the temperature to significantly increase during the state changes of melting (B) and boiling (D). Heating when there is no state change happening results in temperature increasing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

Source: Mr. Kent's Chemistry Page n.d.

The students consistently identify temperature as a measure of the average kinetic energy of invisible particles of water. They correctly relate higher temperatures with increase particle motion, and lower temperatures with decrease particle motion. Based on their own experiments and the teacher demonstration, students readily **explain [SEP-6]** that the upward lines occur when there is no state change happening. They also readily state that the flat lines at B and D occur when there is a state change happening. However, they have a hard time clearly explaining why the temperature is not increasing during melting and boiling even though more thermal energy keeps being added.

Ms. L then displays a graphic showing the state changes as equations (figure 5.6). She walks students through the example of melting, pointing to each component as she describes it, “If you start with water as a solid (ice) and add energy, you get liquid water.” Then, she asks students to identify which of the equations apply to the day’s observations. Once they identify the right equation, she tells students to use that equation to **explain [SEP-6]** why the temperature remains fairly constant during evaporation even though thermal energy continues to be added. After five minutes, the student group that includes Kelly starts clapping and cheering. Other students asks them what has happened.

**Figure 5.6: Equations Representing State Changes in Water**



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.

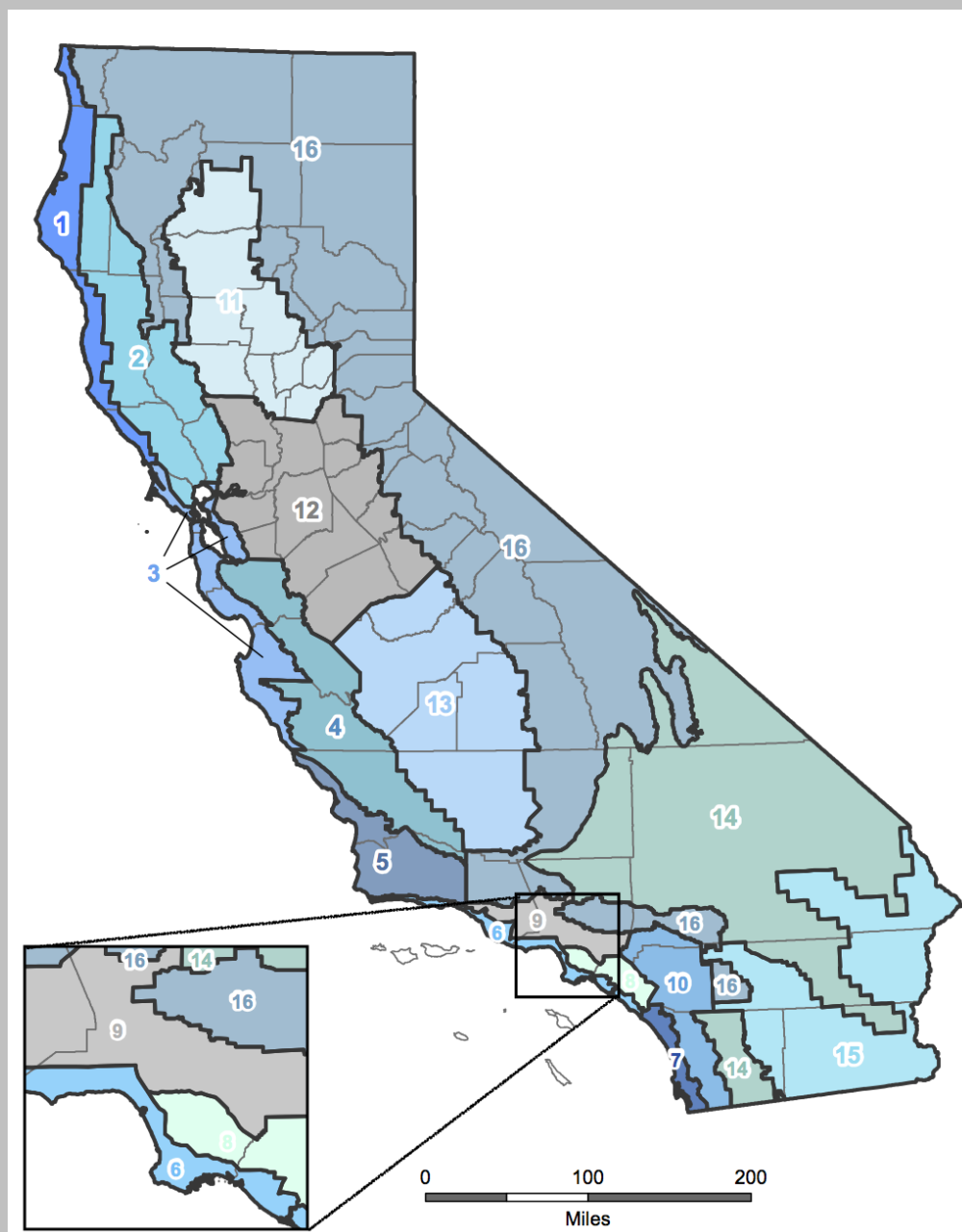
Kelly stands up and says that she thinks they had finally explained it, but didn’t know if they could repeat the explanation. After encouragement, she says, “The hot plate keeps giving off thermal energy. Usually that makes the water particles move faster, so then the temperature goes up. But once the water boils, the hot plate energy makes the boiling thing happen instead of making the particles move faster. So then the temperature does not change. I think I just said that the right way, didn’t I?”

## **Days 5-9 – Questions about California’s Climate Zones**

**Investigative phenomenon:** California has different climate zones

Ms. L begins the next set of lessons by asking students how many different kinds of places they know about in California. The conversation leads 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 distributes a map showing 16 different California climate zones (figure 5.7). Students work in eight groups to identify the previously listed locations on the map, any new locations that the map make them think about, and also discuss what they think a “climate zone” means.

**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

After the students have time to engage with the task and do a preliminary whole class sharing, Ms. L provides a handout describing eight representative zones that she condenses from the *Pacific Energy Center's Guide to California Climate Zones*. She

The CA Science Framework was adopted by the California State Board of Education on November 3, 2016. The CA Science Framework has not been edited for publication. © by the California Department of Education.

uses a combined student-choice/teacher-assignment technique to allocate the eight zones among the groups. Each team has to research their climate zone and develop posters **communicating [SEP-8]** key features about their climate zone including topography, geographic locations, distinctive climate features, and representative graphs of annual temperatures/precipitation.

Students share and learn about the different climate zones through a gallery walk of the posters, listening to presentations by the groups, and **asking questions [SEP-1]** of the presenters. Most of the student questions are about factual matters at first, so Ms. L encourages 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 help summarize the differences between weather and climate, the different kinds of climate zones in California, and possible **causes [CCC-2]** for the differences in annual temperatures and precipitation. Students highlight key **patterns [CCC-1]** (e.g., **effects [CCC-2]** of latitude, altitude, closeness to the ocean, and closeness to mountains). Student teams also record any “**cause and effect [CCC-2]**”, or “why”, questions they had about the data.

Toward the end of the week, each team shares their “why” **questions [SEP-1]**. The questions tend 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 places near the ocean have temperatures that change less between day and night;
- \* why higher altitudes have so much rain; and
- \* why the deserts are located where they are.

Ms. L concludes this discussion by saying that they will conduct some investigations during the next week to help answer the last three questions, and that they will cover



the first question in their next IS 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 provides students a procedure to **investigate** [SEP-3] differences between heating air and heating water. They use an electric light to heat two identical bottles closed with rubber stoppers. One of the bottles is filled with water and the other bottle is filled with air. Their task is to record and graph the temperatures for 10 minutes while the light is on and then another 15 minutes after turning off the light. Ms. L finds that her students take very poor quality measurements when they do not understand the procedures. While one approach is to ask students to plan the entire investigation themselves, she finds that they are not quite ready at this point in the school year to design sophisticated investigations. Ms. L develops a technique to scaffold the planning of investigations. Her handout of procedures has two columns – one with the procedures and a second one with the label “reason for this step” that has blanks for students to record data. Ms. L demonstrates how to fill in the table by demonstrating what she would put for the justification of step 1. For step two, she writes two possible justifications and asks the students to select the explanation that they think is most clear. For step three, she writes an incomplete reason and asks students to evaluate why the explanation is insufficient. Ms. L then has students work in groups to record the reasons for the remaining steps. Ms. L calls their attention to the data sheet and labeled graph that she has included in the written procedures. She tells them that in future experiments the student teams will get to design their own data sheets and graph labels. Before students record any actual data, she has them draw a sketch of what they think the graph will look like after the experiment. As she circulates around the room, she prompts 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 increases on average to 55°C while the temperature in the water bottle

only increases on average to 23°C. After the lights are turned off, the air bottle temperature generally decreases about 30°C while the water bottle decreases on average only 1.5°C. Ms. L has the students compare their prediction to the actual observations. Was anything unexpected?

After **conducting the investigation [SEP-3]**, each student team creates and displays a poster showing their results. In their poster, they made a claim about the differences between heating air and heating water, and they write or illustrate the **evidence [SEP-7]** for their claim. After a gallery walk and whole class discussion, the class reaches a consensus claim that the same amount of added thermal energy **causes [CCC-2]** the temperature of air to increase much more than the temperature of water, and that the water releases its thermal energy much slower than the air did.

One student group agrees with the statement about the increase in temperature. However they **argue that the evidence [SEP-7]** for a difference in cooling is very weak. It is not fair, they point out, to compare cooling from 55°C with cooling from 23°C. Ms. L takes this unplanned opportunity of the excellent student critique to ask if there is a way to make a better comparison of the cooling rates of air and water. Several student groups propose pre-heating bottles of air and water to the same temperature, and then comparing their rates of cooling. A team of students volunteer to demonstrate the experiment the following day. Their subsequent demonstration confirms that the same volume of water cools at a much slower rate than the same volume of air. Since thermal energy depends not on the volume of material but instead of the amount of the material (its mass), the student comparison is not the most scientifically accurate. MS-PS4-3 requires that students be able to design an experiment that holds mass constant, but Ms. L is happy to see that her students recognize the need for consistency when they use equal volumes of material.

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

She points out to students that the bottle with water feels much heavier and wonders if that has something to do with it. This prompts another demonstration comparing two

different masses of water. Students complete 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.

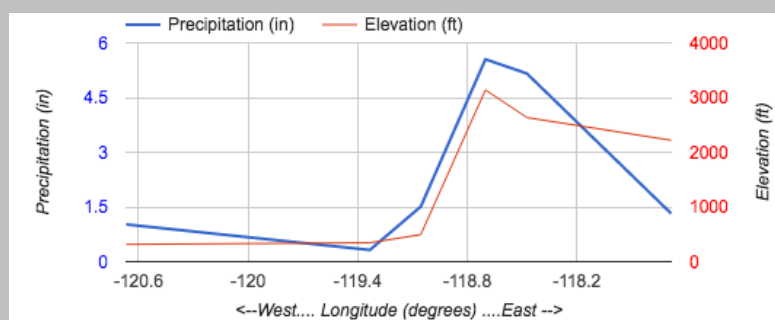
Ms. L challenges her students to use the key ideas from their investigation to **explain [SEP-6]** the **pattern [CCC-1]** that California locations near the ocean have less variation in day/night temperature than locations farther away from the ocean. Each team then **communicates [SEP-8]** its explanation and reasoning to a different team. The process of creating, critiquing, and revising these explanations takes 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 transition to their questions about the precipitation differences. Students know it snows in the mountains, so Ms. L decides to have them investigate the amount of rainfall in east-west transects across California. Students obtain rainfall amounts from an online database by clicking stations on a map (see California Data Exchange Center at <http://cdec.water.ca.gov/cdecstation/>). For each station, the database reports the latitude, longitude, monthly rainfall, and the elevation of the station (along with other weather data). Students make a graph of rainfall versus longitude and a graph of elevation versus longitude (figure 5.8). Because they want to compare the shapes of the two curves, Ms. L teaches students how to plot the two lines on the same graph using different vertical axes.

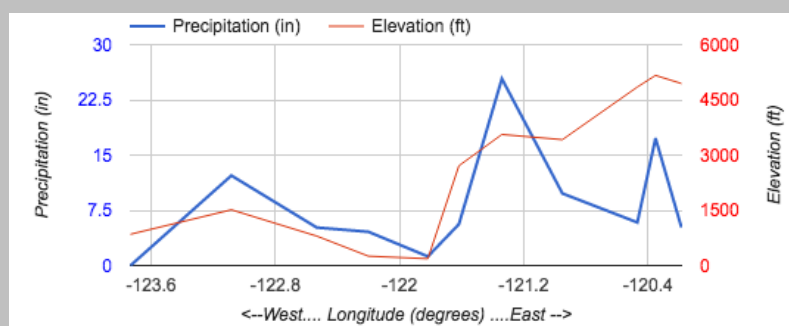
**Figure 5.8. Profile of Annual Rainfall Across California Heading East From San Luis Obispo**



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

Different students plot different locations in California and they all discover a remarkable **pattern [CCC-2]** where the rainfall seems to go up as elevation goes 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.

When Ms. L asks students to explain what causes this relationship, students come up with some crazy theories. Students do know that it tends to be colder in the mountains, so Ms. L asks them to relate this idea back to the condensation they learned about earlier in the lesson sequence. What happens to water when it gets colder? Ms. L helps asks students to write an explanation in their science notebooks that responds to the prompt, “It rains more at higher elevations because...” Their model is relatively simplistic in middle school and does not include the effects of relative humidity, but they are able to tie together many of the essential concepts.

Some students notice that the eastern part of the graphs tend to be high elevation, but the rainfall is lower there. They **ask questions [SEP-1]** about what could cause this pattern. Ms. L shows them animations of satellite maps of atmospheric moisture and precipitation for several storms moving across California. The storms tend to move from west to east, with the precipitation stopping as the storm moves to eastern California. Ms. L introduces the idea that the matter has moved. Students need 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 draw 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 begin by reviewing the features of a systems diagram (boundary, components, inputs/outputs, interactions, and system property).

After the student teams complete their initial models, Ms. L initiates an activity that helps them create more accurate and complex water cycle diagrams. She knows from experience and research that while students often can list the locations where water is located, they tend to have very 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 leads students through a simple kinesthetic game. Each student plays the role of a water particle (or H<sub>2</sub>O molecule if students are comfortable with that terminology) and move around the room through different stations that represent different places that water is located (ocean, plant, atmosphere, cloud, mountain glacier, polar ice cap, etc.). At each station, the student rolls dice and read from an instruction sheet whether they stay at that station for another turn or move to a different station via a water cycle process. In essence, the students use their own bodies as components in a physical **model [SEP-2]** of all the processes of the water cycle.

After the exercise, students comment about it and summarize what they learned. Key points include:

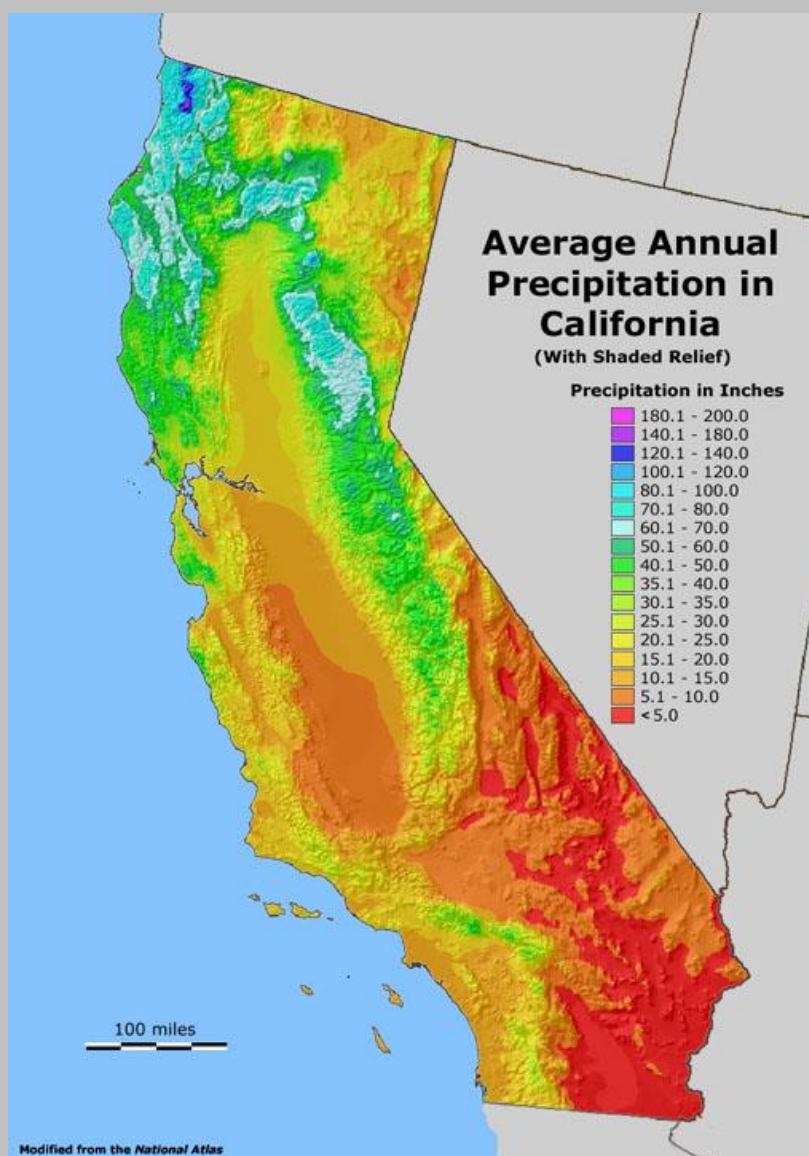
- \* the number of inputs and outputs for the different reservoirs;
- \* the different residence times in the reservoirs;
- \* the changes in state associated with the water cycle interconnections;
- \* the cyclical, rather than linear, nature of the water cycle; and
- \* the role of gravity in **causing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

After this kinesthetic lesson, student teams return to their regional water cycle diagrams and incorporate more of these interconnections, inputs and outputs. Students then share their regional water cycle diagrams, critique and extend each other's presentations, and achieve a more complete group understanding of water cycle reservoirs and processes. As a whole class activity, they create a color-coded map representing the average annual precipitation that includes all of their California regions. To create this representation, they need to collaborate on deciding the range of values to use, and how to represent the entire spectrum of data. They compare their whole class model with a representation that Ms. L downloads from the internet (figure 5.10),



which they then use 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.

### **Days 15 – Explaining California Climate**

The lesson sequence concluded with presentations that the class makes for different audiences about California climate and precipitation. In each presentation, students highlight the **patterns [CCC-1]** of temperature and precipitation in each of the eight

California regions that they had investigated. They also **explain [SEP-6]** the different factors that were involved in **causing [CCC-2]** significant climate patterns such as comparatively small variation in coastal day/night temperatures, high levels of mountain precipitation, and the rain shadow effect of coastal and Sierra Nevada mountains on the Central Valley and on Eastern California respectively.

### **Vignette Debrief**

In this multi-week vignette, students apply PS concepts to explain an ESS observation about climate and LS observation about habitats. Ms. L struggled with how long to spend on each section, but quickly realizes that even three weeks on this vignette felt rushed. She let students 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 take much longer than she thought. But her assessment of student work shows that students gain a much better understanding using this student-centered approach than when she speeds through things 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 description describes this blend, the sections below focus on relevant aspects of each dimension in isolation, along with ties CA CCSS and the EP&Cs.

**SEPs.** As the students become 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 focus on different states of matter (PS1.A) and the definition of thermal energy (PS3.A). Students build on this definition on Days 3-4 and richly explore the relationship between thermal energy, states of matter, and a particle model of matter (MS-PS1-4) on Days 10-12. Days 5-9 focus on general observations of weather and climate in California (ESS2.D). On Days 13-15, students engage in integrating the PS and ESS 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 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).

*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 students were able to ask informed questions based on their own experience on Day 9.

*CA CCSS Connections to English Language Arts and Mathematics.* On Days 4 and 13-14, students focus on developing and interpreting graphs (6.SP.4). Students obtain and evaluate information about California's climate zones on Days 5-9. Students engage 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 practice 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.  
[http://www.energy.ca.gov/maps/renewable/building\\_climate\\_zones.html](http://www.energy.ca.gov/maps/renewable/building_climate_zones.html)  
 (accessed January 3, 2017).

Geology Cafe. 2012. Precipitation and Relief Map of California.  
[http://geologycafe.com/california/maps/california\\_precipitation&relief1.htm](http://geologycafe.com/california/maps/california_precipitation&relief1.htm)  
 (accessed October 20, 2016).

Mr. Kent's Chemistry Page. N.d. Complex Calorimetry Problems.

<http://www.kentchemistry.com/links/Energy/ComplexCalProblems.htm> (accessed October 20, 2016).

## 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 set 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 by having them understand the water cycle processes by investigating the levels of the tides in one coastal city. Have students use a cause and effect chart to identify the changes in the water cycle reservoirs respective to the effect the gravity from the moon and the position of the sun. Have students 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 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 (CA EP&C III). Even in years with abundant precipitation, California still draws water from a total of seven nearby states in addition to its own supply (Klausmeyer and Fitzgerald 2012). 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 takes occasional walking field trips to a creek near the school to study the local ecosystem. This time, students collect water samples and bring them back to the classroom. Mrs. N asks students if they would want to drink the water in the puddles and they all say no because it is too 'dirty.' But what does it mean for water to be dirty? Students take turns looking at drops of water under the classroom microscopes. They notice all sorts of tiny plants, moving animals, and bits of dirt even in water samples that appear clear to the naked eye. Mrs. N gives the students the opportunity to compare water from a local pond with tap water. They compare the pond water, to filtered pond water and then tap water. Students observe that the filtered pond water has fewer particles, than the unfiltered pond water, and that the tap water has almost no particles in it. Mrs. N challenges students to come up with a system to **quantify [CCC-3]** the amount of contamination in a water sample. Each group constructs a bar graph showing the relative amount of contaminants and then compares their measurement to the other groups. Are the differences related to the measurement technique or the water samples themselves? Student groups decide to switch water droplet microscope slides with

**Everyday phenomenon:** Our drinking water is not pure H<sub>2</sub>O.

another team to test out their ideas.

Water is one of California's most important natural resources (ESS3.A). Students then **obtain 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 evaluate how their water compares to another city (such as Flint, Michigan which experienced unacceptable levels of lead contamination in 2015). They learn 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 draw atomic-level representations of the

solution of liquid water and heavy metal as mixtures of moving molecules. They use 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

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

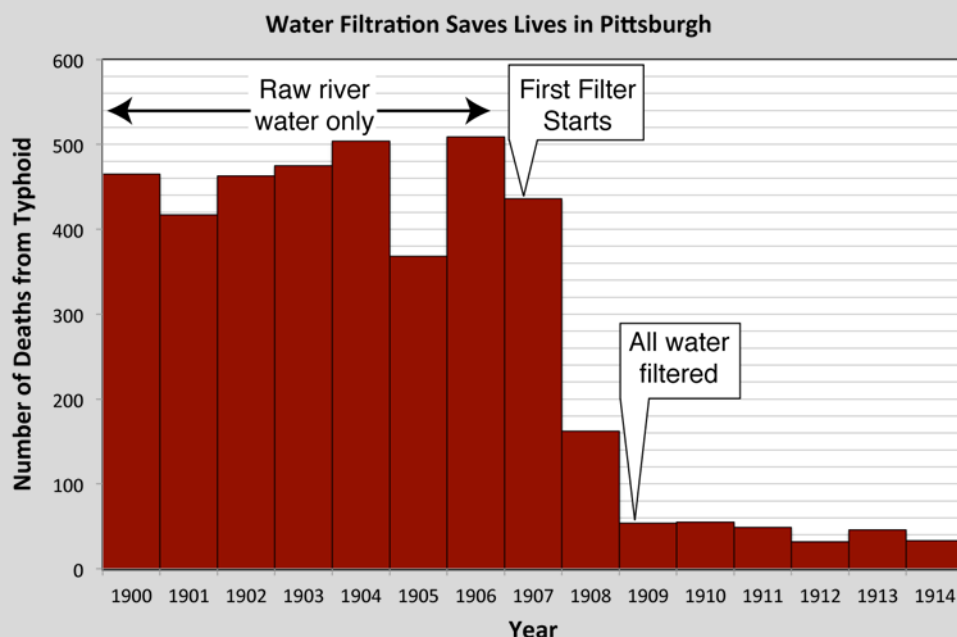
many years to cause observable health effects, so Mrs. N decides to focus on infectious diseases with their short-term health impacts.

While students can see the differences in both the real life water and the measurements, they do not yet appreciate why these numbers matter. Mrs. N sets 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).

Sacramento was not unusual and infectious diseases were a major problem in US cities until midway through twentieth century. Mrs. N was born in Pittsburgh where the

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

rate of death from diseases in 1900 was the highest of any major US city. Students read an article about how city health officials and engineers changed that by installing a water filtration system in their public water system that cut the death rate from typhoid by almost a factor of 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

Mrs. N wants to make sure that students are 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 has students draw a simple **pictorial model [SEP-2]** that illustrates the relationships. Each student then individually writes a caption with an **explanation [SEP-6]** about how water filters remove organisms that **cause [CCC-2]** disease. Mrs. N tells students that next week they will design and test their own water filters.

Before moving on, Mrs. N leads 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 tells students that people releasing materials like

sewage into a river is called water pollution. She asks students if they are aware of any water pollution at the school or in the local community. Students identify several examples of pollution on campus and in the streets by the school, including oil dripping from cars that then flows down the gutters on the street and into the storm drains. One of the students mentions that she has seen drains along the street that are labeled, “no dumping, leads to ocean.” Mrs. N asks, “Why is this important?” Several students mention that on a recent field trip to the coast they learned that oil coming from the storm drain system has been observed along the coast and it has damaged parts of the coastline and some of the wildlife that lives there (CA EP&Cs II and IV). Mrs. N asks 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 PE MS-ESS3-4).

Mrs. N asks students if they think that we still dump our sewage into rivers and water. They then learn more about modern wastewater treatment (see “Our Water: Sources and Uses” at <http://californiaeei.org/framework/sci/OurWater>) 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 the air movements that drives 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 towards phenomena in their daily lives such as the warming effect of rubbing hands together or doing vigorous exercise. Building on those kinds of

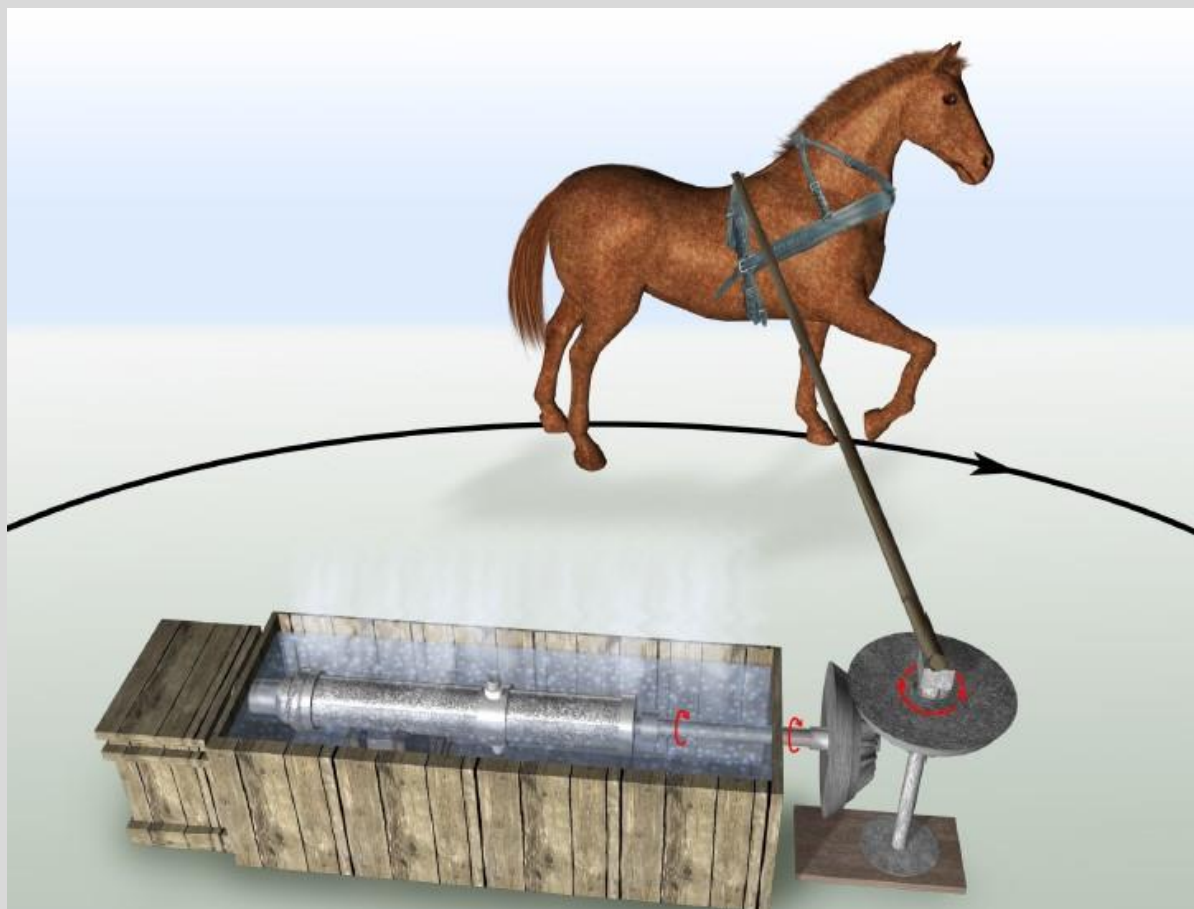
**Investigative phenomenon:** Count Rumford showed a horse was able boil water by running around in circles to turn a metal cylinder.

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.

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 where 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.



**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.

The day after the homework reading, the students discussed in small groups 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 transferred to kinetic energy of the iron boring machine which transferred to thermal energy of the water;

\*at the particle level, kinetic energy of the boring machine transferred to kinetic energy of the water particles.

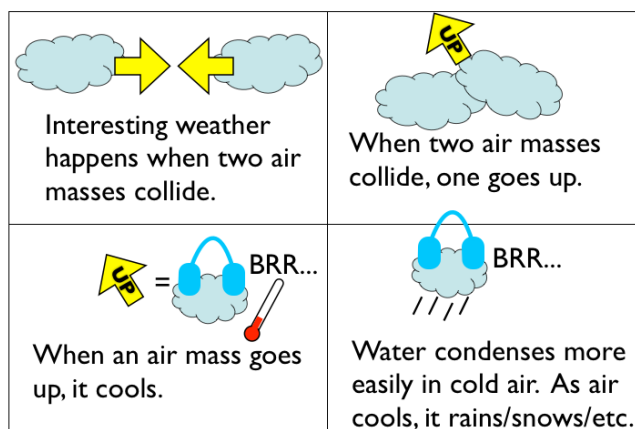
The following day, Mr. A introduced the design challenge for students in teams of three to **design, construct, and test a device [SEP-6]** that either minimizes or maximizes the transfer of thermal energy. Mr. A facilitated a whole class discussion about constraints (such as safety, cost, class time, and availability of materials/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 then need opportunities to investigate how different materials respond to heating (solids such as ice melting, liquids such as a pot of miso soup, and gases such as a flask with a balloon on top, 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 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://phet.colorado.edu/en/simulation/states-of-matter-basics>). 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 take 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 <http://www.goes.noaa.gov/browse3.html>), 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 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

These same physical principles allow students to explain weather patterns within California. Why does it rain and snow more at high 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 <http://californiaeei.org/framework/sci/Precip> provides a variety of resources that can support this instruction.

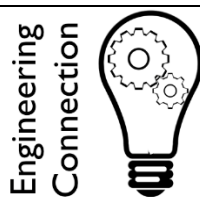
Students may be able to share based on personal experience that mountain temperatures tend to be cooler than temperatures at lower elevations. A very important climate consequence of the colder temperatures at higher altitudes is that rising air becomes colder and can hold less water vapor. As a result 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 towards 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 hits (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 towards 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 (CA EP&C V).

## Integrating the CCCs in Grade Six Instructional Segment 2

The CCC of “**Scale, Proportion, and Quantity [CCC-3]**” at the middle school level includes the notion that, “Time, 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 disciplines, 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 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 **Energy and Matter [CCC-5]** refer often 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.



## 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?

### Performance Expectations

*Students who demonstrate understanding can:*

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



weather stations.]

**MS-ESS2-6. Develop and use a model to describe how unequal heating and rotation of the Earth cause patterns of atmospheric and oceanic circulation that determine regional climates.**

[Clarification Statement: Emphasis is on how patterns vary by latitude, altitude, and geographic land distribution. Emphasis of atmospheric circulation is on the sunlight-driven latitudinal banding, 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.]

**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**

<p><b>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.]</b></p>		
<p>The bundle of performance expectations above focuses on the following elements from the NRC document <i>A Framework for K–12 Science Education</i>:</p>		
<p><b>Highlighted</b></p> <p><b>Science and Engineering Practices</b></p>	<p><b>Highlighted</b></p> <p><b>Disciplinary Core Ideas</b></p>	<p><b>Highlighted</b></p> <p><b>Crosscutting Concepts</b></p>
<p>[SEP-1] Asking Questions and Defining Problems</p>	<p>ESS2.C: The Roles of Water in Earth’s Surface Processes</p>	<p>[CCC-1] Patterns</p>
<p>[SEP-2] Developing and Using Models</p>	<p>ESS2.D: Weather and Climate</p>	<p>[CCC-2] Cause and Effect</p>
<p>[SEP-3] Planning and Carrying Out Investigations</p>	<p>PS3.A: Definitions of Energy</p>	<p>[CCC-3] Scale, Proportion, and Quantity</p>
<p>[SEP-4] Analyzing and Interpreting Data</p>	<p>PS3.B: Conservation of Energy and Energy Transfer</p>	<p>[CCC-4] System and System Models</p>
<p>[SEP-6] Constructing Explanations (for science) and</p>		<p>[CCC-5] Energy and Matter: Flows, Cycles,</p>

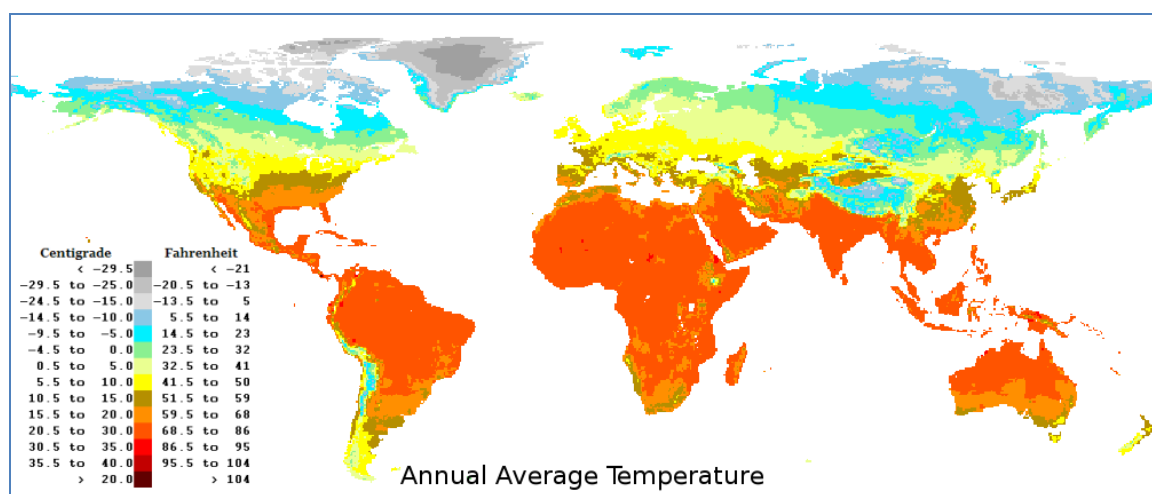
The *CA Science Framework* was adopted by the California State Board of Education on November 3, 2016. The *CA Science Framework* has not been edited for publication. © by the California Department of Education.

<b>Designing Solutions (for engineering)</b>  <b>[SEP-7] Engaging in Argument from Evidence</b>  <b>[SEP-8] Obtaining, Evaluating, and Communicating Information</b>	<b>ETS1.A: Defining and Delimiting Engineering Problems</b>  <b>ETS1.B: Developing Possible Solutions</b>	<b>and Conservation</b>  <b>[CCC-6] Structure and Function</b>
<p><i>Highlighted California Environmental Principles &amp; Concepts:</i></p> <p>Principle II The long-term functioning and health of terrestrial, freshwater, coastal and marine ecosystems are influenced by their relationships with human societies.</p> <p>Principle IV The exchange of matter between natural systems and human societies affects the long term functioning of both.</p>		
<p><i>CA CCSS Math Connections:</i> 6.SP.2, 4, 5, MP.2, MP.4</p>		
<p><i>CA ELD Connections:</i> ELD.PI.6.1,5,6 a-b, 9,10,11a</p>		
<p><i>CA CCSSELA/Literacy Connections:</i> RST.6-8.1,2,3,4,7,9 RI.6.8, WHST.6-8.1,2,7,8,9, SL.6.5</p>		

In this IS, students will 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: Climate Charts 2007.

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]** 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 enabled 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 IS 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 IS.

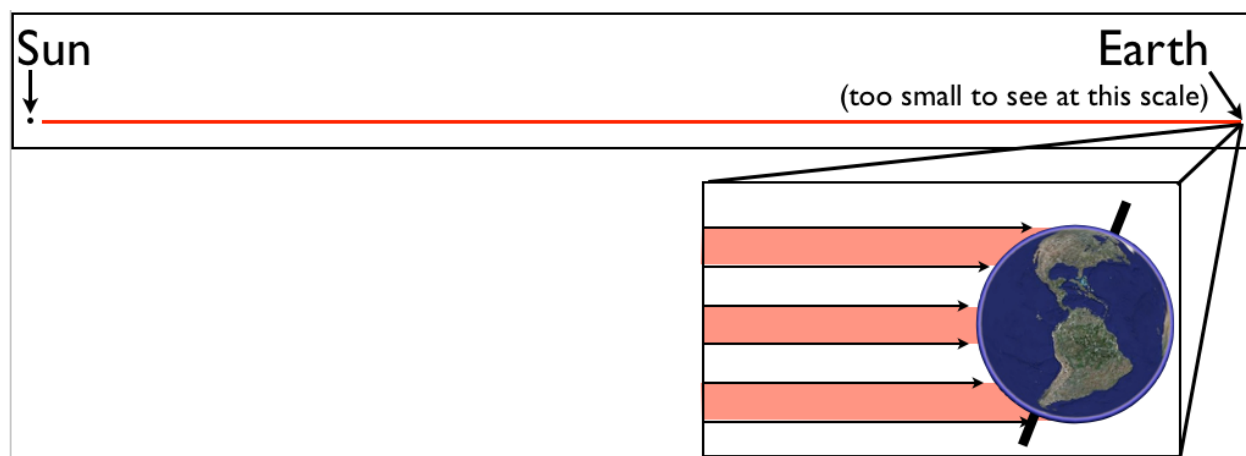
### Climate Depends on Latitude

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 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 the 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

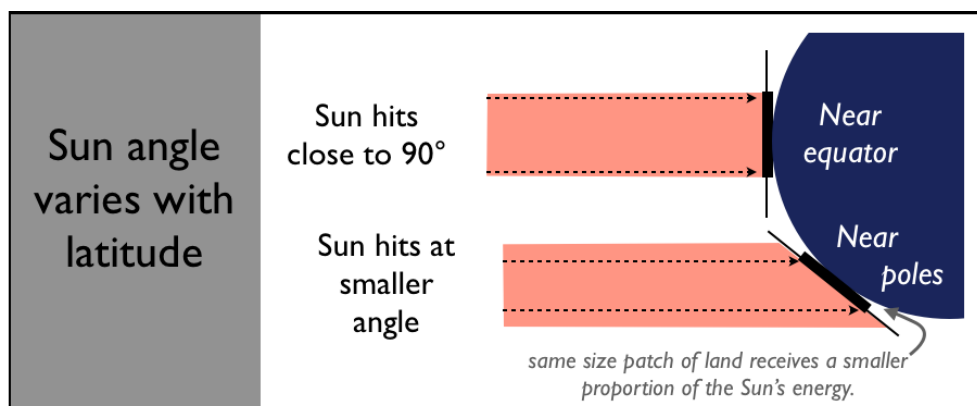
poles because of Earth's round shape. The light spreads out over a larger area near the poles (figure 5.16), meaning that each square foot patch of the surface receives a smaller **proportion [CCC-3]** of the energy coming from the Sun than that same patch does at the equator, which causes the sunlight on that patch to be less intense. When the sun shines down at a  $90^\circ$  angle, a patch of land receives twice the energy compared to a  $30^\circ$  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.

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 spread 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  $90^\circ$ , the energy is spread out over a larger area. Diagram by M. d'Alessio.

### 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.). 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**

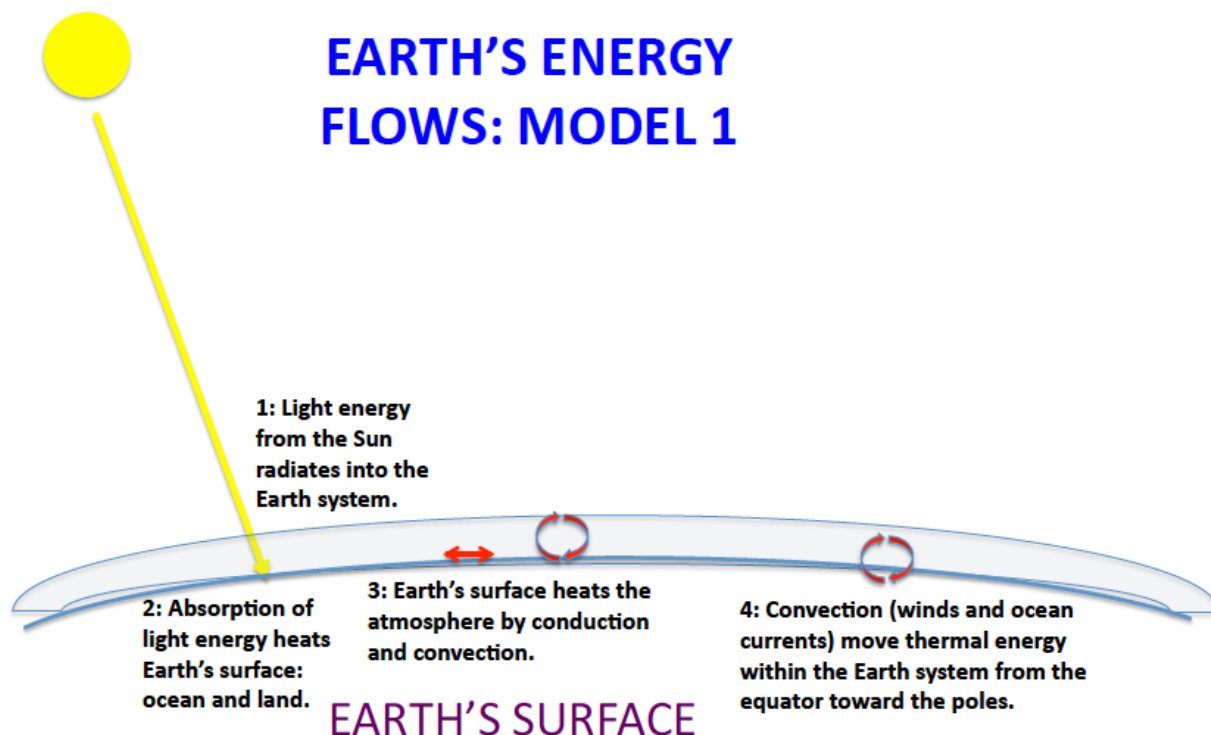
WAYS THERMAL ENERGY MOVES	PHYSICAL SCIENCE	EXAMPLES
<b>CONDUCTION</b>	Warm object touches cooler object and makes it warmer. Electromagnetic waves not involved	Hot sand burns your feet. Hot ground warms air that touches it. Handle of heated pan becomes hot.
<b>CONVECTION</b>	Warm liquid or gas flows into cooler area and makes it warmer. Electromagnetic waves not involved.	Warm air rises and is replaced by cooler air. Hot water in heated pot rises from bottom to top.
<b>RADIATION</b>	Objects do not touch each other. Electromagnetic waves radiate from warmer object, are absorbed by cooler object and make it warmer.	Sunlight heats your body Standing near a hot wall or hot cliff. A wood fire or an outside gas or electric heater heats your body.

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.<sup>1</sup>

**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.

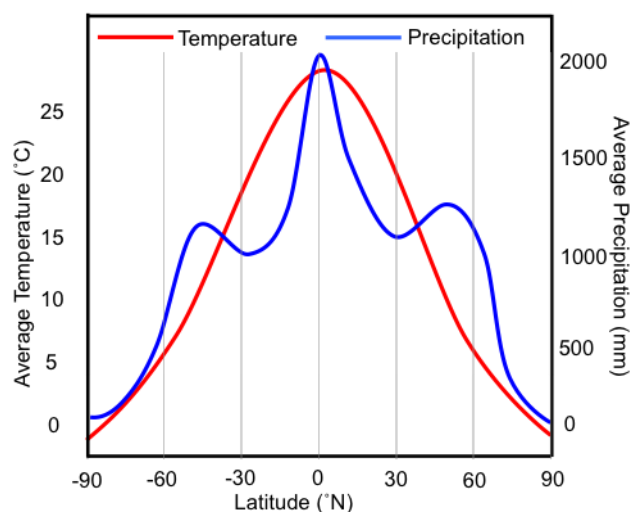
The teacher can prompt students to think about and discuss concept number four in figure 5.17, the transfer of thermal energy by convection. Why does thermal energy move from the equator toward the poles? Student **explanations [SEP-6]** should include the evidence from prior **investigations [SEP-3]** 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

<sup>1</sup> In Instructional Segment 4, students will learn via Model 2 that radiation from Earth's surface also plays a very significant role in heating the atmosphere and in Earth's global climate.

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.

**Figure 5.18. Temperature and Rainfall Vary Systematically with Latitude**

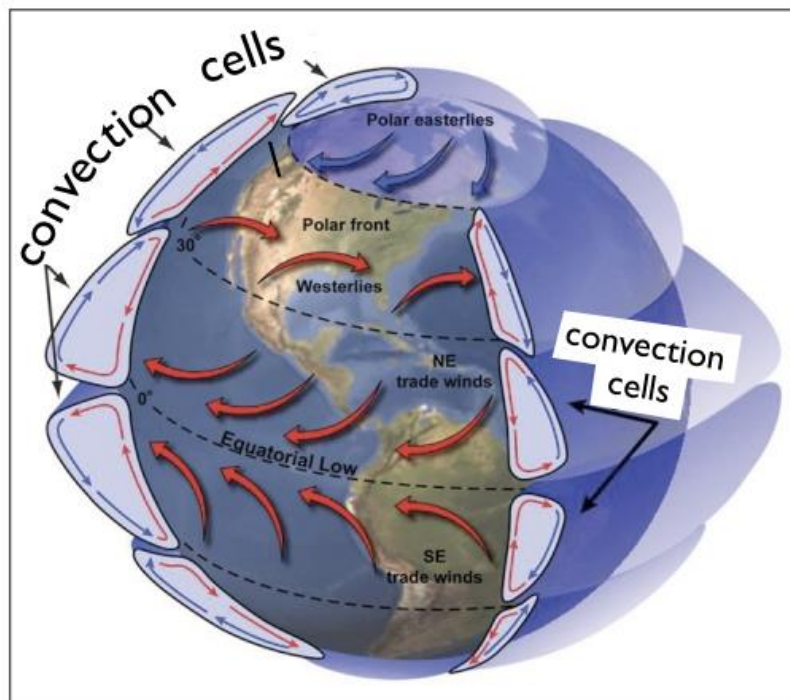


Source: Thebiologyprimer 2015

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 degrees latitude toward the poles (skinny red and blue arrows in the convection cells). Image credit: Adapted from Summey n.d.

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 mountains 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 by Dr. Art Sussman, courtesy of WestEd.

## Organism Traits, Heredity, and Reproduction

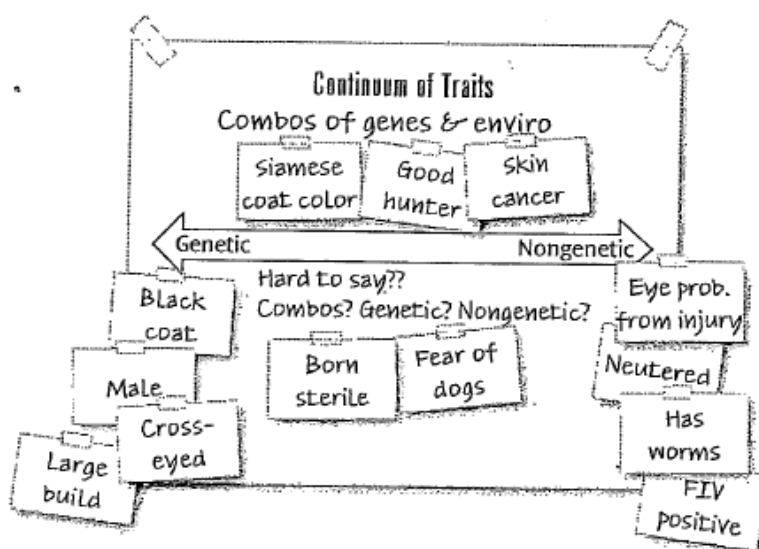
Ecosystems develop around the abiotic conditions such as climate because these abiotic factors strongly influence the kinds of organisms that can live in an environment. These same factors also help **determine [CCC-2]** the organism structures and behaviors (adaptations) that will have the most success with respect to survival and reproduction. Teams of students can research a distinctive environment (e.g., the barren granite of the peaks in the Sierra Nevada mountains, the dark shade beneath towering coast redwood trees, or the brackish mud of a salt marsh), and 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? Hence the transition to heredity and reproduction. Students have been gathering evidence that organisms look and act like their parents since back in grade one (1-LS3-1; 3-LS3-1). Now, they begin to develop models of the mechanisms for heredity.

Organism structures and behaviors are features that generally apply to all members of a species. Examples of human features are eye color, body size, blood type, and personality 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 very 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 school student, this discussion of traits goes beyond scientific facts (Health Standards 7-8.1.8G, 7-8.2.2.G).

Discussions of traits can get side-tracked by either/or arguments about the roles of genes and 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 very 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 very 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 extremes examples (figure 5.20).

**Figure 5.20. Genetic vs Environmental Traits**



Some traits are essentially all genetic, and some are mostly environmental. Most traits are strongly influenced by genes and the environment. Source: Daehler and Folsom 2015.

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 very large range and have been extensively studied. In some areas of the western US, 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-2]** that would determine if any of the height difference is due to genetic differences

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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 vary and control for in 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, 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 PEs 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 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 Genetic Science Learning Center website (Sexual vs. Asexual Reproduction accessed at: <http://learn.genetics.utah.edu/content/basics/reproduction/>). Ms. Z provided background information about reproduction in sunflowers, earthworms, strawberries, and whiptail lizards. Students discussed in teams how to describe the reproductive process in each organism (asexual, sexual, or both) and the **evidence [SEP-7]** for their categorizations. Whole class sharing resulted in common answers and evidence. Small student teams then had time to explore the website (possibilities would be in computer lab, in class with tablets, at home, in a library) in order 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 pasted 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 paid attention 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 Genetic Science Learning Center resource to list and compare all animal behaviors that play a significant role in the reproduction. In order to

do so, the students discuss the criteria for how they will categorize different kinds of behavior. If students have difficulty suggesting valuable criteria, the teacher can prompt the discussion with examples that exemplify 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 to dying off)? Ms. Z presents students 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 instructs 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 provides 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 pick one of the suggested examples of female choice or a different one that they independently researched and **evaluated [SEP-8]**.

After the teams have conducted the first round of research, the whole class decides on the criteria for a complete investigation and report. Teams extend and conclude their

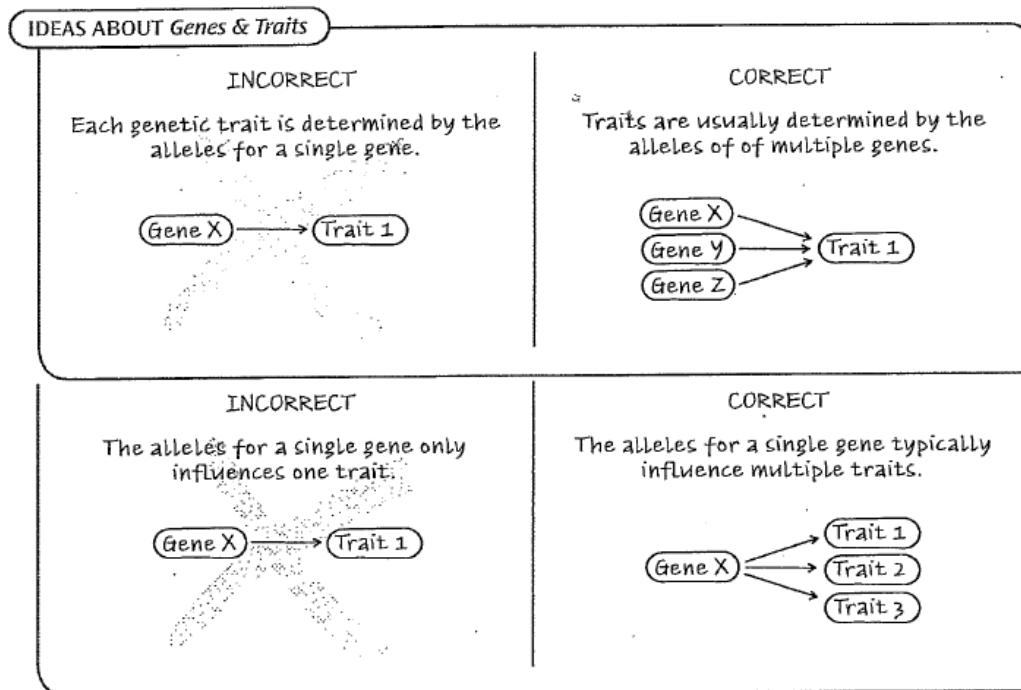
investigation by developing and presenting a report to the class about their example of female choice including **explaining [SEP-6]** the evidence and reasoning how the behavior affects the probability of successful reproduction (MS-LS1-4).

These life science learning experiences in grade six provide a foundation for deeper explorations in grade seven (PEs and DCIs focused on LS2: Ecosystems) and in grade eight (PEs 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 allows students to develop models 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 misconception that each trait is caused by one gene. Students may also hold a parallel misconception that each gene influences only one trait. Students can counter these misconceptions 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 concepts 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: Daehler and Folsom 2015.

## 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
<p><i>Guiding Questions:</i></p> <ul style="list-style-type: none"> <li>• How do human activities affect Earth’s systems?</li> <li>• How do we know our global climate is changing?</li> </ul>
Performance Expectations
<p><i>Students who demonstrate understanding can:</i></p> <p><b>MS-ESS3-3. Apply scientific principles to design a method for monitoring and minimizing a human impact on the environment.*</b></p> <p>[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).]</p> <p><b>MS-ESS3-5. Ask questions to clarify evidence of the factors that have caused the rise in global temperatures over the past century.</b></p> <p>[Clarification Statement: Examples of factors include human activities (such as fossil fuel combustion, cement production, and agricultural activity) and natural processes (such as changes in incoming solar radiation or volcanic activity). Examples of evidence can include tables, graphs, and maps of global and regional temperatures, atmospheric levels of gases such as carbon dioxide and methane, and the rates of human activities.</p>

Emphasis is on the major role that human activities play in causing the rise in global temperatures.]

**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-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*:

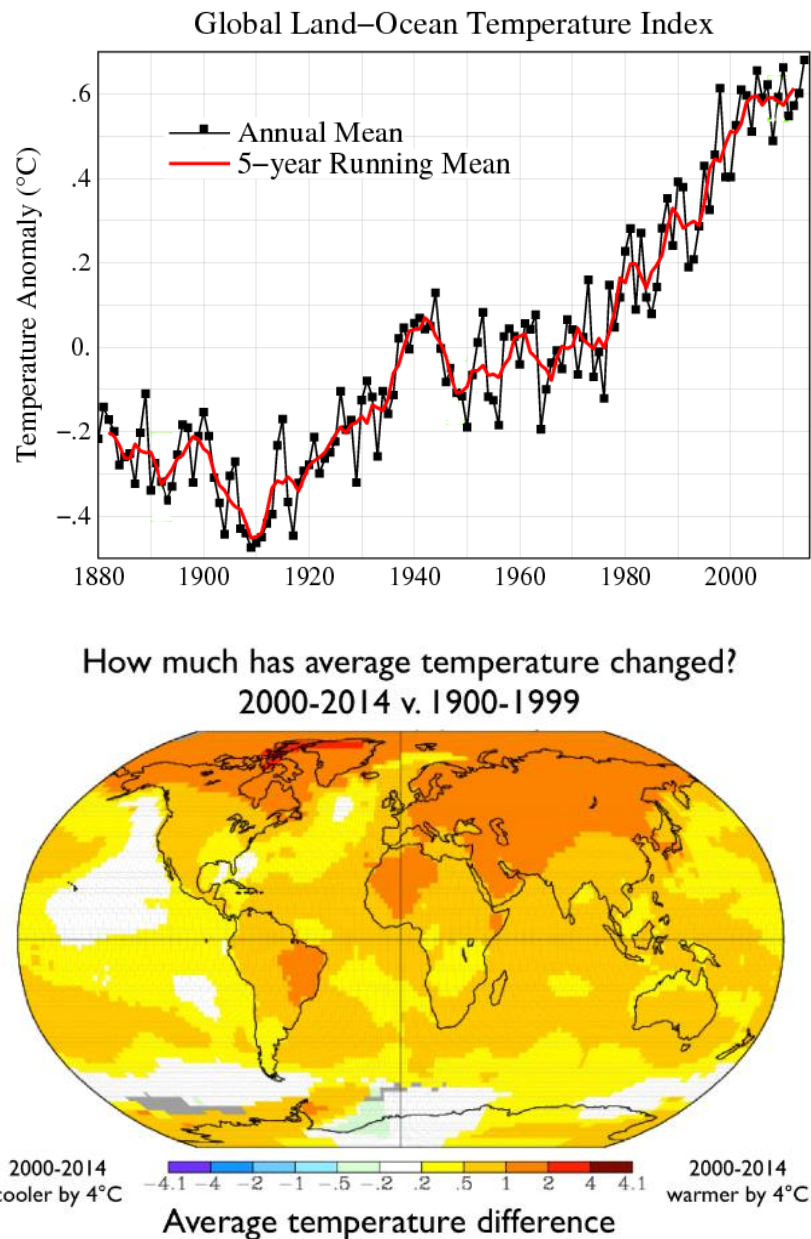
Highlighted Science and Engineering Practices	Highlighted Disciplinary Core Ideas	Highlighted Crosscutting Concepts
[SEP-1] Asking Questions and Defining Problems	ESS3.C: Human Impacts on Earth Systems	[CCC-1] Patterns
[SEP-2] Developing and Using Models	ESS3.D: Global Climate Change	[CCC-2] Cause and Effect
[SEP-3] Planning and Carrying Out Investigations	LS1.B: Growth and Development of Organisms	[CCC-3] Scale, Proportion, and Quantity
[SEP-4] Analyzing and Interpreting Data		[CCC-4] System and

<p><b>[SEP-5] Using mathematics and Computational Thinking</b></p> <p><b>[SEP-7] Engaging in Argument from Evidence</b></p> <p><b>[SEP-8] Obtaining, Evaluating, and Communicating Information]</b></p>	<p><b>ETS1.A: Defining and Delimiting Engineering Problems</b></p> <p><b>ETS1.B: Developing Possible Solutions</b></p>	<p><b>System Models</b></p> <p><b>[CCC-5] Energy and Matter: Flows, Cycles, and Conservation</b></p> <p><b>[CCC-7] Stability and Change</b></p>
<p><i>Highlighted California Environmental Principles &amp; Concepts:</i></p> <p>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.</p> <p>Principle II The long-term functioning and health of terrestrial, freshwater, coastal and marine ecosystems are influenced by their relationships with human societies.</p> <p>Principle IV The exchange of matter between natural systems and human societies affects the long term functioning of both.</p>		
<p><i>CA CCSS Math Connections:</i> MP.2, 6RP.1,6.EE.6, 6.SP.2,4</p>		
<p><i>CA ELD Connections:</i> ELD.PI.6.1,5,6 a-b, 9,10,11a</p>		
<p><i>CA CCSS ELA/Literacy Connections:</i> RI.6.8,RST.6-8.1, 2 WHST.6-8.7, WHST.6-8.8,</p>		



In this IS, students collect evidence that Earth’s climate is changing. At the sixth grade 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. Middle school students 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 IS, 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, <http://cal-adapt.org/tools/>). 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 sixth grade.

**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 21st century to the 20th century (bottom). The 21st century is warmer than the 19th and 20th centuries. Source: NASA 2016.

### Opportunities for ELA/ELD Connections

To help data come alive and help students compile it for 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 ad for an environmental magazine that includes a headline, a picture and a visual that represents [SEP-8] the data gathered. Have each group present their ad to the class as if the class was 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 ELA/Literacy Standards: RST.6–8.2, 7; WHST.6–8.7, 9; SL.6–8.5

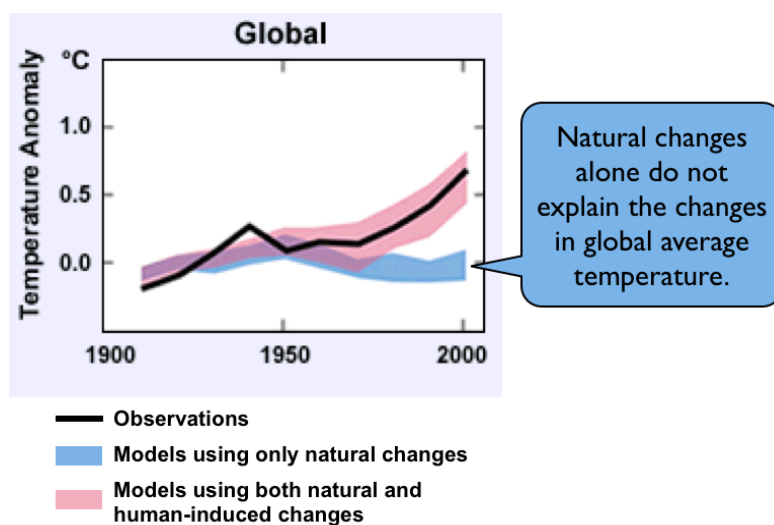
CA ELD Standards: ELD.PI.6–8.9

### Climate Change Causes

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 (see ESS3.D). When ocean currents change their flow **patterns [CCC-1]**, such as during El Niño Southern Oscillation conditions, some global regions become warmer or wetter and others become colder or drier. When scientists make computer simulations that include only these natural **changes [CCC-7]**, they cannot match the temperature changes from the last century (figure 5.23). But there are also changes that are caused by human activity (CA 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 a very similar **patterns [CCC-1]** to 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**

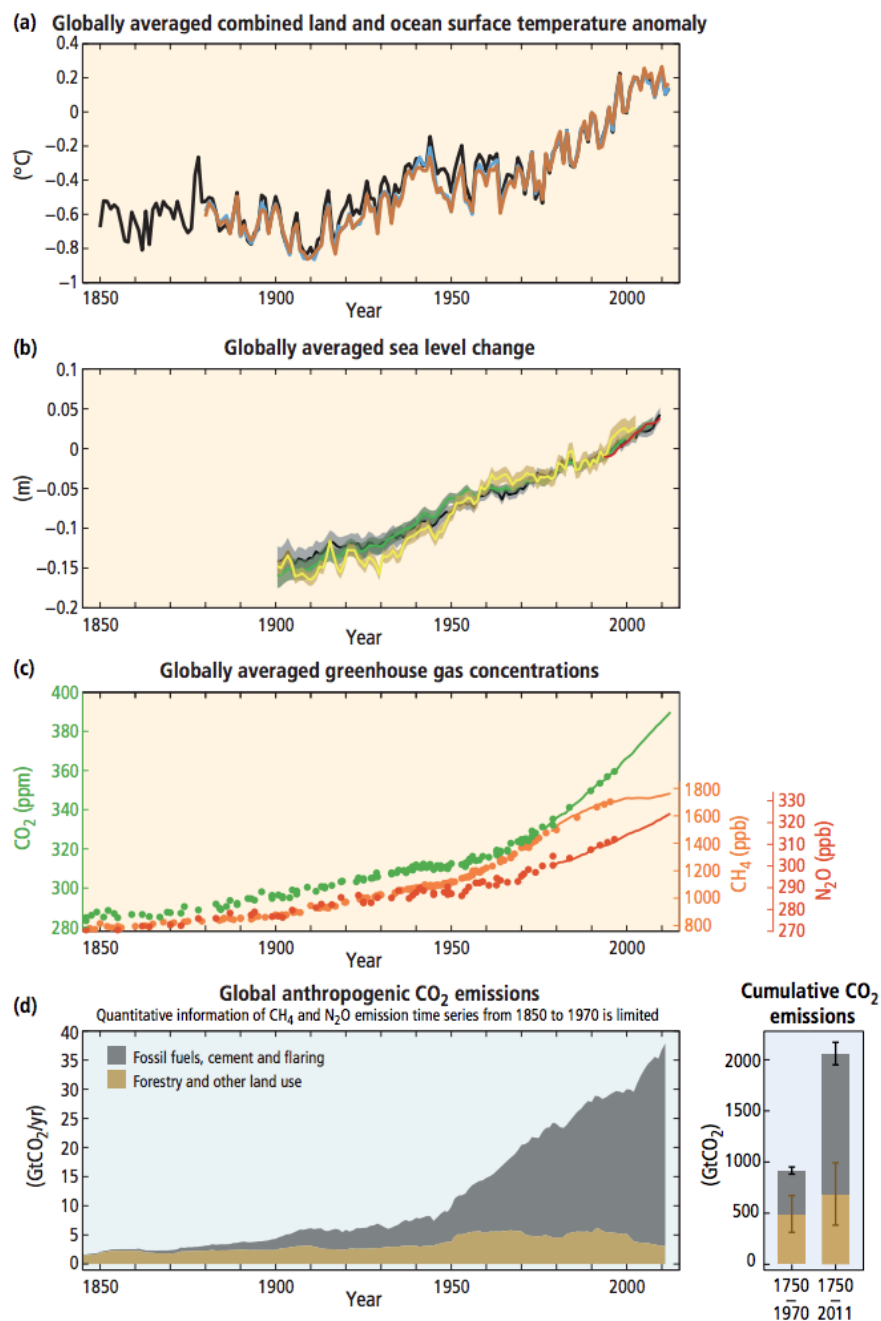


Outputs of different computer models of global climate compared to observations. The colored bands are thick because they represent hundreds of different models created by many different researchers using different assumptions. While the models have slight variations in their output, only models that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

the observed temperature record. Source: Intergovernmental Panel on Climate Change (IPCC) 2014.

### Opportunities for Math Connections

Global average temperature rises as humans emit more greenhouse gases. This rate of emission depends on two key variables: population growth, and energy consumed per person. Students must **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 US 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 US (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 in the continent of Africa. These comparisons are examples of ratios and ratio language (CA CCSSM 6.RP.1). Many developing countries around the world have growing populations and are rapidly changing their lifestyles to include more energy intensive tools. They will start consuming energy at rates more like California or even the US average, which could have a huge impact on global climate and global emissions. Computer **models [SEP-2]** that forecast **changes [CCC-7]** in global climate rely on accurate estimates about energy consumption in the future, and in high school students will use computer simulations to explore the effects of these assumptions (HS-ESS3-5).

**Figure 5.24. Global Warming Cause and Effect**

Graphs with similar trends and patterns illustrate global warming causes and effects.

Source: IPCC 2014.

## 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 middle school grades includes PEs 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 focused on designing a method for monitoring and minimizing a human impact on the environment. The following snapshot addresses that PE and has an emphasis on engineering design.

Integrated Grade Six Snapshot 5.4. Monitoring and Minimizing Human Environmental Impacts
<b>Anchoring phenomenon:</b> Monarch butterflies fly long distances every year.
<p>Following their <b>investigations [SEP-3]</b> 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 very long distances to California. The students live in a coastal town with one of the major California winter nesting areas for monarch butterflies. They were very concerned when they learned that climate change was affecting organism migrations.</p> <p>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 <b>scale [CCC-3]</b> about all the places that the</p>



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, the local threats to the Monarchs (especially related to habitat, food and climate), and possible local solutions to those threats (MS-ESS3-3).

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

Students in Team B argued that the Monarchs, and lots of other organisms, needed long-term solutions to climate change especially switching to renewable energy sources, and they **gathered information [SEP-8]** about making electricity from solar photovoltaic cells. Their project integrated PS and ESS DCIs while designing a solution to an LS 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 and any 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 oriented at a specific angle relative to the 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, especially with helping them establish a shared understanding about clearly articulating the 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 whole system property that emerges from the interactions of organisms with each other and with the huge diversity of Earth environments. 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. Integrated Grade Six can help build a middle school foundation of science and engineering understandings and practices related to citizenship and sustainability that can grow in depth in the succeeding middle school and high school grades. (Two EEI Curriculum units, "Energy: It's Not All the Same to You" <http://californiaeei.org/framework/sci/Energy> and "Responding to Environmental Change" <http://californiaeei.org/framework/sci/Respond> provide a variety of resources that can support this instruction.)

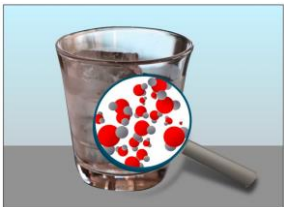

## **Grade Seven – Preferred Integrated Course Model**

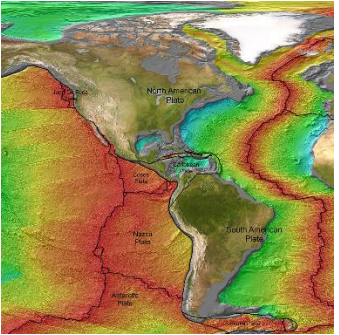

This section is meant to be a guide for educators on how to approach the teaching of the CA NGSS in grade seven according to the Preferred Integrated Course Model (see the introduction to this chapter for details regarding different models for grades six, seven, and eight). This section is not meant 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 PEs into integrated groups that can effectively guide instruction in four sequential IS. There is no prescription regarding the relative amount of time to be spent on each IS. 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’s 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's systems.

IS		Life Science	Earth & Space Sciences	Physical Science	Engineering, Technology, and Applications to Science
1	<b><i>Living and nonliving things are made of atoms</i></b>				
	 <p>Source: M d'Alessio</p>	Organisms are made of molecules of mostly six different elements.	<p>Earth materials are mostly made of eight different elements.</p> <p>Earth has mineral, energy, and water resources.</p>	<p>The interaction and motions of atoms explain the properties of matter.</p> <p>Thermal energy affects particle motion and physical state.</p>	
2	<b><i>Matter cycles and energy flows in systems of all scales within the Earth system.</i></b>				
	 <p>Source: Cambridge College Primary Science 2017</p>	Organisms grow and get energy by rearranging atoms in food molecules.	Earth's cycles of matter are driven by solar energy, Earth's internal thermal energy, and gravity.	<p>Chemical reactions make new substances and can release or absorb thermal energy.</p> <p>Mass is conserved in physical changes and chemical reactions.</p>	<p>Design Criteria</p> <p>Evaluate Solutions</p> <p>Analyze data</p> <p>Iteratively test and modify</p>
3	<b><i>Natural processes and human activities have shaped Earth's resources and ecosystems.</i></b>				

IS		Life Science	Earth & Space Sciences	Physical Science	Engineering, Technology, and Applications to Science
	 <p>Source: Lim 2008</p>	<p>Matter cycles and energy flows among living and nonliving parts of ecosystems.</p> <p>Resource availability affects organisms and ecosystem populations.</p> <p>Ecosystems have common patterns of organism interactions.</p>	<p>Fossils, rocks, continental shape, and seafloor structures provide evidence of plate motion.</p> <p>Geoscience processes unevenly distribute Earth's mineral, energy, and groundwater resources.</p>	<p>Chemical reactions make new substances.</p> <p>Mass is conserved in physical changes and chemical reactions.</p>	
4	<b><i>Human activities help sustain biodiversity and ecosystem services in a changing world.</i></b>				
	 <p>Source: Environmental Management 2016 Wiki 2016</p>	<p>Biotic and abiotic changes affect ecosystem populations.</p> <p>Design solutions can help maintain biodiversity and ecosystem services.</p>	<p>Geoscience processes change Earth's surface.</p> <p>Damage from natural hazards can be reduced.</p>	<p>Synthetic materials impact society.</p>	<p>Design criteria</p> <p>Evaluate solutions</p> <p>Analyze data</p>

A primary goal of this section is to provide an example of how to bundle the PEs 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 IS. As shown in figure 5.25, the overarching guiding concept for the entire year is that, “Natural processes and human activities cause energy to flow and matter to cycle through Earth’s systems.” Concepts across the disciplines integrate within each of the four IS. Each IS has a summary sentence, such as for IS1, “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 CCC can help with the learning of the specific topic and simultaneously deepen the understanding of the CCC. IS2 expands the instructional focus by including a highly detailed vignette that describes instruction over a much longer time period.

In IS2, 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 of food by plants and the breaking down of this food by all organisms set 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]**. Through engaging 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 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 result 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.

Towards the end of the year, students address challenges to sustainability by applying their understandings 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.

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

According to the development progressions in the CA NGSS (Appendix 1 of this Framework), **patterns [CCC-1]** at the middle school level include the concept, “Macroscopic patterns are related to the nature of microscopic atomic-level structure.” IS1 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
<p><i>Guiding Questions:</i></p> <ul style="list-style-type: none"> <li>• How does the matter in living and nonliving things differ?</li> <li>• How does adding or removing thermal energy affect the physical states of matter?</li> <li>• How do interactions at the atomic level help us understand the observable properties of organisms and nonliving matter?</li> </ul>
Performance Expectations
<p><i>Students who demonstrate understanding can:</i></p> <p><b>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</b></p>



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-PS1-1. Develop models to describe the atomic composition of simple molecules and extended structures.** [Clarification Statement:

Emphasis is on developing models of molecules that vary in complexity. Examples of simple molecules could include ammonia and methanol. Examples of extended structures could include sodium chloride or diamonds. Examples of molecular-level models could include drawings, 3D ball and stick structures, or computer representations showing different molecules with different types of atoms.] [Assessment Boundary: Assessment does not include valence electrons and bonding energy, discussing the ionic nature of subunits of complex structures, or a complete description of all individual atoms in a complex molecule or extended structure is not required.]

**MS-PS1-3. 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 assessed in 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
<p>[SEP-2] Developing and Using Models</p> <p>[SEP-6] Constructing Explanations (for science) and Designing Solutions (for engineering)</p> <p>[SEP-7] Engaging in Argument from Evidence</p>	<p>PS1.A: Structure and Properties of Matter</p> <p>PS3.A: Definitions of Energy</p> <p>LS2.A: Interdependent Relationships in Ecosystems</p> <p>ESS3.A: Earth's Natural Resources</p>	<p>[CCC-1] Patterns</p> <p>[CCC-2] Cause and Effect</p> <p>[CCC-3] Scale, Proportion, and Quantity</p> <p>[CCC-5] Energy and Matter: Flows, Cycles, and Conservation</p>

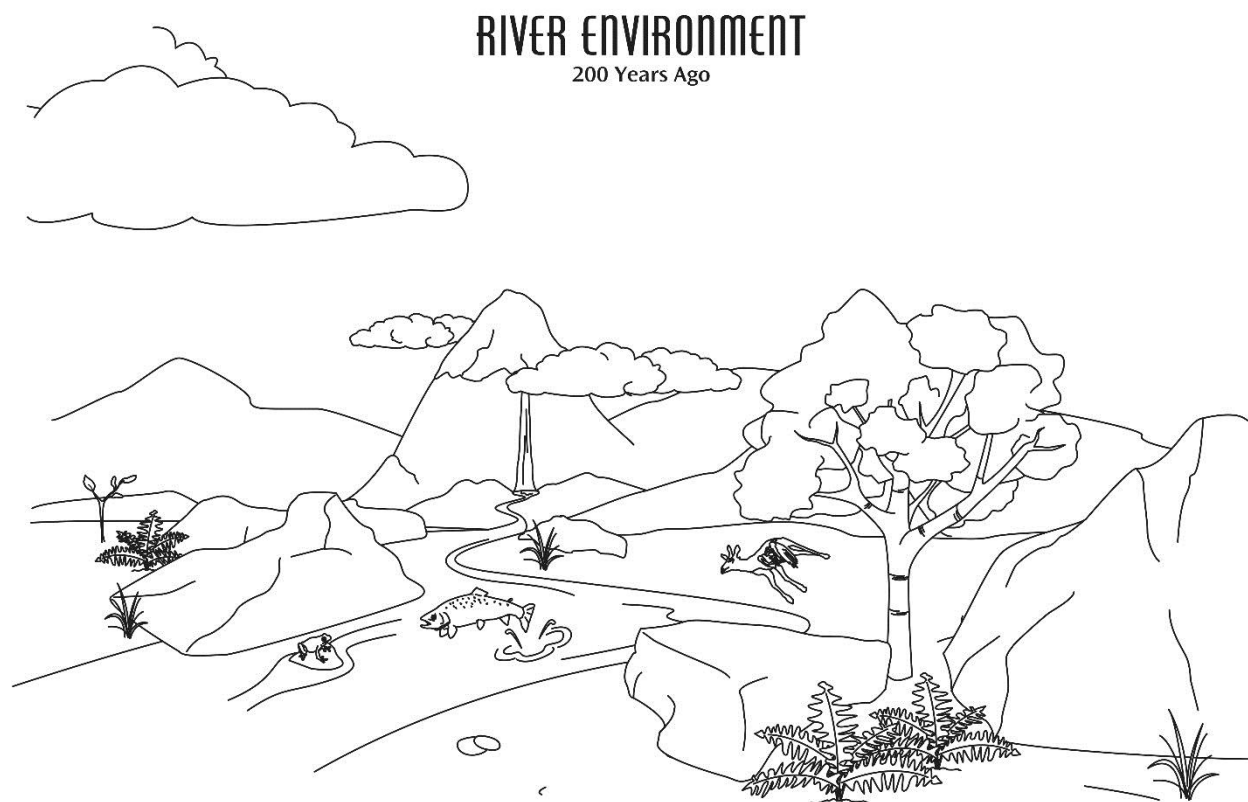
		<b>[CCC-6] Structure and Function</b>
<p><i>Highlighted California Environmental Principles &amp; Concepts:</i></p> <p>Principle I The continuation and health of individual human lives and of human communities and societies depend on the health of the natural systems that provide essential goods and ecosystem services.</p> <p>Principle II The long-term functioning and health of terrestrial, freshwater, coastal and marine ecosystems are influenced by their relationships with human societies.</p>		
<p><i>CA CCSS Math Connections:</i> 6.EE.6, 6.RP.3, 6.NS.5, 7.EE.4, MP.2, MP.4,</p>		
<p><i>CA ELD Connections:</i> ELD.PI.6.1,5,6 a-b, 9,10,11a</p>		
<p><i>CA CCSSELA/Literacy Connections:</i> RST.6-8.1,7, WHST.6-8.2,8,</p>		

For this IS, 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. Are there **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, <http://we-mss.weebly.com/teacher-resources.html>).

Environment diagrams should be selected so that they include living and nonliving parts of environments (to motivate MS-LS2-3) and illustrate processes that may cause uneven distributions of resources in different environments (to motivate MS-ESS3-1). 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: Daehler and Folsom 2013.

### **Particle Models of Materials in the Environment**

One of the key features of the environment diagrams 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 middle school

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 out of, 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 (sixth grade MS-LS1-1), all of 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 middle and high school. In grade seven, students will include features that:

- particles are always moving,
- particles can interact (including collide, attract, and repel one another), and
- 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.

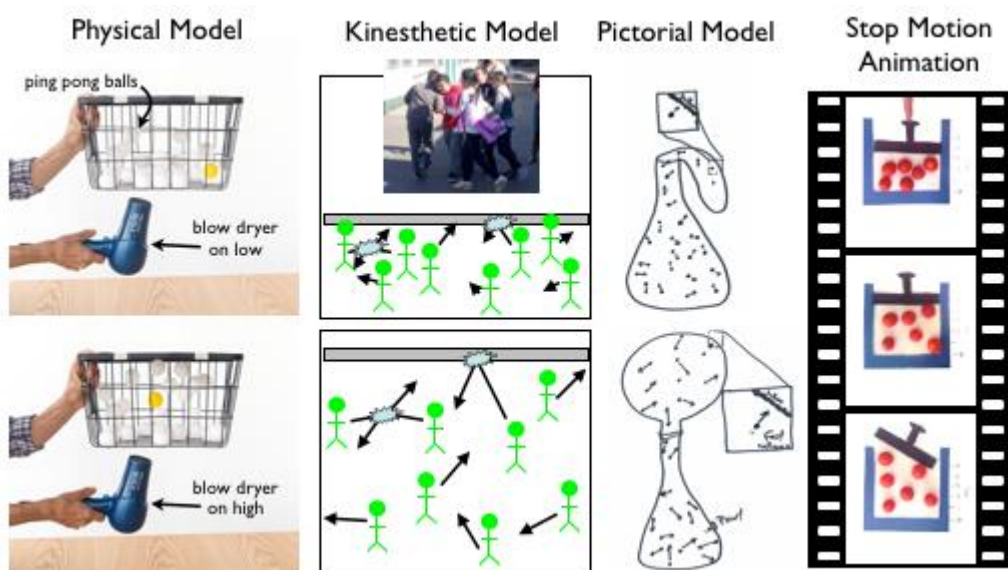
The **structure [CCC-6]** of atoms, the periodic table, and the details of chemical bonding are all addressed in detail when it is developmentally appropriate during high school (HS-PS1-1 through HS-PS1-8). This focus contrasts with the 1998 CA Science Content Standards where the periodic table was introduced in fifth grade and the interior **structure [CCC-6]** of atoms was introduced in eighth grade. 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 name 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 part of the middle grade expectations. 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 IS and then formally introduce the distinction between atoms and molecules near the end.

In Preferred 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, 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 IS 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, the phenomena students should be able explain or predict 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 representation they use to depict their conceptual models can be physical, kinesthetic (using their bodies), pictorial (a diagram), use 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 body 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 a lot of time, and a simple two minute demonstration can sometimes spur model development and revision that takes several class periods. For example, push a cork down to the bottom of a 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

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 quicker 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 collision 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. 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 our 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.). Thinking about water specifically can help this process because students the familiar experience of changing water from one state to another requires only a change in temperature (and therefore kinetic energy of particles). The phenomena that you cannot pull many solids apart is a good cue 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**

<b>Physical State</b>	<b>Particle Perspective</b>	<b>Macroscopic Properties</b>
<p><b>Solid</b></p> <p>State associated with lowest temperatures and/or highest pressures.</p>	<p>Particles have least freedom of motion. Forces of attraction between particles lock them in their local neighborhood where they vibrate in place.</p>	<p>Solids maintain their volume and keep their shape independent of their container.</p>
<p><b>Liquid</b></p> <p>State associated with “moderate” temperatures and/or “moderate” pressures.</p>	<p>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.</p>	<p>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.</p>
<p><b>Gas</b></p> <p>(3) <i>Students fill in this blank space third.</i></p> <p>State associated with high temperatures and/or “low” pressures.</p>	<p>(2) <i>Students fill in this blank space second.</i></p> <p>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.</p>	<p>(1) <i>Students fill in this blank space first, then the middle and lastly the left.</i></p> <p>Gases have no fixed volume and will spread out within any size container.</p>

Given the example of solids and liquids, students can fill out the bottom row of this table 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 change 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 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.).

**Table 5.8. Physical States at Normal Atmospheric Pressure**

ELEMENT	GAS STATE	LIQUID STATE	SOLID STATE
<b>Water</b>	Above 100°C	From 0°C to 100°C	Below 0°C
<b>Copper</b>	Above 2,560°C	From 1,084°C to 2,560°C	Below 1,084°C
<b>Helium</b>	Above -270°C	Below -270°C	Never
<b>Nitrogen</b>	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 participle 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 about whether the behavior of different substances (such as helium, nitrogen, copper) are true or false using evidence about the atomic/molecular composition of matter.

CA CCSS 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 that shows a snow-capped mountain. In grade six, students observed patterns that led them to the ESS 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 PS 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 resist 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 explored matter as particles, they noticed 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 middle school (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 PE 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, and these atoms are common in the non-living parts of the environment as well. Teachers can simulate this process using an interactive web page where students click on objects or using flash cards 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.

## 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:*

**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-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.

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
<p>[SEP-1] Asking Questions and Defining Problems</p> <p>[SEP-2] Developing and Using Models</p> <p>[SEP-3] Planning and Carrying Out Investigations</p> <p>[SEP-6] Constructing Explanations (for science) and Designing Solutions (for engineering)</p> <p>[SEP-7] Engaging in Argument from Evidence</p> <p>[SEP-8] Obtaining, Evaluating, and Communicating Information</p>	<p>LS1.C: Organization for Matter and Energy Flow in Organisms</p> <p>PS1.A: Structure and Properties of Matter</p> <p>PS1.B: Chemical Reactions</p> <p>ESS2.A Earth's Materials and Systems</p> <p>ETS1.A: Defining and Delimiting Engineering Problems</p> <p>ETS1.B: Developing Possible Solutions</p>	<p>[CCC-1] Patterns</p> <p>[CCC-2] Cause and Effect</p> <p>[CCC-4] System and System Models</p> <p>[CCC-5] Energy and Matter: Flows, Cycles, and Conservation</p> <p>[CCC-6] Structure and Function</p>

	<b>ETS1.C: Optimizing the Design Solution</b>	
<p><i>Highlighted California Environmental Principles &amp; Concepts:</i></p> <p>Principle III Natural systems proceed through cycles that humans depend upon, benefit from and can alter.</p> <p>Principle IV The exchange of matter between natural systems and human societies affects the long term functioning of both.</p> <p>Principle V: Decisions affecting resources and natural systems are based on a wide range of considerations and decision-making processes.</p>		
<p><i>CA CCSS Math Connections:</i> 6.EE.9, MP.2, MP.4, 6.SP.4,5, 7.EE.3, 7.SP.7</p>		
<p><i>CA ELD Connections:</i> ELD.PI.6.1,5,6 a-b, 9,10,11a</p>		
<p><i>CA CCSSELA/Literacy Connections:</i> RST.6-8.1,2,3,7, WHST.6-8.2,7,8,9, SL.7.5</p>		

Students have been investigating the relationships between plants and animals since kindergarten (K-LS1-1) and 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's 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:*

**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.**

**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
<p>[SEP-1] Asking Questions and Defining Problems</p> <p>[SEP-2] Developing and Using Models</p> <p>[SEP-3] Planning and Carrying Out Investigations</p> <p>[SEP-7] Engaging in Argument from Evidence</p> <p>[SEP-8] Obtaining, Evaluating, and Communicating Information</p>	<p>LS1.C Organization for Matter and Energy Flow in Organisms</p> <p>PS1.A Structure and Properties of Matter</p> <p>PS1.B Chemical Reactions</p> <p>ETS1.A Defining and Delimiting Engineering Problems</p> <p>ETS1.B Developing Possible Solutions</p> <p>ETS1.C Optimizing the Design Solutions</p>	<p>[CCC-1] Patterns</p> <p>[CCC-2] Cause and Effect</p> <p>[CCC-4] System and System Models</p> <p>[CCC-5] Energy and Matter: Flows, Cycles, and Conservation</p> <p>[CCC-6] Structure and Function</p>
<p><i>Highlighted California Environmental Principles &amp; Concepts:</i></p> <p>Principle III Natural systems proceed through cycles that humans depend upon, benefit</p>		

from and can alter.
Principle IV The exchange of matter between natural systems and human societies affects the long term functioning of both.
<b>Connections to the CA CCSSM:</b> MP. 5
<b>Connections to CA CCSS for ELA/Literacy:</b> RST.6–8.7, 9; SL.7.1
<b>Connections to CA ELD Standards:</b> 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.

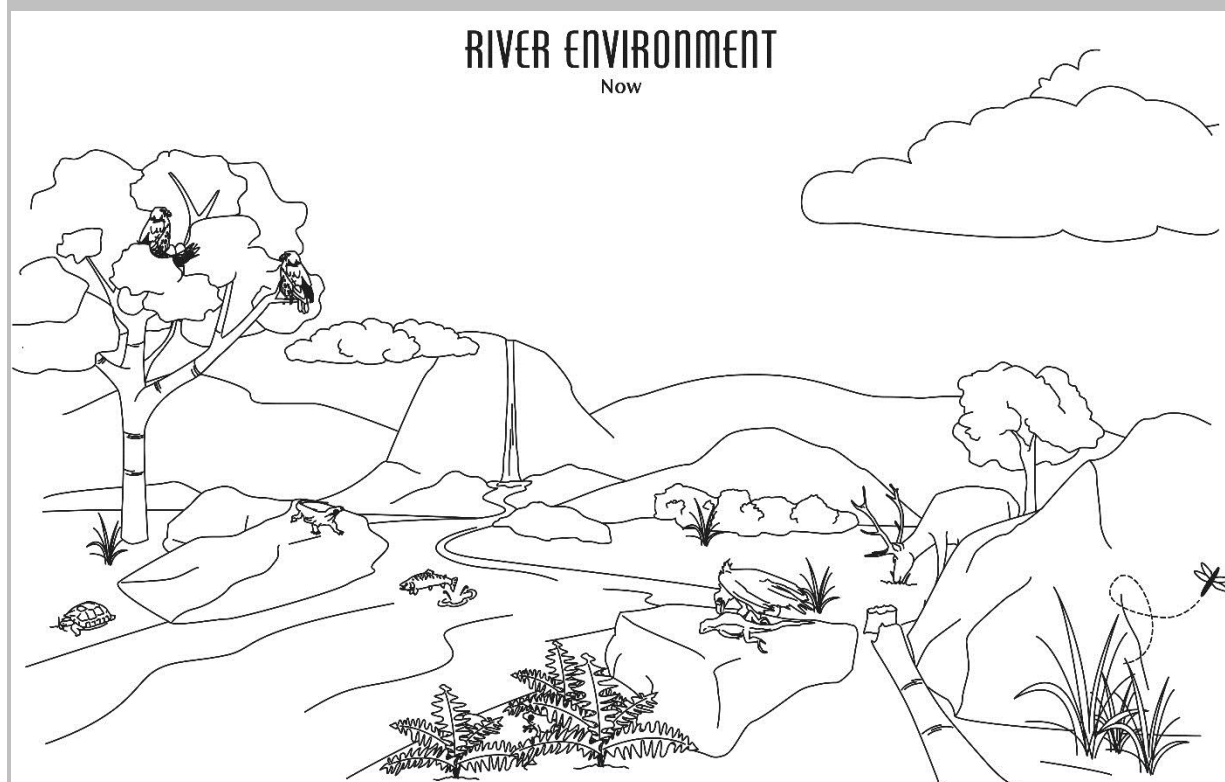
<b><i>Day 1: Classifying changes in a natural environment</i></b>  Students identify changes that happened over 200 years in a river environment and ask questions about the similarities and differences between these changes.	<b><i>Day 2: Identifying and Defining Chemical Changes</i></b>  Students analyze observations of substances before and after they interact to determine features characteristic of chemical changes.	<b><i>Days 3-4: Models of Photosynthesis</i></b>  Students engage in a short engineering design challenge to find an effective physical model for atoms and molecules in the photosynthesis reaction.
<b><i>Day 5: Energy and the chemical reaction of respiration</i></b>  Students struggle with and	<b><i>Days 6-8: “Energy Love” Investigations</i></b>  Students explore hands-on stations with different	<b><i>Day 9: Models of Energy from Food</i></b>  Students grapple with models of the flow of

discuss how to represent energy using their physical model of the respiration reaction.	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.	energy in a chemical system.
<b><i>Days 10-13: Engineering design challenge to quantify energy released</i></b>  Students refine the design of a food calorimeter that converts chemical potential energy into thermal energy.	<b><i>Day 14: Organism energy/matter system diagram</i></b>  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 a new illustration of the same location today (figure 5.28). What has changed?

**Figure 5.28. River Environment**

The previously viewed river environment 200 years later. Adapted from Daehler and Folsom 2013.

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 whole class sharing and reaching 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]** they had about the changes that had happened in the natural environment. In the subsequent whole class sharing and discussions, 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.

### ***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 **analyze [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 that 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<sub>2</sub>O.” 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 sealed bag so that no matter can enter or leave and watch to see if the mass changes. As they found in grade five (MS-PS1-2), the mass remained unchanged for all the changes. “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 share 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 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.

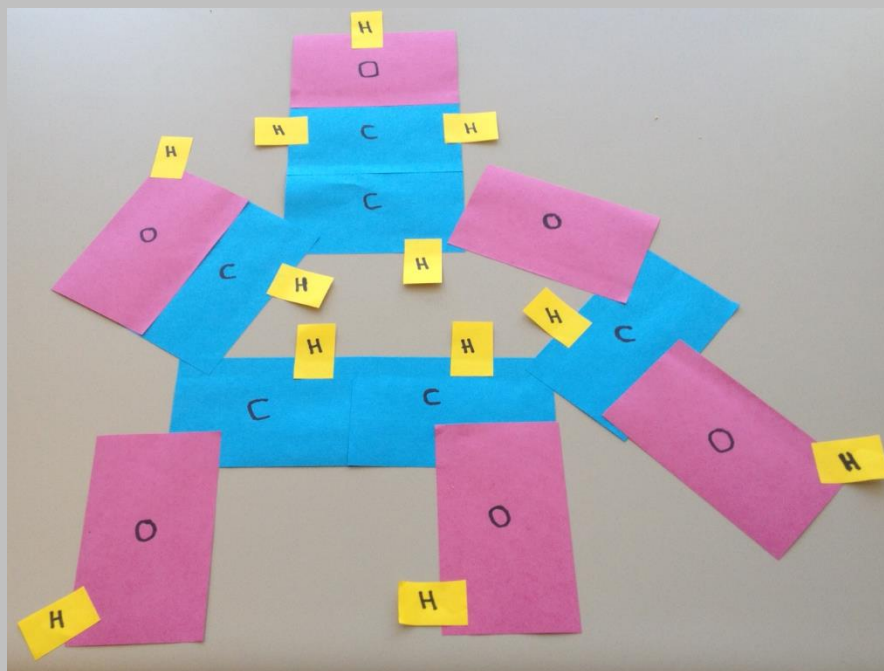
Marco, the reporter for one student group, described how they used a different type of toy brick for each molecule. Most of the other student groups had used a similar type of modeling. Marco explained how their **model [SEP-2]** represented carbon dioxide with the small black brick (“just like coal”), 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 student 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.

**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.

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.

**Day 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 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

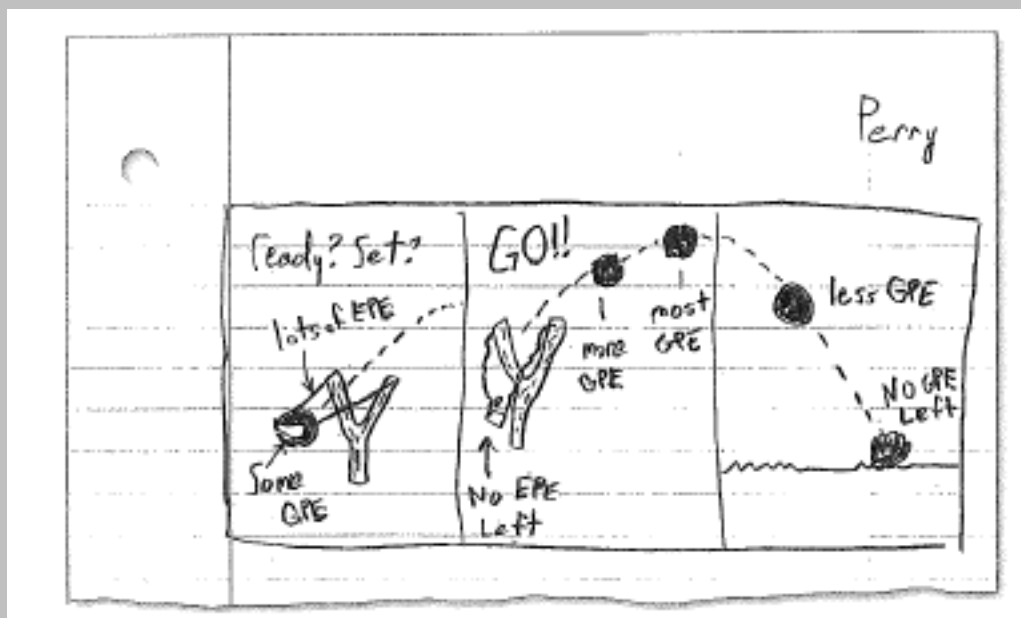
background established, Mr. G steered the class back to the chemical reactions of photosynthesis and respiration.

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: Table based on Daehler, Shinohara, and Folsom 2011a.

**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: Daehler, Shinohara, and Folsom 2011a.

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’s 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 in in cells as food 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 say 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 can 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).



**Figure 5.31. Two Different Categories of Chemical Reactions**

Energy Releasing Reactions	Energy Absorbing Reactions
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.

***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 grade 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 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 shows the students a prototype calorimeter made out of a soda can. Students will 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 are advanced for his middle school students (they complete this activity in the high school Three Course Chemistry in the Earth System course), but Mr. G has set up an interactive spreadsheet where all they do is enter their measurements and they get the estimate of the food's calories content. Mr. G wants the students to optimize this prototype so that it creates 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 need to capture as much of the **energy [CCC-5]** from the food as possible. Safety concerns place constraints on the types of materials they can 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 use the same food with a known calorie content and check to see how well their device reproduces the known value and identify design elements of the calorimeters that worked best (MS-ETS1-3). At the end of the design and testing, students can use their calorimeter to measure the calorie content of other foods. Groups

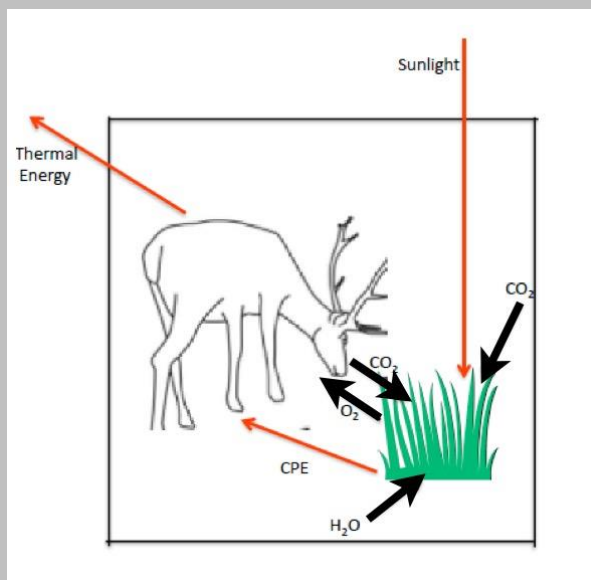
then share posters that **communicate [SEP-8]** their design to their peers. They include diagrams with annotations that describe how the different **structures [CCC-6]** and materials help make the device meet the design criteria.

### ***Day 14 – Organism energy/matter system diagram***

**Investigative Phenomenon:** Animals survive and grow by eating food.

Mr. G told the class they were going to ‘zoom out’ to **cycles of matter and the flows of energy [CCC-5]** from the point of view of whole organisms. He first 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.

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.

**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 black arrows represent matter. CPE is chemical potential energy. Provided by Dr. Art Sussman, courtesy of WestEd.

### Vignette Debrief

In this vignette, the teacher introduced phenomena related to physical and chemical changes via 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 focuses more on lessons that connect 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 CA CCSS and the EP&Cs.

**SEPs.** Students focused on developing models [SEP-2] throughout this vignette, with them spending all of Days 3-4, 8, 9, and 14 on 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 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 v. chemical change’ by having students ‘discover’ the categories themselves and then refining their labels to reflect the current state of scientific vocabulary, rather than beginning with the scientific terminology as a straight definition.

**DCIs.** Chemical reactions (PS2.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 have tracked the flow of matter in elementary school, tracking energy as it changed between various forms is the key addition to

understanding CCC-5 at the middle school level (see the progressions in Appendix 3 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 write up.

*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 are crucial for understanding EPC IV (“The exchange of matter between natural systems and human societies affects the long-term functioning of both.”). Mr. G could easily extend 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 notice 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 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 misconception 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 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 to as 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 cycle through melting and solidifying as they get buried where they warm up as because they are closer to the hot interior, or rise towards the surface where they cool. The movement of rocks upwards 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.

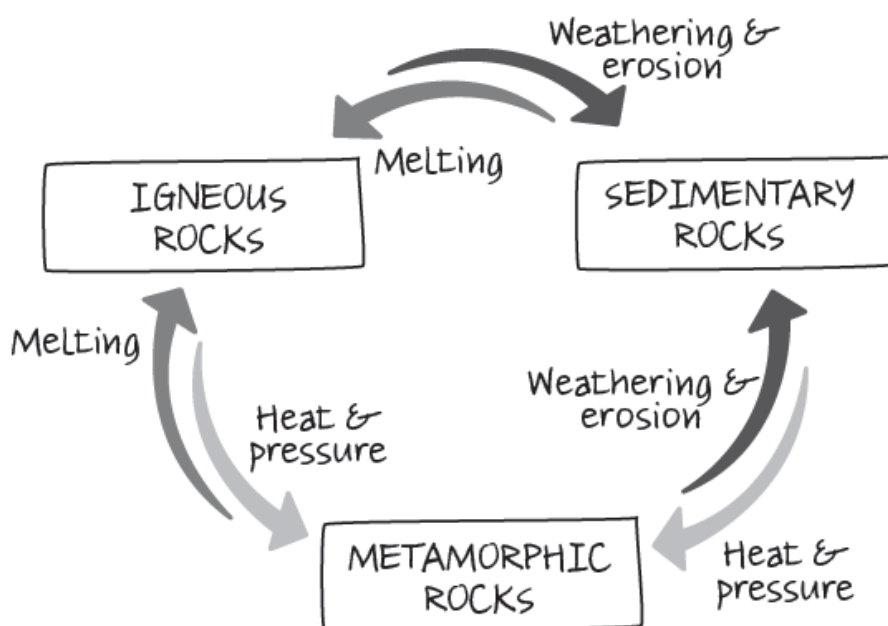
Near the surface, rocks also form and break down by interacting with other Earth systems – namely, the atmosphere, hydrosphere (Earth's water including ice) and biosphere (Earth's life). For example, exposure to air, wind, and biological activity all **cause [CCC-2]** rock to weather (change physically 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.).

**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: Daehler and Folsom 2013.



**Table 5.9. Benefits and Limitations of Classic Rock Cycle Diagram**

Benefits	Limitations
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: Based on Folsom and Daehler 2012.

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 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]**.

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

When students look out a landscape, they might see trees in some places but not others and a gold mine on one hill but not another. In this IS, students focus on explaining why things are located where they are, both organisms within an ecosystem and resources and hazards on the planet. In both cases, interactions within and between different Earth's 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.

<b>Integrated Grade Seven – Instructional Segment 3: Natural Processes and Human Activities Shape Earth's Resources and Ecosystems</b>
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<i>Guiding Questions:</i>
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- |  |
|--|
| <ul style="list-style-type: none"> <li>• How can we use interactions between individual rocks or individual organisms to understand systems as big as the whole geosphere or whole ecosystem?</li> <li>• How can we use patterns in geosphere interactions to predict the location of resources?</li> <li>• How can we use patterns in ecosystem interactions to predict how organisms compete and share resources?</li> </ul> |
|--|

<b>Performance Expectations</b>
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<i>Students who demonstrate understanding can:</i>
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<p><b>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:</b></p>
--

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.]

**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.]

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

Highlighted Science and Engineering Practices	Highlighted Disciplinary Core Ideas	Highlighted Crosscutting Concepts
[SEP-2] Developing and Using Models	LS2.A: Interdependent Relationships in Ecosystems	[CCC-1] Patterns
[SEP-4] Analyzing and Interpreting Data	LS2.B: Cycles of Matter and Energy Transfer in Ecosystems	[CCC-2] Cause and Effect
[SEP-6] Constructing Explanations (for science) and Designing Solutions (for engineering)	ESS2.B: Plate Tectonics and Large Scale System Interactions	[CCC-4] System and System Models
[SEP-8] Obtaining, Evaluating, and Communicating		[CCC-5] Energy and Matter: Flows, Cycles, and Conservation

<b>Information</b>	<b>ESS3.A: Earth's Natural Resources</b>  <b>PS1.B: Chemical Reactions</b>	
<p><i>Highlighted California Environmental Principles &amp; Concepts:</i></p> <p>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.</p> <p>Principle II: The long-term functioning and health of terrestrial, freshwater, coastal and marine ecosystems are influenced by their relationships with human societies.</p> <p>Principle III Natural systems proceed through cycles that humans depend upon, benefit from and can alter.</p> <p>Principle IV The exchange of matter between natural systems and human societies affects the long term functioning of both.</p> <p>Principle V Decisions affecting resources and natural systems are complex and involve many factors.</p>		
<p><i>CA CCSS Math Connections:</i> 6.EE.6,9, 6.SP.4,5, 6.RP.3,7.EE.4, MP.2,</p>		
<p><i>CA ELD Connections:</i> ELD.PI.6.1,5,6 a-b, 9,10,11a</p>		
<p><i>CA CCSSELA/Literacy Connections:</i> RST.6-8.1,2,7,9, WHST.6-8.1,2,9, SL.7.1, SL.7.4, SL.7.5</p>		

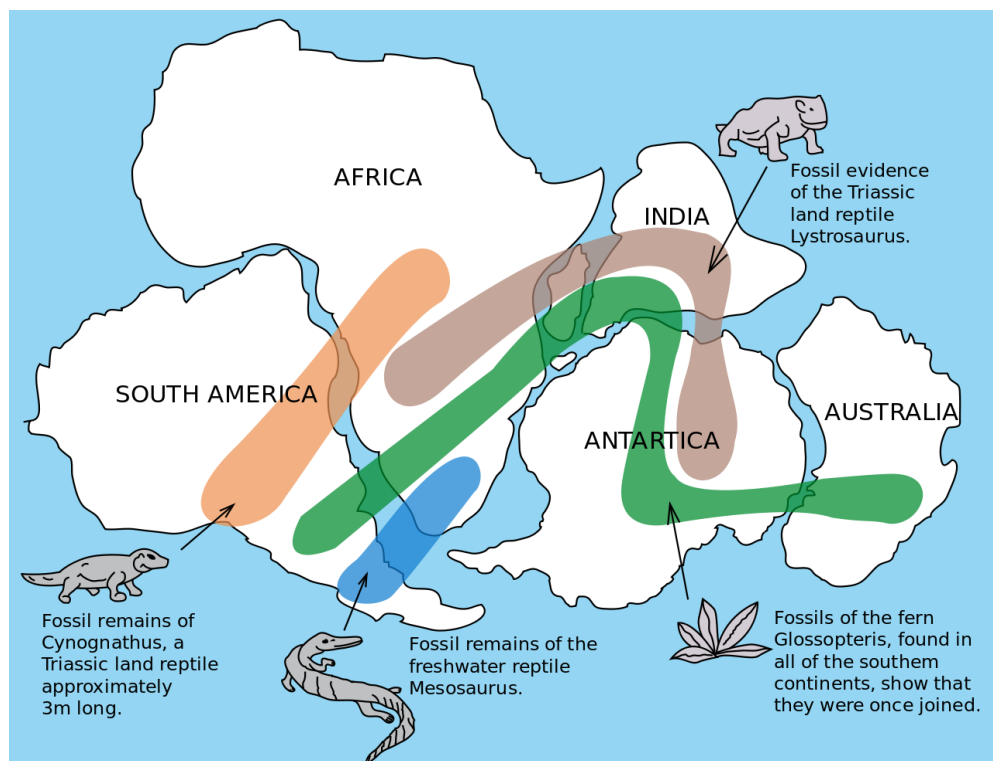
Back in Integrated grade six, students examined a satellite view of California and explained some of the features they saw (figure 5.4). They return to that image and look for evidence of mountains. California has two main mountain ranges, one along the coast and one on the east side. The anchoring phenomenon they consider is that both

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 1900's 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 1900's. Students identify that the rocks in the Appalachian mountains have very similar features to those in the Scottish Highlands; rocks from South African and Brazilian 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 jig-saw 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 where 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

Wegener also traced the past positions and motions of ancient glaciers based on grooves cut by those glaciers in rocks, and also by rock deposits that the glaciers left on different continents. 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 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 prediction [CCC-2]**." Wegener could not propose any possible mechanism that would cause continents to plow through the ocean over great distances. In the absence of a mechanism to cause the proposed movements of continents, the early twentieth century geologists rejected Wegener's claims. Middle school students focus first on **analyzing [SEP-4] the evidence [SEP-7]** accumulated since Wegener's time that provide even more definitive evidence that there has been motion of plates (MS-ESS2-3). 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

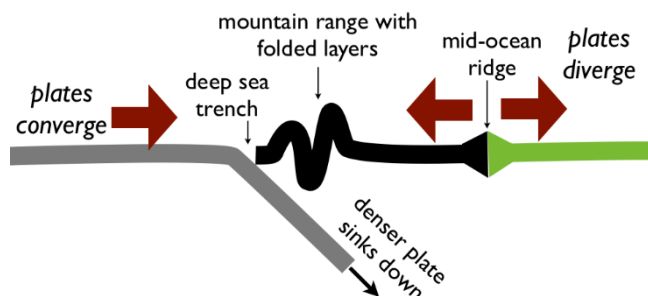
3 km in height above the ocean floor and has a length of about 10,000 km running from a few degrees south of the North Pole down almost all the way to the Antarctic Circle. While basically continuous across a huge part of the planet, it is far from straight. By tracing out the shape of the continental 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 was spreading away uniformly from the Mid-Atlantic Ridge and crashing into the Pacific Ocean on the other side. Seafloor structures also give one more key piece of **evidence [SEP-7]** about plate motions: there are very deep canyons in the ocean that parallel coastlines and island chains in many locations. Just off the west coast of South America, students can notice a very deep trench in the ocean floor. A physical **model [SEP-2]** with two foam blocks (or even notebooks) representing plates helps illustrate why such a trench forms where one of the plates sinks down beneath the other due to density. It is 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

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, the location of deep sea trenches along the coasts of some continents are strong **evidence [SEP-7]** that plates move apart at some locations, together at others, and sliding past one another in other locations. These motions are the driving forces for a wide range of processes that shape earth's surface and cause interactions with the anthroposphere.

### 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 must 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 six 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 US. 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 can pass 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, and 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%. 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 receiving sediment from the Sierra Nevada Mountains. 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 quicker). 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 out their findings.

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

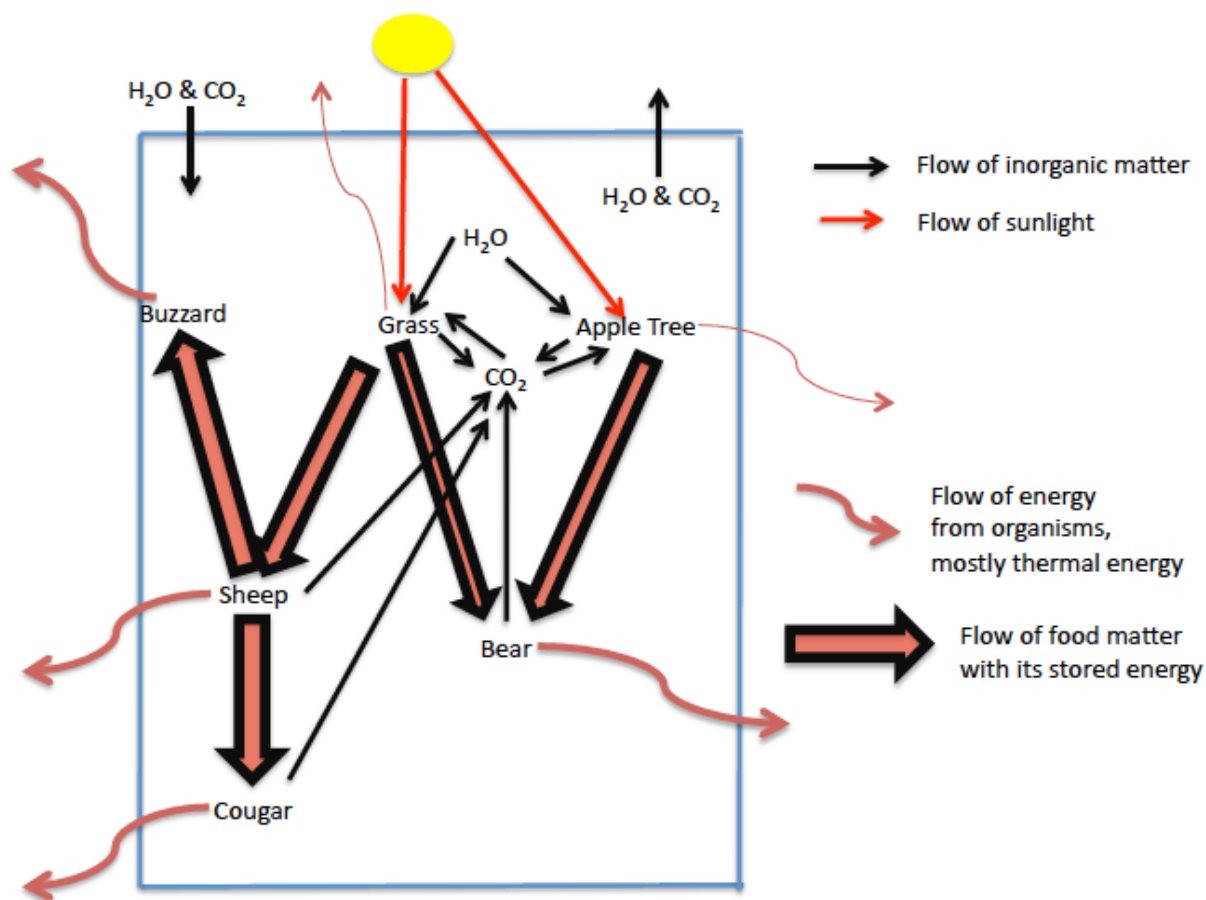
CA ELD Standards: ELD.PI.6–8.3

## Ecosystem Models

Water and other natural resources provide a strong link with the IS3 life science ecosystem PEs 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-5]** 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.

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 due to 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

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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, “Models 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 in order 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 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 (CA EP&C IV).

With their ecosystem model in place, students can fully utilize 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<sub>2</sub> 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 is 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; 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).

## 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
<p><i>Guiding Questions:</i></p> <ul style="list-style-type: none"> <li>• What natural processes and human activities threaten biodiversity and ecosystem services?</li> <li>• How can people help sustain biodiversity and ecosystem services in a changing world?</li> </ul>
Performance Expectations
<p><i>Students who demonstrate understanding can:</i></p> <p><b>MS-LS2-4. Construct an argument supported by empirical evidence that changes to physical or biological components of an ecosystem affect populations.</b> [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.]</p> <p><b>MS-LS2-5. Evaluate competing design solutions for maintaining biodiversity and ecosystem services.*</b> [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.]</p> <p><b>MS-ESS2-2. Construct an explanation based on evidence for how geoscience processes have changed Earth’s surface at</b></p>

**varying time and spatial scales.** [Clarification Statement:

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

**MS-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.

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

<p><b>Highlighted</b></p> <p><b>Science and Engineering Practices</b></p>	<p><b>Highlighted</b></p> <p><b>Disciplinary Core Ideas</b></p>	<p><b>Highlighted</b></p> <p><b>Crosscutting Concepts</b></p>
<p><b>[SEP-1] Asking Questions and Defining Problems</b></p> <p><b>[SEP-2] Developing</b></p>	<p><b>LS2.C Ecosystem Dynamics, Functioning and Resilience</b></p> <p><b>LS4.D Biodiversity and</b></p>	<p><b>[CCC-2] Cause and Effect</b></p> <p><b>[CCC-4] System and System Models</b></p>

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<p><b>and Using Models</b></p> <p><b>[SEP-3] Planning and Carrying Out Investigations</b></p>	<p><b>Humans</b></p> <p><b>ESS2.A Earth Materials and Systems</b></p> <p><b>ESS2.C Roles of Water in Earth’s Surface Processes</b></p> <p><b>ESS3.A Natural Resources</b></p> <p><b>ESS3.B Natural Hazards</b></p> <p><b>PS1.B: Structure and Properties of Matter</b></p> <p><b>ETS1.A: Defining and Delimiting Engineering Problems</b></p> <p><b>ETS1.B: Developing Possible Solutions</b></p>	<p><b>[CCC-5] Energy and Matter: Flows, Cycles, and Conservation</b></p>
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<i>Highlighted California Environmental Principles &amp; Concepts:</i>		
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.		
<i>CA CCSS Math Connections:</i> MP.2, MP.4, 6.EE.6, 6.RP.3, 7.EE.4		
<i>CA ELD Connections:</i> ELD.PI.6.1,5,6 a-b, 9,10,11a		
<i>CA CCSSELA/Literacy Connections:</i> RI.7.8, RST.6-8.1,7,8, WHST.6-8.1,2,9, SL.7.5,		

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 IS, and they do not just

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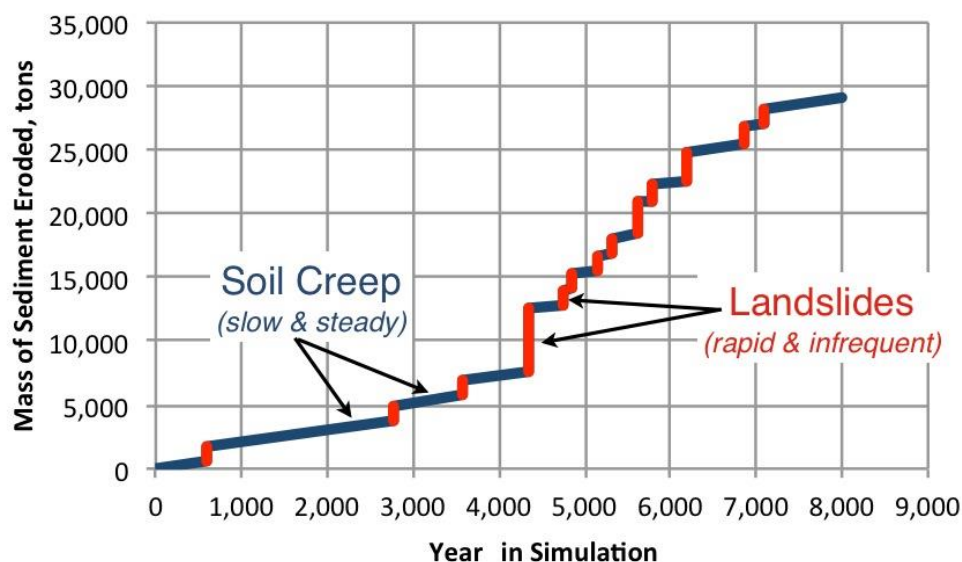
happen during earthquakes. Over just three days in 1982, heavy rains triggered more than 18,000 landslides in the San Francisco Bay Area (USGS 1988) and landslides following wildfire are a constant concern throughout the state. After students **obtain information [SEP-8]** about these mega landslide 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 an anchored netting, but roots also have a competing effect where they weaken material by breaking rocks apart. In some situations, the latter may

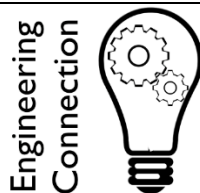
become more important than the former. Students have to struggle with this apparent contradiction and add both processes into their model of landslides.

The clarification statement for MS-ESS2-2 emphasizes one of the key ESS DCIs for middle school 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 how much sediment moved by slow and steady processes like soil creep and how much by rapid and infrequent landslides over 8,000 years. 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.



### 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, <http://landslides.usgs.gov/hazards/warningsys.php>). 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 Mt. 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 grade 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, the three Concepts associated with Principle III are:

- 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 that is vital for life exists on Earth in a closed loop of cyclical changes.

The environmental human impacts that students explore throughout middle school 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 (CA 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 like 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 decides 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 begin 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 must provide **examples and reasoning [SEP-7]** about how these different components can **affect [CCC-2]** the population of organisms (MS-LS2-4); their reasoning refers 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).

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, including:

- 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 realize that both ‘natural’ and a ‘disturbed’ ecosystems are changing, and hope to be able to document how the rates of natural **change [CCC-7]** compare to the rates of human-induced changes (ESS3.C). Mr. R shares these questions with the volunteers at a local nature center that try to help him prepare the investigation. Mr. R can’t make the logistics work out this year, but he puts his wheels in motion about how to set things up for next year. Even if it never works out, Mr. R decides that the activity of planning the investigation is very worthwhile for his students. He thinks about how to frame the activity next year so that it feels authentic but so that the students won’t feel disappointed if they can’t actually implement their project. His goal is to eventually get students to 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 CA NGSS in grade eight according to the Preferred Integrated Learning Progression 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.

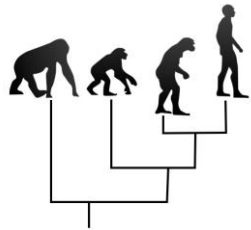

A primary goal of this section is to provide an example of how to bundle the PEs into integrated groups that can effectively guide instruction in four sequential IS. There is no prescription regarding the relative amount of time to be spent on each IS. As shown in figure 5.38, the overarching guiding 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's systems at different spatial scales today also caused changes in the past.

IS		Life Science	Earth & Space Sciences	Physical Science	Engineering, Technology, and Applications to Science
1	<b><i>Objects move and collide.</i></b>				
	 <p>Source: Ninjatacoshell 2009</p>	Living systems are affected by physical changes in the environment. Both the physical and biological changes are recorded in the fossil record.	The fossil record documents the existence, diversity, extinction, and change of life forms throughout Earth's history.	<p>Newton's Laws explain the forces and motions of objects on Earth and in space.</p> <p>Velocity and mass determine the results of collisions between objects.</p>	<p>Design Criteria</p> <p>Evaluate Solutions</p> <p>Analyze data</p> <p>Iteratively test and modify</p>
2	<b><i>Noncontact forces influence phenomena locally and in the solar system</i></b>				
	 <p>Source: Gemini Observatory 2008</p>		<p>Models explain lunar phases and eclipses of the Sun and Moon.</p> <p>Gravity plays the major role in determining motions with the solar system and galaxies.</p>	<p>Gravitational and electromagnetic fields are the basis of noncontact forces.</p> <p>Changing the arrangement of objects in a system affects the potential energy stored in that system.</p>	

3	<b><i>Evolution explains life's unity and diversity.</i></b>				
	 <p>Source: Adapted from Tkgd2007 2008</p>	<p>Mutations in genes affect organisms' structures and functions.</p> <p>Evidence from fossils, anatomy, and embryos support the theory of biological evolution.</p> <p>Natural selection is the main mechanism that leads to evolution of species that are adapted to their environment.</p>	<p>Rock layers record Earth's history like pages in a book.</p>	<p>Chemical reactions make new substances.</p> <p>Mass is conserved in physical changes and chemical reactions.</p>	
4	<b><i>Human activities help sustain biodiversity and ecosystem services in a changing world.</i></b>				
	 <p>Source: Environmental Management 2016 Wiki 2016</p>	<p>Changes to environments can affect probabilities of survival and reproduction of individual organisms, which can result in significant changes to populations and species.</p>	<p>Annual cycles in the amount of sunlight absorbed cause Earth's seasons.</p> <p>Increases in human population and per-capita consumption impact Earth's systems.</p>	<p>Waves are reflected, absorbed, or transmitted through various materials.</p> <p>Wave-based digital technologies provide very reliable ways to encode and transmit information.</p>	<p>Design criteria</p> <p>Evaluate solutions</p>

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

Integration within each IS 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 IS tells a coherent story that generally includes two or more science disciplines that meaningfully connect with each other within that IS (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). IS1 and IS4 also feature engineering design intimately connected with the IS science concepts.

Perhaps the most important perspective with respect to Integrated Grade Eight is that it serves as a capstone for the middle school grade 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 SEPs and unifying concepts that students experience and apply in CA NGSS middle grades science.

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

<b>Integrated Grade Eight – Instructional Segment 1: Objects Move and Collide</b>
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*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?

<b>Performance Expectations</b>
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*Students who demonstrate understanding can:*

**MS-LS4-1. Analyze and interpret data for patterns in the fossil record that document the existence, diversity, extinction, and change of life forms throughout the history of life on Earth under the assumption that natural laws operate today as in the past.**

[Clarification Statement: Emphasis is on finding patterns of changes in the level of complexity of anatomical structures in organisms and the chronological order of fossil appearance in the rock layers.] [Assessment Boundary: Assessment does not include the names of individual species or geological eras in the fossil record.]

**MS-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.**

**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.

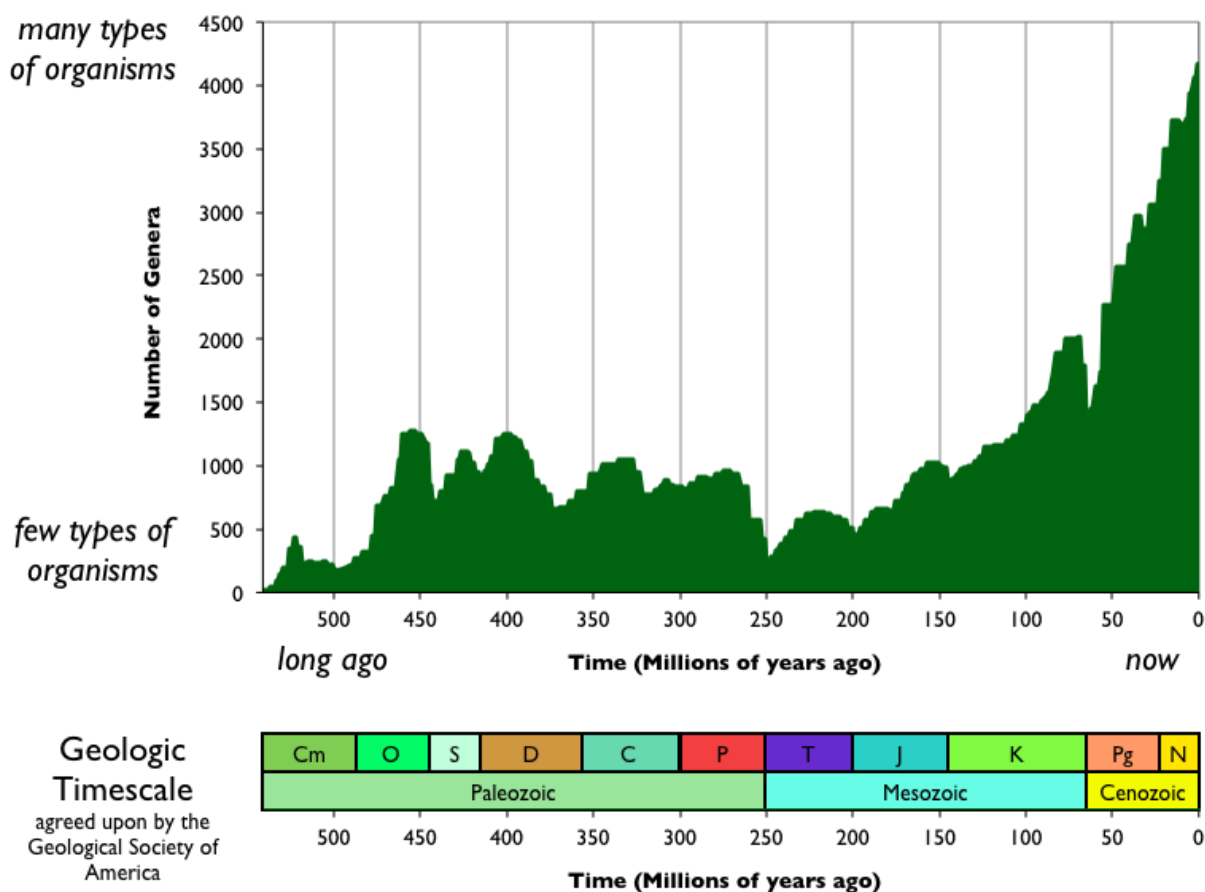
The bundle of performance expectations above focuses on the following elements from the NRC document *A Framework for K–12 Science Education*:

Highlighted Science and Engineering Practices	Highlighted Disciplinary Core Ideas	Highlighted Crosscutting Concepts
[SEP-1] Asking Questions and Defining Problems	LS4.A Evidence of Common Ancestry and Diversity	[CCC-1] Patterns
[SEP-2] Developing and Using Models	PS2.A Forces and Motion	[CCC-2] Cause and Effect
[SEP-3] Planning and Carrying Out Investigations	PS2.B Types of Interactions	[CCC-4] System and System Models
[SEP-4] Analyzing and		[CCC-5] Energy and

<b>Interpreting Data</b>  <b>[SEP-6] Constructing Explanations (for science) and Designing Solutions (for engineering)</b>  <b>[SEP-7] Engaging in Argument from Evidence</b>  <b>[SEP-8] Obtaining, Evaluating, and Communicating Information</b>	<b>PS3.A Definitions of Energy</b>  <b>ETS1.A Defining and Delimiting Engineering Problems</b>  <b>ETS1.B Developing Possible Solutions</b>  <b>ETS1.C Optimizing the Design Solution</b>	<b>Matter: Flows, Cycles, and Conservation</b>
<i>Highlighted California Environmental Principles &amp; Concepts:</i>		
<p>Principle II The long-term functioning and health of terrestrial, freshwater, coastal and marine ecosystems are influenced by their relationships with human societies.</p> <p>Principle V Decisions affecting resources and natural systems are complex and involve many factors.</p>		
<i>CA CCSS Math Connections:</i> 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,		
<i>CA ELD Connections:</i> ELD.PI.6.1,5,6 a-b, 9,10,11a		
<i>CA CCSSELA/Literacy Connections:</i> RST.6-8.1,3,7,9, WHST.6-8.7,8,9, SL.8.5,		

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 IS, but understanding this phenomena 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 live. 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?



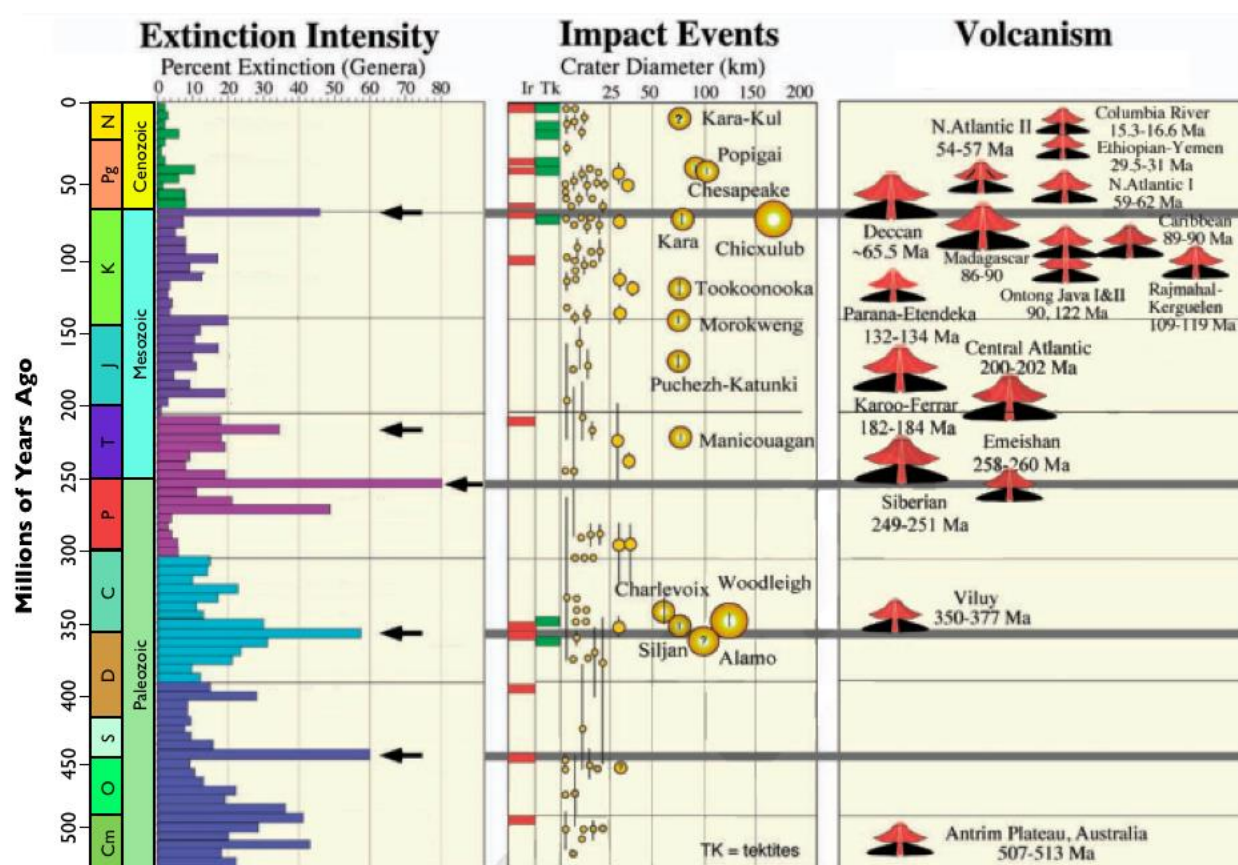
**Figure 5.39. Number of Types of Marine Animals from the Last 542 Million Years**

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.

Students brainstorm possible causes of extinction events. Even if students 'know' what caused the extinction of the dinosaurs from their prior knowledge, are all extinction events all caused by the same process? 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. 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 exists

to supports many competing ideas (figure 5.40) and leads to viable arguments that could explain each extinction event and 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.

One likely mechanism that explains some mass extinctions is the impact of a large asteroid that causes 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 IS that focuses on PS 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 ESS phenomena of an asteroid impact and asking questions about the speed of the impactor, Ms. Z focuses on the PS DCIs about

motion. Ms. Z’s students just finished activities where they described motion in terms of speed. She decides to use free Forces and Motion education animations (see <https://phet.colorado.edu/en/simulation/forces-and-motion-basics>) 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 begins by showing students a toy car and asking them to explain in words why the car is not moving. Some students have good ideas, but many struggle to find the right words to express the answer to this seemingly obvious question. She connects to students’ investigations from grade three with balanced forces (3-PS2-1). Using an example of a toy car, she writes 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 asks students why she emphasizes the phrase, “at that instant.”

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

Having established some background, she instructs the students to work individually or with a partner to explore their assigned animation, such that one-third of the class explores one of the three animations (Motion; Friction; Acceleration). They record in their notebooks what they do, any conclusions they reach, and any questions the animation raises.

In the succeeding days, class sessions focus on the animations in the order of Motion, then Friction, and finally Acceleration. As the students present, they or Ms. Z use 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 agree 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]** result 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 are 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 IS 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 PEs for eighth grade 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 where 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.cabrillo.edu/~dbrown/tracker/>), use a motion sensor probe, or use computer simulations.

From a mathematics 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 can still retain preconceptions such as 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.

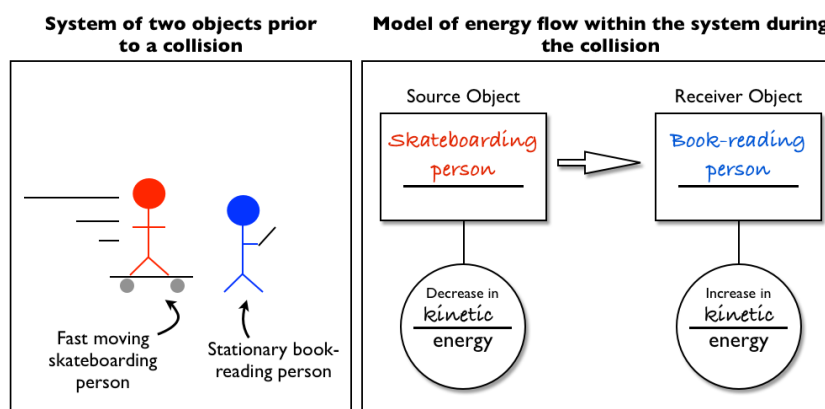
The **energy [CCC-5]** perspective can help students understand why objects slow down. The kick transferred kinetic energy from the foot to the soccer ball. If no interactions remove kinetic energy from the soccer ball, it makes sense that the ball will keep moving at the same speed in the same direction. 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



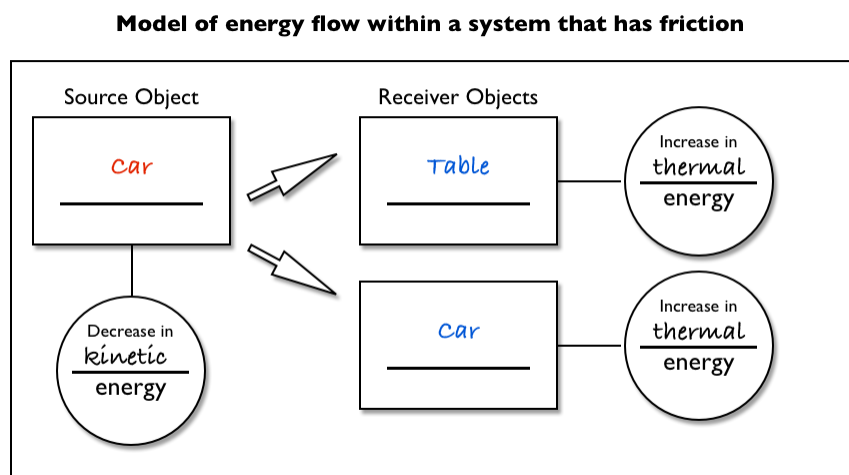
kinetic energy should speed up). Students can use these types of diagrammatic models to illustrate transfers of energy.

**Figure 5.41. Energy Transfer in a Collision**



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

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 some of the energy must go somewhere. 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.

With some 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.). In order to measure consistent

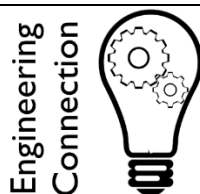


**patterns [CCC-1]**, students will need to **plan their investigation [SEP-3]** (MS-PS2-2) such that the source object has a consistent speed (by rolling down a ramp of a fixed distance, for example). This procedure will ensure that the initial kinetic energy is constant and lead to a consistent force 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 PE 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: Collisions

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 PE 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 that 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 PE 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 from the K-T boundary. 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 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 school grade span. 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 Grades Six and 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.

Utilizing this CCC throughout the middle grade span 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 Preferred Integrated model is that students see how understanding one discipline can enhance understanding in others.

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

## **Integrated Grade Eight Instructional Segment 2: Noncontact Forces Influence Phenomena**

Many phenomena are controlled by forces that do not touch. 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 has waited 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:*

**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.]

**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*:

<div> <p><b>Highlighted</b></p> <p><b>Science and Engineering Practices</b></p> </div>	<div> <p><b>Highlighted</b></p> <p><b>Disciplinary Core Ideas</b></p> </div>	<div> <p><b>Highlighted</b></p> <p><b>Crosscutting Concepts</b></p> </div>
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<b>[SEP-1] Asking Questions and Defining Problems</b>	<b>ESS1.A: The Universe and Its Stars</b>	<b>[CCC-1] Patterns</b>
<b>[SEP-2] Developing and Using Models</b>	<b>ESS1.B: Earth and the Solar System</b>	<b>[CCC-2] Cause and Effect</b>
<b>[SEP-3] Planning and Carrying Out Investigations</b>	<b>PS2.B: Types of Interactions</b>	<b>[CCC-4] System and System Models</b>
<b>[SEP-4] Analyzing and Interpreting Data</b>		<b>[CCC-5] Energy and Matter: Flows, Cycles, and Conservation</b>
<b>[SEP-5] Using mathematics and Computational Thinking</b>		
<b>[SEP-6] Constructing Explanations (for science) and Designing Solutions (for engineering)</b>		
<b>[SEP-7] Engaging in Argument from Evidence</b>		
<b>[SEP-8] Obtaining,</b>		



<b>Evaluating, and Communicating Information</b>		
<i>CA CCSS Math Connections:</i> 6.RP.1, 6.EE.2,6, 7.RP.2, 7.EE.3,4, MP.2, MP.4,		
<i>CA ELD Connections:</i> ELD.PI.6.1,5,6 a-b, 9,10,11a		
<i>CA CCSSELA/Literacy Connections:</i> RST.6-8.1,3,7, WHST.6-8.1,7, SL.8.5,		

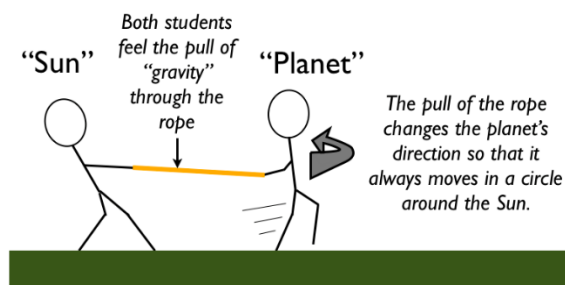
One of the biggest challenges of studying non-contact forces is that it is difficult to visualize them. How do you see the invisible? In fact, one of the challenges that students must meet in the CA NGSS is to **plan investigations [SEP-3]** that provide evidence that fields exist between objects interacting through non-contact 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 IS, 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, but how does a force that draws things together cause 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 IS, 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 towards 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 he or she moves 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.

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 <http://spaceplace.nasa.gov/how-orbits-work/en/>).

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 science 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 have, with larger masses causing stronger pulls. Because of the huge masses of planets, stars and galaxies, 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.

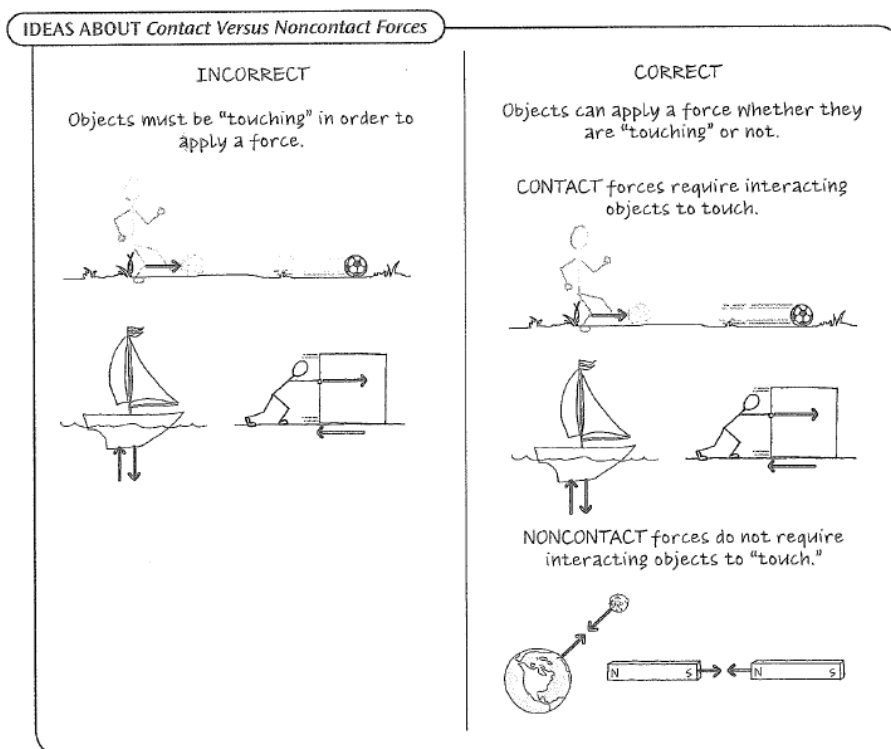
Typically in educational settings, students have been presented with established models that resulted from decades or centuries of observations and investigations. Over those long periods of time scientists developed, argued about and revised models to explain observed phenomena, and they made predictions 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 current consensus completed models. 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 eighth grade, middle school students have been 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 the 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 towards the planet itself. 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 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://phet.colorado.edu/sims/html/gravity-force-lab/latest/gravity-force-lab\\_en.html](https://phet.colorado.edu/sims/html/gravity-force-lab/latest/gravity-force-lab_en.html)). Students can apply their knowledge of gravitational forces to simulations of much more complex planetary systems (Test Tube Games, <http://www.testtubegames.com/gravity.html>) 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: Daehler, Shinohara, and Folsom 2011b.

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 <http://www.amnh.org/explore/science->

[bulletins/earth/documentaries/grace-tracking-water-from-space/article-grace-watches-earth-s-water](#)).

### 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 middle school 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.

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

CA ELD Standards: ELD.PI.6–8.9

### Non-contact Forces and Energy

MS-PS3-2 connects these **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 had 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..

**Table 5.10. Forms of Energy**

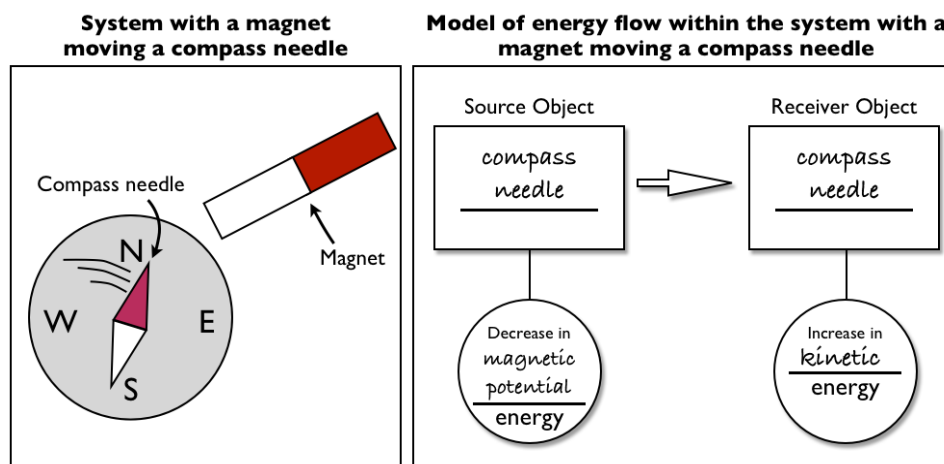
<b>ENERGY OF MOTION</b>  Energy due to the motion of matter	<b>ENERGY OF POSITION</b>  Energy due to the relative positions of matter
Kinetic Energy  Thermal Energy [often called Heat Energy]  Light Energy  Sound Energy  Electrical Energy	Gravitational Potential Energy  Elastic Potential Energy  Chemical Potential Energy  Magnetic Potential Energy  Electrostatic Potential Energy

Source: Daehler, Shinohara, and Folsom 2011a.



Unlike gravitational fields around stars and planets that are hard to visualize, students can easily **collect data [SEP-8]** about position and orientation of iron filings contained within 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.

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 school grade 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 school physical science PEs 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. Students benefit from far better images from satellites. They investigate images of its surface features and snapshots of eruption plumes and discover evidence for Io's active volcanism. They collect and **compare data [SEP-4]** about the size of volcanoes and eruptions on Io to those on Earth (MS-ESS1-3) and use their findings to support the claim that Io is the most volcanically active body in the solar system. Students look at thermal infrared images of Io and see 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 school level. It focuses on the idea of energy transfer without dwelling on the complex details. After reading the article, Mr. J instructs students to draw diagrams that model the **flow of energy [CCC-5]** in these **systems [CCC-4]**.

Over the next several days, they explore each of these possible mechanisms. The article emphasizes that all three mechanisms **cause [CCC-2]** some heating of Io. In middle school, 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 middle school students are expected to explore magnetic fields in the CA NGSS. The students **analyze [SEP-4]** the magnetic field strength recorded by a satellite as it passes close to the Jupiter and **ask questions [SEP-1]** about the factors that affect the strength (MS-PS2-3).

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

The article describes how Io receives energy from constant pulling by Jupiter and its other moons. Students use a virtual telescope simulator to examine the orbits of Io and the other moons of Jupiter and discover that Io's orbital period is exactly half that of Europa and one fourth of Ganymede. Students use this evidence to **support the claim [SEP-7]** that the planets interact with one another through gravity (MS-PS2-4). They draw diagrams with arrows that indicate the direction of gravitational attraction between the moons at different snapshots in time where they have different relative positions. They use these **models [SEP-2]** to describe how the moons affect one another's motion (MS-ESS1-2). Students also use 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 end 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 asks them to predict what the time interval might be for each of the mechanisms. He scaffolds the discussion and directs 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 **analyze data [SEP-4]** to determine the actual time interval between eruptive peaks (Rathbun et al. 2002). They find 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 draws explicitly draws attention to the importance of time **scale [CCC-3]**, noting that students are 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 remains a mystery to the students!

### **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 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:*

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

events within them.]

**MS-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 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.]

\*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	ESS1.C The History of Planet Earth	[CCC-1] Patterns
[SEP-2] Developing and Using Models	LS3.A Inheritance of Traits	[CCC-2] Cause and Effect
[SEP-3] Planning and Carrying Out Investigations	LS3.A Variation of Traits	[CCC-3] Scale, Proportion, and Quantity
[SEP-4] Analyzing and Interpreting Data	LS4.A Evidence of Common Ancestry and Diversity	[CCC-4] System and System Models
[SEP-5] Using Mathematics and Computational Thinking	LS4.B Natural Selection	[CCC-6] Structure and Function
[SEP-6] Constructing Explanations (for	LS4.C Adaptation	[CCC-7] Stability and Change

<b>science) and Designing Solutions (for engineering)</b>  <b>[SEP-7] Engaging in Argument from Evidence</b>  <b>[SEP-8] Obtaining, Evaluating, and Communicating Information</b>		
<i>Highlighted California Environmental Principles &amp; Concepts:</i>  Principle II The long-term functioning and health of terrestrial, freshwater, coastal and marine ecosystems are influenced by their relationships with human societies.		
<i>CA CCSS Math Connections:</i> 6.RP.1, 6.SP.5, 6.EE.6, 7.RP.2, MP.4,		
<i>CA ELD Connections:</i> ELD.PI.6.1,5,6 a-b, 9,10,11a		
<i>CA CCSSELA/Literacy Connections:</i> RST.6-8.1,4,7,9, WHST.6-8.2,8,9, SL.8.1,4,5		

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 IS, students will consider that very few dinosaur fossils are found in rock layers slightly below the K-T impact boundary (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 school 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 5.2). 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 5.2. 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 pm on December 31

Source: Information from Sussman 2006.

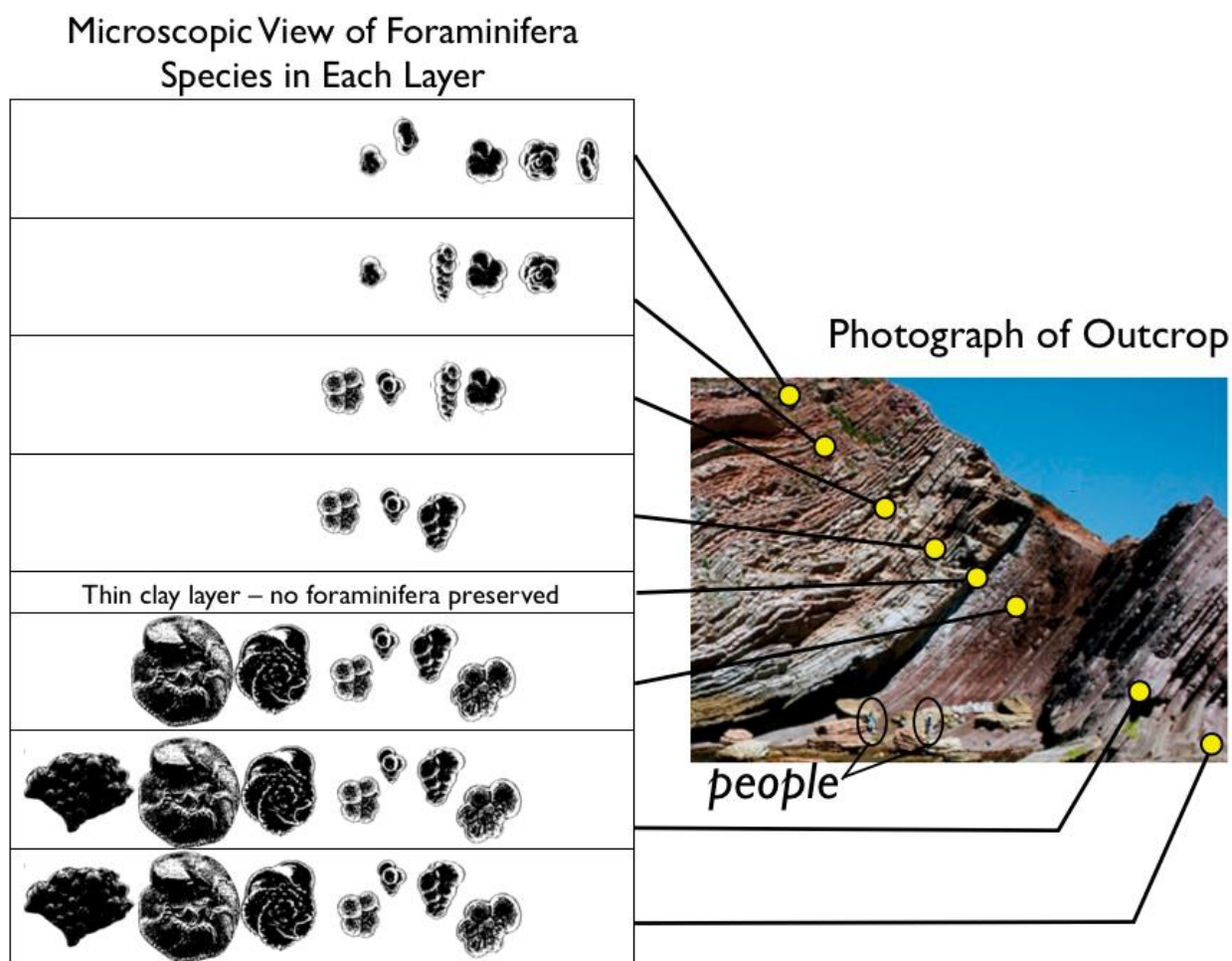
The clarification statement for MS-ESS1-4 indicates that the emphasis of this PE is not on the geologic timescale itself, but rather how different evolutionary and geologic events are put into a sequence using evidence from rock strata. Students identified patterns in rock layers and used them to interpret 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 record 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 5.2 (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, <http://education.usgs.gov/lessons/schoolyard/CoolGeologyActivity.html>). 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.

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 die 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 IS shifts to LS 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.

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

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's systems and interactions between them, but 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 know about how environmental changes impact living things, Ms. Q starts 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?

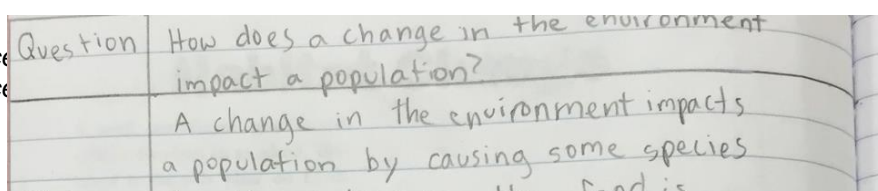
**Anchoring phenomenon:** Finches on the Galapagos Islands have different size and shape beaks.

Ms. Q introduces 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 asks students to record observations of the finches and questions they have about them. She then presents students with a page from Darwin's ornithological notes (where Darwin describes his confusion over the birds). She asks 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 engage in the Clipbird activity (Janulaw and Scotchmoor 2011). In this hands-on simulation, students use 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 separates two different populations of birds. Each population begins 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' diverges on the two sides of the mountains and the food supply changes. Before actually acting out the simulation each season, students predict the outcome knowing the food supply. After season four, students **construct an explanation [SEP-6]**, using **cause and effect [CCC-2]** evidence to address the question: how does change in the climate impact each population (MS-LS4-4, MS-LS4-6)? They write in their notebooks, share with their team, and finally revise their thinking as appropriate and construct a single team explanation (figure 5.48).

**Figure 5.48: Preliminary Student Explanation of the Clipbird Scenario**





Source: Photo provided by Jill Grace

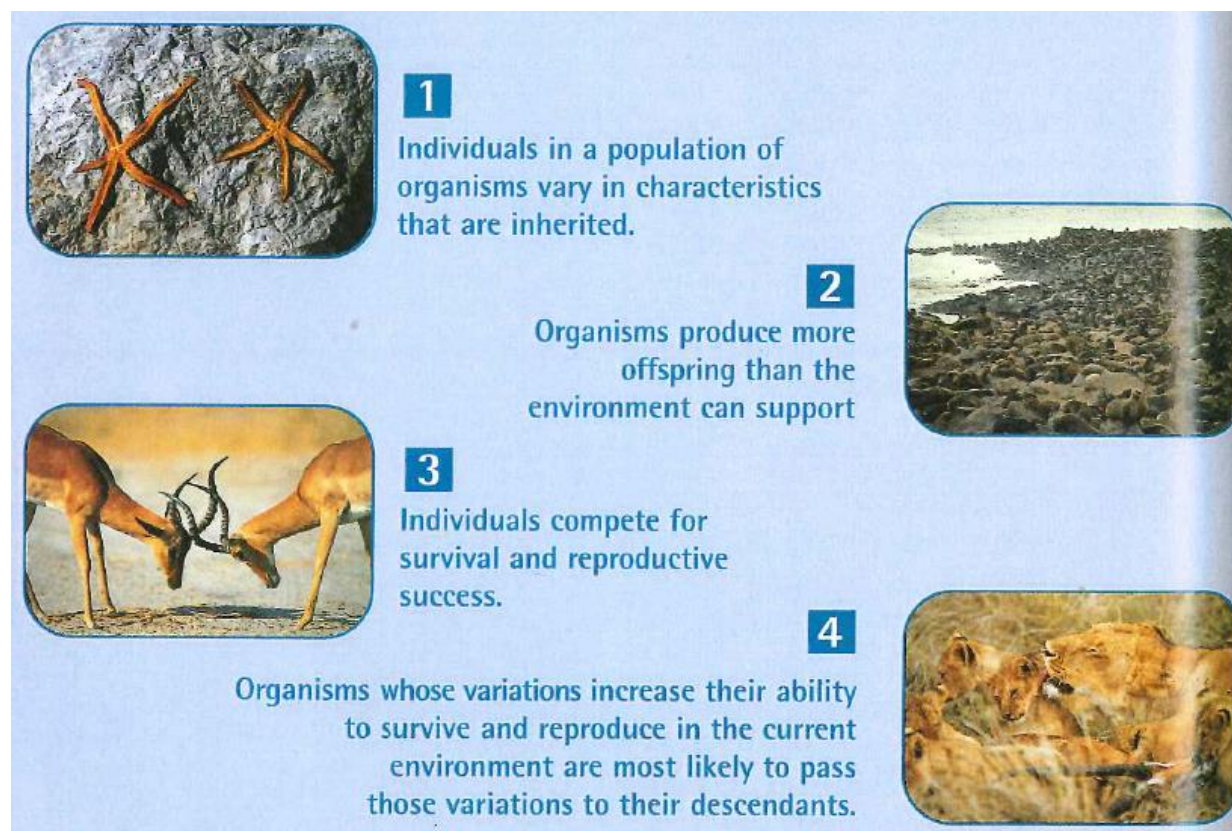
The following day, Ms. Q asks her students to think of ways they can be more certain or “sure” that their **explanation [SEP-6]** is accurate. This eventually leads to a discussion of sample size, and Ms. Q presents the students with data from all of her classes. She asks the students to consider ways in which the data can be displayed to better understand it, and students agree they should combine and then graph the data. **Organizing and presenting the data [SEP-4]** in a visual form (graph) helps students

make sense of the information and enables them to discuss and work with their team to **review and revise their explanations [SEP-4]** through the lens of **cause and effect [CCC-2]**.

How would the populations change after 100 generations or even 1,000? Ms. Q informs the class that their simulation is based on an actual study by scientists and they can observe the effects. She spends the next several days exploring actual data from Grant and Grant (2014) and media resources (Howard Hughes Medical Institute 2014), including articles that describe 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 Science 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 5.49Figure 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: Sussman 2006.

Darwin lived in England in the mid- to late 1800's. His country led the world in advancements of geologic ideas, 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 depend 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 of the CCC of **stability and change [CCC-7]**. By the end of

middle school, they 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 life 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 provides a tangible example where 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 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 internet resources (e.g., Weed to Wonder: Domestication, <http://www.weedtowonder.org/domestication.html>) 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 (<http://www.hhmi.org/biointeractive/popped-secret-mysterious-origin-corn>) 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 by competition in changing environments.

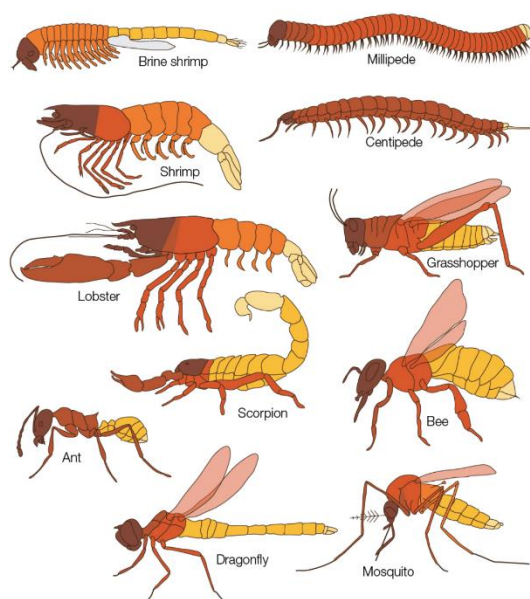
### **What Causes Variation?**

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, is 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**



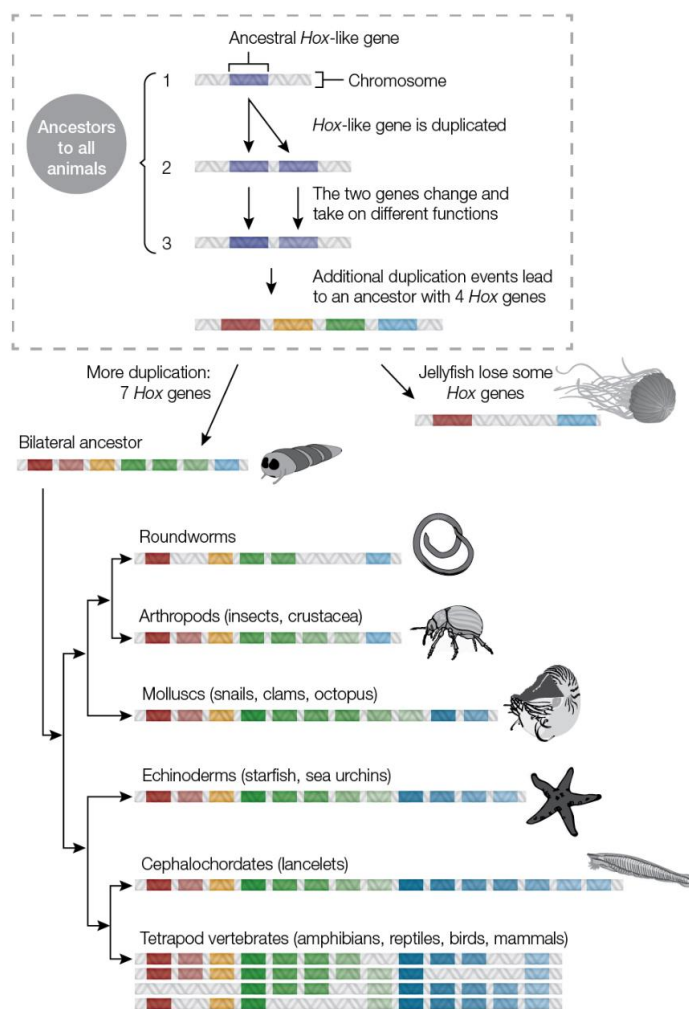
Source: Genetic Science Learning Center, University of Utah N.d.

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: Genetic Science Learning Center, University of Utah N.d.

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.nsta.org/publications/press/extras/files/virus/Virus-Activity1.pdf>). 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 5.3). 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 5.3. Possible Results of a Mutation**

<b>(A Change in the Sequence of DNA Letters)</b>		
<b>Type of Mutation</b>	<b>Effect on Protein Folding</b>	<b>Effect on Protein Function</b>
Neutral	No significant change	No significant change
Harmful	Protein can fold	Decrease in or



	in a different way	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).

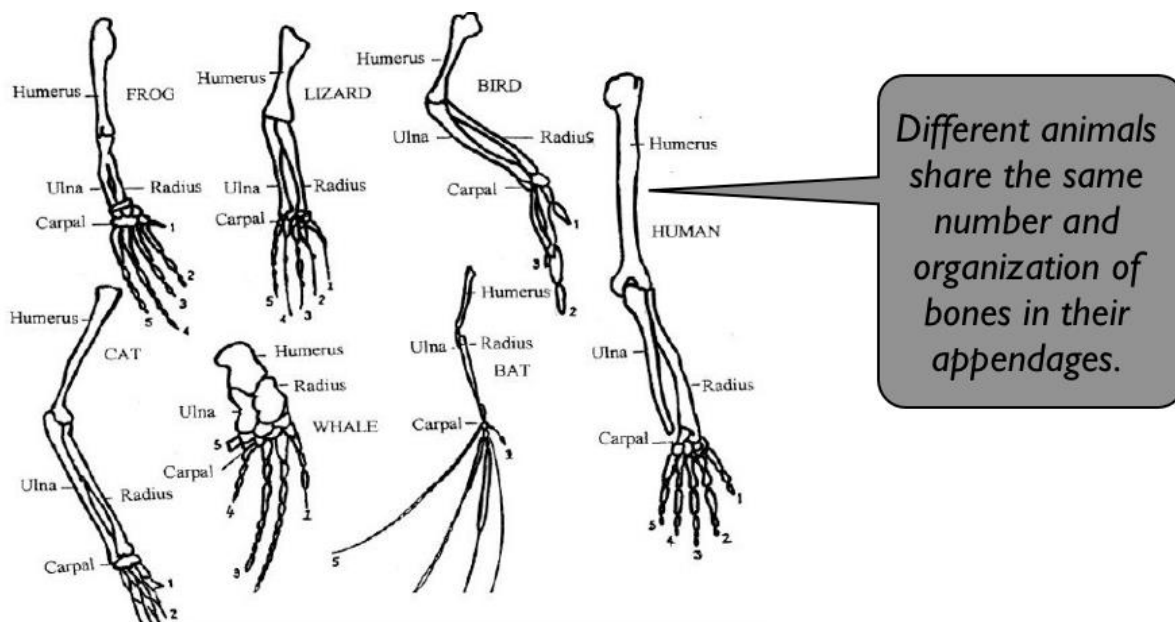
## Unity and Diversity of Life

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 PEs 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**



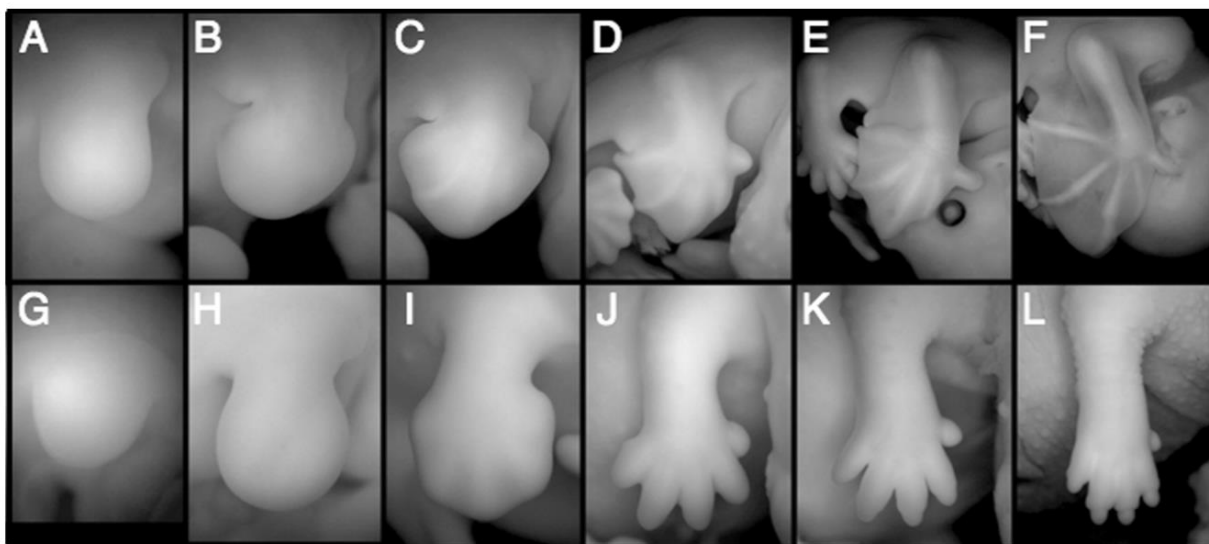
Anatomy reveals both the unity of basic bone structures and the diversity of organisms.

Source: Lawson 2007.

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 organisms 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: Cretokos et al. 2008.

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.

<b>Integrated Grade Eight Snapshot 5.9. Simulating Mutant Hands</b>
<b>Anchoring phenomenon:</b> People have hands. (How did they evolve?)
<p>Darwin himself pointed to human hands and asked questions about how they came to be, and researchers are starting to figure things out using a combination of fossil discoveries, embryological development, and artificial gene editing.</p>
<b>Investigative Phenomenon:</b> A transitional fossil shows a fish with fins that look more

like limbs of a land-dwelling animal.

Ms. R's students begin 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 that is a fish with fins that look more like the limbs of land-dwelling animals. How did arms and hands evolve from fins (whose supporting rays 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 explore an interactive simulator of a zebrafish. The computer screen provides students a control panel where they can copy, move, or delete different segments of the genetic code of the zebrafish. They can also insert special genetic code from a jellyfish to track the proteins built by each gene. After students modify a gene, they watch as the zebrafish develops. Through systematic **investigation [SEP-3]**, students isolate the effects of the individual genes. They try 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 create a poster **communicating [SEP-8]** the evidence that explains how human hands slowly evolved from fish fins. Their posters include 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 helps 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 IS (Table 5.2). 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 unit 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?

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

This IS features a very important concept related to the CA NGSS Earth and Space Science strand: “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 IS, students re-visit 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.

<b>Integrated Grade Eight – Instructional Segment 4: Sustaining Local and Global Biodiversity</b>
<p><i>Guiding Questions:</i></p> <ul style="list-style-type: none"> <li>• What are the characteristic properties and behaviors of waves?</li> <li>• What human activities harm Earth’s biodiversity and what human activities help sustain local and global biodiversity?</li> <li>• How does communication technology encode information and how can digital technologies be used to help sustain biodiversity?</li> </ul>
<b>Performance Expectations</b>
<p><i>Students who demonstrate understanding can:</i></p> <p><b>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.]</b></p> <p><b>MS-PS4-2. Develop and use a model to describe that waves are reflected,</b></p>

**absorbed, or transmitted through various materials.**

[Clarification Statement: Emphasis is on both light and mechanical waves. Examples of models could include drawings, simulations, and written descriptions.] [Assessment Boundary: Assessment is limited to qualitative applications pertaining to light and mechanical waves.]

**MS-PS4-3. Integrate qualitative scientific and technical information to support the claim that digitized signals are a more reliable way to encode and transmit information than analog signals.**

[Clarification Statement: Emphasis is on a basic understanding that waves can be used for communication purposes. Examples could include using fiber optic cable to transmit light pulses, radio wave pulses in Wi-Fi devices, and conversion of stored binary patterns to make sound or text on a computer screen.]

[Assessment Boundary: Assessment does not include binary counting. Assessment does not include the specific mechanism of any given device.]

**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.]

**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-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	PS4.A: Waves Properties	[CCC-1] Patterns
[SEP-2] Developing and Using Models	PS4.B: Electromagnetic Radiation	[CCC-2] Cause and Effect
[SEP-3] Planning and Carrying Out Investigations	PS4.C: Information Technologies and Instrumentation	[CCC-5] Energy and Matter: Flows, Cycles, and Conservation
[SEP-4] Analyzing and Interpreting Data	ESS1.B: Earth and the Solar System	[CCC-6] Structure and Function
[SEP-5] Using Mathematics and Computational Thinking	ESS3.C: Human Impacts on Earth Systems	[CCC-7] Stability and Change
[SEP-7] Engaging in Argument from Evidence	LS4.C: Adaptation	
[SEP-8] Obtaining,	ETS1.A: Defining and Delimiting Engineering	

Evaluating, and Communicating Information	Problems	
<p><i>Highlighted California Environmental Principles &amp; Concepts:</i></p> <p>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.</p> <p>Principle II The long-term functioning and health of terrestrial, freshwater, coastal and marine ecosystems are influenced by their relationships with human societies.</p>		
<p><i>CA CCSS Math Connections:</i> 6.RP.1,3, 6.SP.5, 6.EE.6, 7.EE.3,4, 7.RP.2, 8.F.3, MP.2, MP.4</p>		
<p><i>CA ELD Connections:</i> ELD.PI.6.1,5,6 a-b, 9,10,11a</p>		
<p><i>CA CCSSELA/Literacy Connections:</i> RST.6-8.1,9, WHST.6-8.1,2,9, SL.8.1,4,5</p>		

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,

[http://earthobservatory.nasa.gov/GlobalMaps/view.php?d1=MOD17A2\\_M\\_PSN](http://earthobservatory.nasa.gov/GlobalMaps/view.php?d1=MOD17A2_M_PSN)).

Students can recognize the obvious cycles of the seasons, but they can also notice the effects of deforestation, desertification, and climate change. For this IS, 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 IS, 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 so that scientists can detect the amount of the gas in the air using a satellite with a sophisticated camera.

Students **obtain information [SEP-8]** about the MODIS 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 middle school, 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.

<p style="text-align: center;"><b>Integrated Grade Eight</b> <b>Vignette 5.3. Waves as a Tool in Biology</b></p>
<p style="text-align: center;"><b>Performance Expectations</b></p>
<p><i>Students who demonstrate understanding can:</i></p> <p><b>MS-ESS3-3 Apply scientific principles to design a method for monitoring and minimizing a human impact on the environment.*</b> [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)</p> <p><b>MS-PS4-1. Use mathematical representations to describe a simple model for</b></p>

**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-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*:

<p><b>Highlighted</b></p> <p><b>Science and Engineering Practices</b></p>	<p><b>Highlighted</b></p> <p><b>Disciplinary Core Ideas</b></p>	<p><b>Highlighted</b></p> <p><b>Crosscutting Concepts</b></p>
<p><b>[SEP-1] Asking questions and defining problems</b></p>	<p><b>ESS3.C: Human Impacts on Earth Systems</b></p>	<p><b>[CCC-1] Cause and Effect</b></p>

<b>[SEP-2] Developing and using models</b>	<b>PS4.A: Wave Properties</b>  <b>PS4.B: Electromagnetic Radiation</b>	<b>[CCC-4] Systems and System Models</b>  <b>[CCC-5] Energy and Matter</b>  <hr style="border-top: 1px dashed black;"/>  <b>Influence of Science, Engineering, and Technology on Society and the Natural World</b>
<p><i>Highlighted California Environmental Principles &amp; Concepts:</i></p> <p>Principle II The long-term functioning and health of terrestrial, freshwater, coastal and marine ecosystems are influenced by their relationships with human societies.</p>		
<p><i>CA CCSC Math Connections:</i> 7.SP. 1-3, 8.SP.4</p>		
<p><i>CA CCSC ELA/Literacy Connections:</i> RI.8.2, RI.8.8, SL.8.1,4,6</p>		
<p><i>CA ELD Connections:</i> ELD.PI.8.1,2,4,6a-b,9</p>		

### **Introduction**

This vignette flows from IS3 where 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 transitions her students to the next unit on waves being mindful that she wants 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 decides 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 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.

<b>Day 1: Questioning Claims about Shark Encounters</b>  Students read an article about a string of recent shark sightings and then share their own tales about sharks. They ask questions about how they can distinguish fact from fiction.	<b>Day 2: Data with More Questions than Answers</b>  Students try to interpret a graph of the number of reported shark captures, but find that many factors influence the data set itself.	<b>Day 3: Locating with Sound</b>  Students watch a video about an autonomous underwater vehicle that tracks and films sharks. They use models to reverse-engineer how the device locates the sharks using sound waves.
<b>Day 4: Obtaining</b>	<b>Day 5–6: Light and Sound</b>	<b>Days 7–8: What have we</b>

<p><b>Information about Tags</b></p> <p>Students research about how different types of electronic tags and receivers that use wave technology to collect and transmit information to scientists.</p>	<p>Students obtain information about light and sound and then plan an investigation to explore the differences in how they travel through salt water.</p>	<p><b>learned</b></p> <p>Students explore new understandings from this technology.</p>
<p><b>Days 9–10: Applying understanding to a different population</b></p> <p>Students apply new understandings and predict possible trends in shark populations on the East Coast.</p>	<p><b>Days 11–12: Educating Different Audiences</b></p> <p>Students consider 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 create a public service announcement to target a specific audience.</p>	

***Day 1 – Questioning Claims about Shark Encounters (Engage)***

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

In order 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 share stories they have heard about white sharks, many of which are outlandish and eventually lead to rumors about sharks attacking or eating humans. Mrs. G simply solicits information from the students and lets the excitement in the room build. Mrs. G then begins to direct the conversation. After everyone agrees that sometimes people embellish stories and some things may not be true, Mrs. G asks how students can distinguish accurate information on sharks from the fantastical stories friends and families share. How can they tell if there are more shark encounters this year than in the past? After several months in Mrs. G's class, they all call out, "We need data!"

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

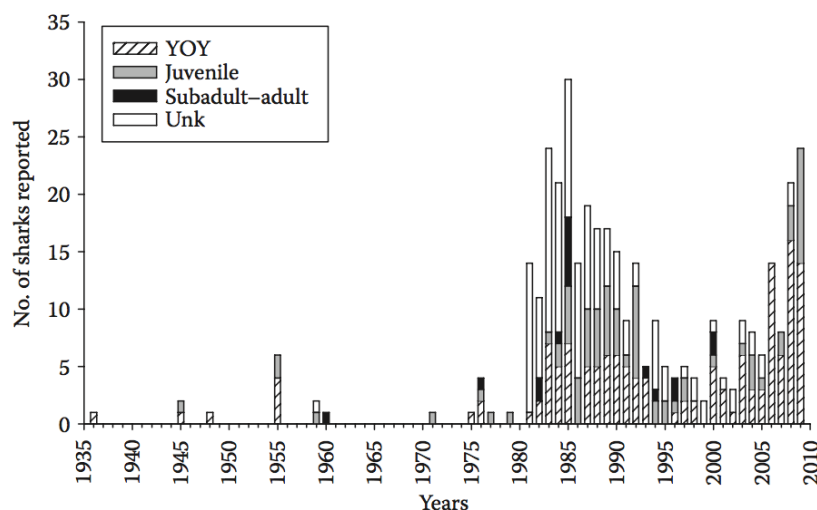
In one team, Minh has a different idea. She often goes to the pier to fish with her family and sometimes catches small "sand sharks". She explains that even her grandfather tells stories of catching sharks when he was a small boy in Vietnam. Mrs. G asks if Minh minds sharing with the class. As Minh begins, José's eyes light up and he begins frantically waving his hand. He, too, goes fishing with his uncle, who owns a sport fishing charter boat. His uncle keeps a log of what everyone catches. When the boat returns to the dock, they have to report what they caught on the trip, and sometimes there is someone at the dock inspects their buckets. The class quickly begins 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 provides students a graph with observations of reported shark catches over the last 100 years (figure 5.54) Once students have a chance to examine and discuss it with their team. Mrs. G asks the class where the title is and students realize it's at the bottom. "Does anyone have any idea what 'temporal trends means?', she asks. One student suggests temperature, and several agree. Mrs. G continues, "What if I told you the word came from a Latin word, *tempus*"? Kim, a music student, replies, "Is that like tempo? We use that word in music, it like, deals with time or something". "Oh, good connection, Kim", says Mrs. G., "It does have to do with time, so here we are looking at temporal trends, or trends over time." She asks students to share what they think YOY, Juvenile, Subadult-adult, and Unk. represented on the graph. She asks 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," offers José. Mrs. G emphasizes that students need to focus in on the data that will help them answer their questions about whether or not sharks are becoming more common along the California coastline and they can ignore the extra details for now.

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

Temporal trends in reported Southern California White Shark captures by age class, 1935–2009. YOY, <175 cm TL; juveniles, 176–300 cm TL; subadult/adult, >300 cm TL; and Unk, size unknown.

Source: Lowe et al. 2012.

Mrs. G asks 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 facilitate each other in generating ideas. Students invite each other to share an idea before any one person shares more than one idea, and they often invite someone who is reluctant to share to be the first one to speak. Mrs. G overhears Minh's group. Minh restates the question for Maria, an English Language Learner who is often reluctant to speak, "Maria, what is your question about this?" pointing to the data in the figure, "This is effect. What happened, what cause?"

Students begin working and charting questions: Why are there so few sharks reported before 1980? Why do the numbers of sharks reported go down in the late 1990's – early 2000's? Why are there so many young sharks and so few adults? Students are then asked to narrow down to one question, and consider possible **causes**

or factors that could have led to that result. Mrs. G selects one group's chart to share with the class because it will allow her to focus on a key issue:

Question:

- Why are 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 so it was harder to catch a white shark.
- There wasn't someone to track information and there weren't computers yet.
- Some people caught white sharks to sell them.
- Once people learned about sharks they were scared and they wanted to kill sharks.

Mrs. G asks 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 are possible, so students need 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 is asked to read a part and then **report a key finding [SEP-8]** on the class white board. From this,

students comment on how messy and confusing the data can be and how there is a lot of information they have to take into account in order to make sense of it without misinterpreting it. For example, in some cases it might look like the white shark population is 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 1980's, as people set out to kill white sharks. Some of this increase was due to more sharks tangled in nets when commercial fishing as demand for human consumption and updated fishing technology increased (EP&C II). Scientists acknowledge that relying on fishing data is helpful because we can start to build some understanding, but it does 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 asks, “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.”

Students begin sharing ideas and Victor suggests using drones to track sharks, and the class erupts in laughter. Mrs. G smiles and says, “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 suggests an underwater robot.

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

Mrs. G shows a short video clip about the Woods Hole Oceanographic Institution’s robotic shark tracker (underwater autonomous vehicle), REMUS (Woods Hole

Oceanographic Institution 2014). Students record “aha moments” and questions in their notebooks as they watch the video.

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

Mrs. G returns 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 goes to seek out the sharks. The video briefly mentions that the robot has a sensor for locating sharks based on acoustic technology (sound waves). Students are surprised that sound can travel through water, but Mrs. G challenges them to try it out next time they are in a swimming pool or bath tub by submerging their head and then tapping on the wall with a metal spoon. Her students complain that they want her to prove it right now, so Mrs. G fills up a tub of water and clinks 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 introduces the terminology, “sound waves are *transmitted* through the water” to label this phenomenon.

Mrs. G asks 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 are pretty confused, but Mrs. G helps prompt students to think creatively. Different groups have different models, with some ‘listening’ for the shark with a microphone and others showing a sonar-style device. Mrs. G tells students that the devices can only detect sharks from a limited distance away and she has them use their model to write an explanation in their notebook about why. She tells them that their explanation should use an energy diagram like they learned about earlier in the year. Most students recognize that the sound waves are a form of energy and that this energy must ‘die out’. In groups, students discuss how to represent ‘die out’ in terms of energy and decide 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 is

trying to get students to consider the amplitude of the sound waves and how 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 asks 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 offer good ideas about possibly disturbing the sharks or other marine wildlife with the loud noises, but she directs 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 shows 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 asks students what they think this tag does and has them modify their diagram to show a tag transmitting a signal that the REMUS receives. Mrs. G reminds students how quickly cell phones run out of charge when someone talks on them constantly and asks for students to think about how they could extend the battery life on the tag even further. Mrs. G then shares another quote from the REMUS web page that describes how the tags attached to the shark do not send out a constant signal, but instead wait to receive a signal from the REMUS robot. That way, they use much less energy in ‘standby’ mode than they would transmitting constant pulses. The sensor on the robot records 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 works a lot like the two human ears spaced a short distance apart (**structure and function [CCC-6]**; the REMUS robot refers to this distance as an ‘ultra-short baseline’). Mrs. G has 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 know that tags exist, Mrs. G tells them that these devices attached to a shark’s fin can actually record all sorts of information and send it back to scientists. She asks them to record ideas in their notebook about what sort of data the tag could collect. She partners students who have mobile devices with those that don’t to **obtain information [SEP-8]** about what shark tags actually measure, and suggests they look up SPOT and PAT tags as these are commonly used on white sharks. The students develop a list of things the tags can measure such as temperature, depth, and light intensity. At one team, Trinh wonders aloud how this will tell them anything about what’s going on with the shark and how we would get the information from the tag. Her teammate, Oscar, reading from his phone, mentions that, “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 swims up to the surface, we would know where the shark is, but the PAT tags are designed to pop off and float to the surface.” Trinh comments, “That’s strange, why does it have to transmit at the surface? Don’t waves travel underwater?”

**Day 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 have heard of radios before, the idea of thinking of these as waves is 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 gives the class time to dig deeper into radio waves and sound waves and explore the phenomenon of what happens to waves in water. She asks them to think of objects in the classroom that use radio waves and those that use sound waves. A student thinks of a radio and grabs a small hand-held AM/FM radio. One student questions if radio is the same as sound. Acknowledging this, Mrs. G asks him to think of something that has sound that isn’t a

radio. He grabs the class digital timer. Mrs. G has a large saltwater tank set-up that had been donated to the class, already filled with a saltwater solution she made that morning. She sets out zip-top bags and asks students to **investigate [SEP-3]** the differences between radio waves and sound in water. As they work, she asks them to record procedures, predictions of what will happen when they submerge devices, and give a rationale for their thinking. After each team confirms everyone has their predictions with rationale, students hold the devices in the center of the tank, surrounded by about a foot of water on all sides. To their delight, they can no longer hear the radio after submerging, but can hear a faint buzzer of the timer. Mrs. G has students document the differences in how radio waves and sound waves travel through salt water versus air in a table in their science notebooks using the terms *absorbed* and *transmitted*.

Some of the students remember that light is a wave from grade four and wonder if it is absorbed or transmitted in the water. After a laser safety reminder, Mrs. G encourages students to shine a laser through the saltwater tank. They don't notice anything unusual, but Mrs. G tells them that there are some important effects of light that shark taggers must consider. Mrs. G calls students back to their teams and shows the class a photo of a researcher on a boat trying to tag a shark in the water. She asks them to consider the challenges the researcher has in this task. Students comment that they would be afraid to be so close to a shark and it would be hard because the boat is moving. Mrs. G hints that there is one more challenge they might not have thought of. She has 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 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 are surprised that they all miss. Mrs. G asks them to view the straw at eye level and Victor shouts, "It's crooked!" Mrs. G confirms and mentions that, "what you are calling *crooked* scientists call refraction." Mrs. G then has her students use the PhET simulation, "Bending Light" (<https://phet.colorado.edu/en/simulation/bending-light>) and asks 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 asks students to make three separate **models [SEP-**



**2]** in their notebooks that **predict [CCC-2]** what will 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 have made their predictions, they get a laser and set of blocks, try it out, and update their models in their notebook.

Bringing students back to the challenge of tagging a shark from the surface of a boat, she passes out an index card to each team and asks them to compose a tweet to the @CSULBSharkLab. She promises to really tweet the best one in the class that demonstrates an understanding of how light's behavior makes 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 1970's 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 1990's)
- 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 teach each other about their assigned topics. Together, students make important connections to ideas that relate to consumer demand and certain fishing techniques impacting the food source of young great whites. Mrs. G then passes out copies of an article from a newspaper that describes a study conducted by a graduate student at the CSULB Shark Lab that looked at geopositioning data from tagged juvenile white sharks (Dulaney 2013). Mrs. G carefully selects figures from the source article (Lyons et al. 2013) and has her students **analyze and interpret [SEP-4]** some of the original tracking data. They find that the 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 construct an **argument from this evidence [SEP-7]** that the shark population is increasing, and that the increase is a direct result of the laws that have created protected ‘shark nurseries.’

The tracking data also allow scientists to monitor the fate of sharks that are accidentally caught and released (if the tracker keeps going, the shark must have survived). **Interpreting the data [SEP-4]**, students find that sharks have a high chance of survival, and that the sharks are more likely to die when nets are left out for longer periods (like 1–2 days) than when the net gets pulled in after just a few hours. They will 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 tells students that as newly minted shark experts, they have been hired to study sharks in Cape Cod, Massachusetts. They have had frequent sightings of great white sharks in recent years, so are the same factors **causing [CCC-2]** a similar **trend [CCC-1]** as 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 reminds her students that there were many misunderstanding about sharks at the beginning of their studies. She poses 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 have a few moments to record their thinking in their notebooks and the class discusses. Mrs. G asks the teams to think about what they now know and introduces them to their challenge: to create a public service announcement to help educate different audiences the community. Students decide which audiences would be important to target for this message, create a storyboard to organize their message, and get to work. Groups target the fishing industry, law makers, and the other beach visitors. Mrs. G provides a rubric to help students focus as they work and provides check-in opportunities where teams update her on their progress and get feedback. The students then proudly share their PSA’s 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 phenomena of changing shark populations and behavior are more closely aligned with PEs 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 initial questions raised on Days 1–2.

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 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 is 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 **ask questions [SEP-1]** on Day 2 about the shark siting data they have **analyzed [SEP-4]** and again on Day 3 as they are motivated to learn about sharks. On Day 4, they **develop models [SEP-2]** of how the REMUS robot transmits and receives information from the sharks. They **conduct simple investigations [SEP-3]** on Days 5-6 about light, sound, and radio waves in water. The end with a **communication product [SEP-8]** that presents both their model and their investigation plan in one authentic public service announcement.

**CCCs.** The initial motivation for the sequence involves asking questions about **stability and change [CCC-7]** on Day 2 when students examine data about shark populations. Students eventually use the tracking data to infer the **cause [CCC-2]** of these changes. In addition to this scientific problem, the vignette focuses 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 treats shark tracking technology as a **system [CCC-4]** and students trace out the **flow of energy [CCC-5]** (by sound and radio waves) on Days 3–4 when students explain how REMUS and other shark tags work. The foundation box for MS-PS4-2 attributes **structure and function [CCC-6]** to MS-PS4-2 because the structure of materials determines how they will interact with light and sound, though this CCC is not a major theme emphasized throughout the vignette.

**DCIs.** Shark tags send information via mechanical (sound) or electromagnetic waves (light and radio), introducing students to basic wave properties (PS4.A). These

waves interact with objects and the media through which they travel, being transmitted, absorbed, or reflected (PS4.B). On Day 3, students explore the tag transmissions in terms of energy. They identify that higher amplitude waves contain more energy (PS4.A; MS-PS4-1) by discussing how higher amplitude signals would drain batteries quicker because they require more energy. Students also represent how amplitude decreases with distance as some energy gets absorbed by the water.

In helping students develop models of wave behavior, this vignette goes beyond the assessment boundary of MS-PS4-2. That PE states that wave behavior will only be addressed for light and mechanical waves – introducing the electromagnetic spectrum is beyond the middle school 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 explore sound and light waves, Mrs. G specifically avoids 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 provide 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 focuses 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 since this application of the ESS principles to an LS realm is an excellent way to revisit this grade six PE and the human impacts of ESS3.C.

On Days 9-10, students perform some engineering design thinking where they must select the appropriate technology (radio or sound waves) that best meets the criteria for investigating the Cape Cod sharks (ETS1.B). In this case, students define these criteria based on whether or not the device can transmit measurements that support 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 (CA EP&C II). Students discuss the effects of fishing on shark populations from Days 7-8, and then reconsider specific actions that could minimize human impacts on Days 11-12 when they create 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 analyze 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 engage in structured discourse with teams, including the jigsaw activity on Days 6–7) (SL.8.1). Students also craft a persuasive public service announcement targeting a specific audience based on robust evidence (SL.8.4, 6).

## **Reference**

Developed by Jill Grace

## **Resources**

Dulaney, Josh. 2013. “CSULB Shark Lab Study: Young Great Whites Surviving Fishing Nets.” *Long Beach Press Telegram*. <http://www.presstelegram.com/general-news/20130821/csulb-shark-lab-study-young-great-whites-surviving-fishing-nets> (accessed September 30, 2016).

Lowe, Christopher G., Mary E. Blasius, Erica T. Jarvis, Tom J. Mason, Gwen D. Goodmanlowe, and John B. O’Sullivan. 2012. “Historic Fishery Interactions with White Sharks in the Southern California Bight.” In *Global Perspectives on the Biology and Life History of the White Shark*, by Michael L. Domeier. Boca Raton, FL: CRC Press, 169–185.

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*. <http://www.latimes.com/local/lanow/la-me-ln-great-white-sharks-huntington-beach-20150520-story.html> (accessed September 23, 2016).

Woods Hole Oceanographic Institution. 2014. “REMUS SharkCam: The Hunter and the Hunted.” Posted at *Vimeo*, <https://vimeo.com/101165012> (accessed September 22, 2016).

## Water Waves

Over the course of this IS, 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 <http://phet.colorado.edu/en/simulations/category/physics/sound-and-waves>), 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.

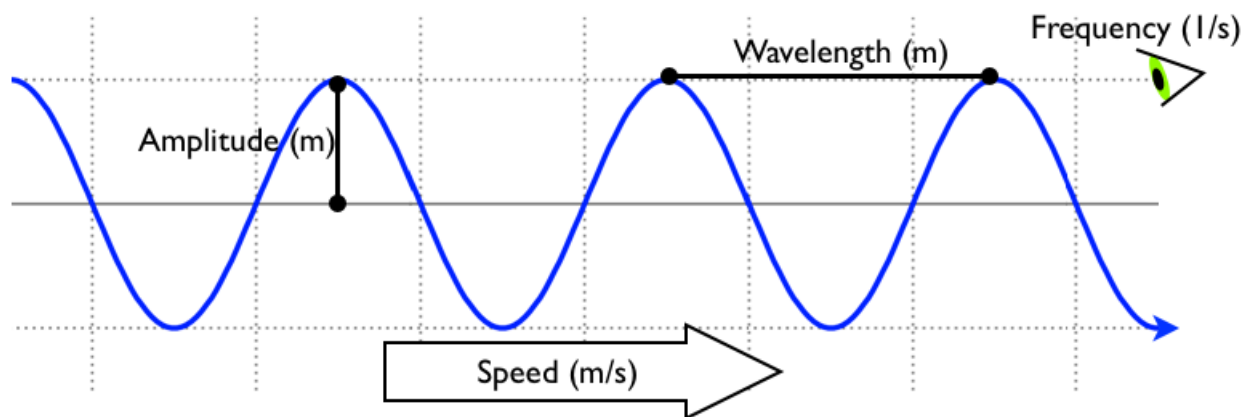
Students **investigate [SEP-3]** a variety of waves they can generate and observe in a flat-bottomed water container (ripple tank). Students observe and discuss general wave properties that they observe including absorption, reflection, transmission of one wave through another, and even make observations 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 allow 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 IS, 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



Having become familiar with the properties of waves and 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 in a higher amplitude, thus qualitatively connecting the growth in amplitude of the wave to an increase in the energy it transmits (MS-PS4-1). Students can make this representation quantitative by dropping 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).

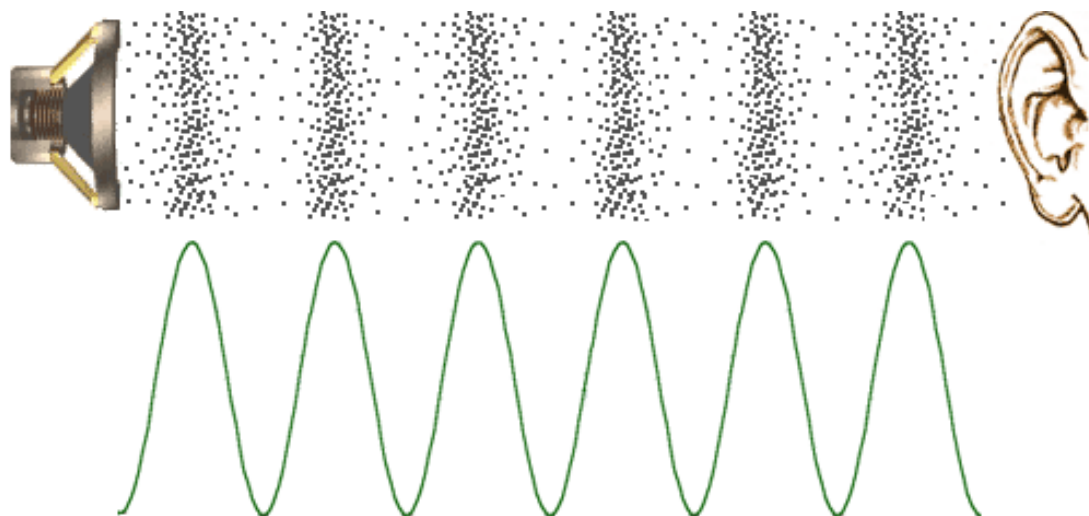
Students' **models [SEP-2]** of wave motion, amplitude, and **energy [CCC-5]** can help them **explain [SEP-6]** why waves break at the beach (enabling California's famous surfing and other beach play). Surfers know that the water in a breaking wave is moving toward the beach (which pushes their surfboard 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: Media College n.d.

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 **patterns [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, 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 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, students' model 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 middle school MS-PS4-1 and MS-PS4-2 explicitly state that electromagnetic radiation (including a discussion of the electromagnetic spectrum) is not assessed in middle school. 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 each 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 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 non-examples, definitions, illustrations of a concept, or essential (or non-essential) characteristics. These strategies help all learners develop effective vocabulary-learning strategies as they acquire content knowledge.

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

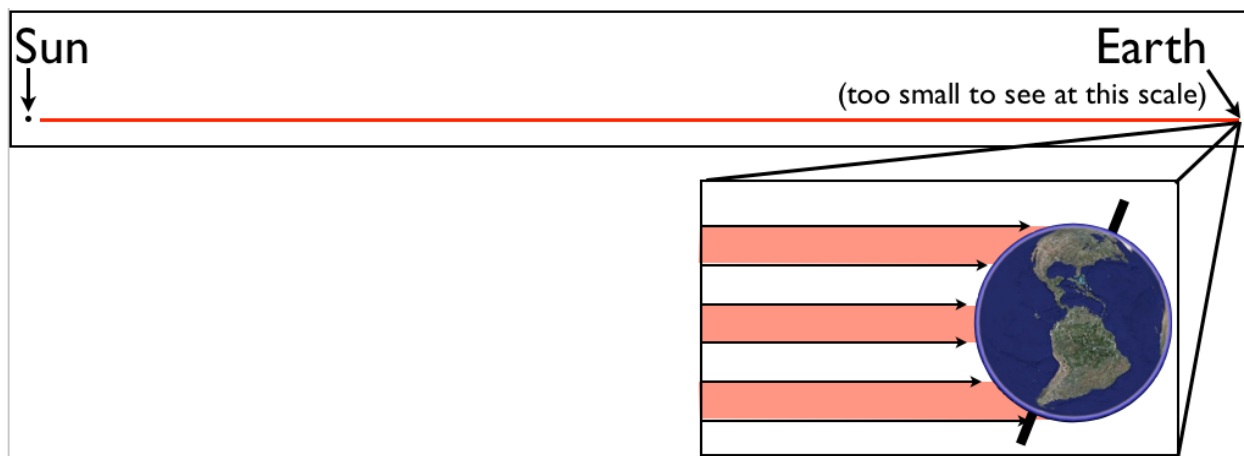
CA ELD Standards: ELD.PI.6–8.6

### 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 ask 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 follow 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.

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 [http://www.spacescience.org/education/extra/kinesthetic\\_astronomy/](http://www.spacescience.org/education/extra/kinesthetic_astronomy/)). They tilt their body towards or away from the Sun at the same  $23.5^\circ$  tilt as the Earth and move around Earth's orbit, making sure that their tilt axis always points towards the North Star. As they move from one side of the Sun to the other, they see how the angle of the Sun's rays **changes [CCC-7]** in the different hemispheres: in the northern hemisphere summer, the tilt brings the angle of the Sun's rays closer to  $90^\circ$  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.climate.gov/teaching/resources/seasons-and-ecliptic-simulator>).

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 <http://www.learner.org/resources/series28.html?pop=yes&pid=9> and in review articles at <http://dx.doi.org/10.3847/AER2010035>). 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 IS 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<sup>2</sup>. 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 longer days (causing longer duration sunlight) and from higher angles in the sky (causing more sunlight 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 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,

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<sup>2</sup> Something similar to this simulation is located here: [http://astro.unl.edu/naap/motion1/animations/seasons\\_ecliptic.html](http://astro.unl.edu/naap/motion1/animations/seasons_ecliptic.html), but it is described in Bakas and Mikropoulos 2003



many of which remain unanswered but could inspire further investigation in the capstone project at the end of the IS.

### Integrated Grade Eight Snapshot 5.9. School Solar Energy Project

**Anchor Problem:** How much energy will solar panels on our school rooftop provide?

Mr. S invites a rooftop solar panel installer to visit his classes. In the days before her visit, the students prepare a list of **questions [SEP-1]** about the factors that affect the amount of energy the panels can generate. When she arrives, she gives a short presentation about solar energy and then goes onto the roof to make measurements. The installer emphasizes 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 sends the results from computer calculations to Mr. S with graphs of the amount of energy the panels will 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 draw **models [SEP-2]** of light traveling in straight lines from the Sun to the rooftop (PS4.B), indicating how trees will 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 are 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 works to **interpret [SEP-4]** the graphs so that they can **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 draw **models [SEP-2]** that illustrate 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 show 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 are repeating their investigations of shadows from grade one (1-PS4-3; 1-ESS1-1) with a more sophisticated level of understanding.

Mr. S has 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 **communicate [SEP-8]** the report's findings. Through a peer review and feedback process, the class revises each product and selects a team of students to make the formal presentation. The school board votes unanimously to allocate funds to install solar panels and the students track the installation progress. The following year, the students analyze 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<sub>2</sub> in the air and transmit this information back to Earth? After having researched water waves, sound, light and electromagnetic radiations (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 5.4 illustrates one kind of summary.

**Table 5.4. Characteristics of Waves**

<b>Type of Wave</b>	<b>Wavelength/Frequency Associated With</b>	<b>Amplitude Associated With</b>
Water wave	Physical distance between top of water waves	Height of the physical wave
Sound wave	Pitch of the sound	Loudness of 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 comes 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 very mechanical ways. For examples, clocks

had an inside pendulum whose movements resulted in the hour and minute hands going round and round. 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.

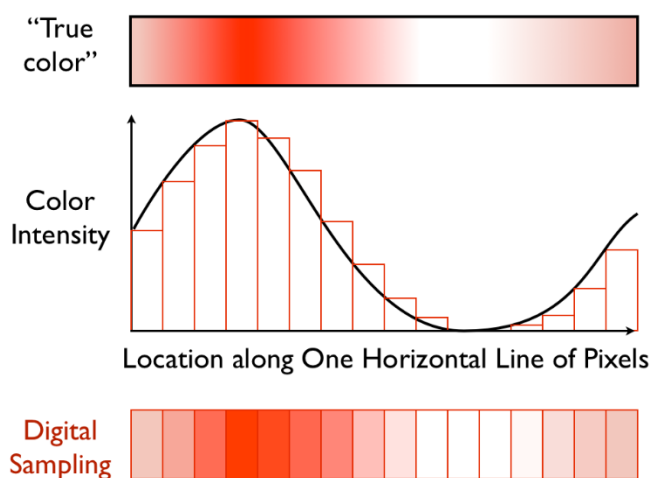
Students can compare the advantages and disadvantages of the earliest mechanisms of transmitting information to the beginning ages of radio to today's wireless cell phones and tablets. Historical examples of encoded information in wave pulses (e.g., drum or smoke signals, the invention of Morse code 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 an AM and an FM radio signal 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 a person hearing the song in the comfort of her 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

thirteen different locations, and summarize the color at each of those thirteen 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

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 school 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]**.

### Integrated Grade Eight Vignette 5.4. Student Capstone Projects

#### Performance Expectations

**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-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-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 a problem.**

Highlighted Science and Engineering Practices	Highlighted Disciplinary Core Ideas	Highlighted Crosscutting Concepts
[SEP-2] Developing and Using Models	ESS3.C Human Impacts on Earth Systems	[CCC-1] Patterns
[SEP-4] Analyzing and Interpreting Data	PS4.C Information Technologies and Instrumentation	[CCC-2] Cause and Effect
[SEP-6] Constructing		

<p><b>Explanations (for science) and Designing Solutions (for engineering)</b></p> <p><b>[SEP-7] Engaging in Argument from Evidence</b></p> <p><b>[SEP-8] Obtaining, Evaluating, and Communicating Information</b></p>	<p><b>LS4.B Natural Selection</b></p> <p><b>ETS1.A Defining and Delimiting Engineering Problems</b></p>	
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*Highlighted California Environmental Principles & Concepts:*

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

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

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

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

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

*Connections to the CA CCSSM: 8.SP.2,4*

*Connections to CA CCSS for ELA/Literacy: RST.6–8.1, 2, 7, 9; RI.8.3; SL.8.1, 4, 6; WHST.6-8.2,7-9*

*Connection to CA ELD Standards: ELD.PI.6-8.1, 9*

### **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.

<b>Day 1: Analyzing Per Capita Consumption</b>	<b>Day 2: Introducing Capstone Projects</b>	<b>Day 3: Focus on Solutions</b>
Students calculate per capita consumption of different countries, develop and critique different ways of communicating these data, and ask questions about trends they see.	Ms. D provides the background about the capstone project and students read and discuss five environmental case studies.	Students read about five case studies of communities that have developed solutions to environmental problems. Students brainstorm ideas for their capstone projects.



<b>Days 4–8: Collaborative Work Sessions</b>  Teams work collaboratively and the teacher helps focus and guide students.	<b>Day 9: Project Presentations</b>  Students prepare final presentations for a school science night.	<b>Day 10: Synthesis</b>  Students from different project groups combine together to identify common elements in the projects and identify how the projects relate to the EP&Cs.
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### ***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 facilitates the discussions and appropriately guides 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 charts their comments, and then asks students if they have any ideas about which areas consume the most resources and why. After a while, students conclude that for each country or continental area, they should probably get **quantitative [CCC-3]** data about total consumption and per-capita consumption.

Ms. D provides each group of students with information about world populations (available at: Data from the Population Reference Bureau report accessed at [http://www.prb.org/pdf13/2013-population-data-sheet\\_eng.pdf](http://www.prb.org/pdf13/2013-population-data-sheet_eng.pdf)) and about consumption of natural resources in the year 2013. In both cases, the datasets include information at the country level (e.g., Brazil) and at a regional level (e.g., South America). The consumption data are 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

<http://www.eia.gov/cfapps/ipdbproject/IEDIndex3.cfm?tid=90&pid=44&aid=8>). Since the total amount of data from the sources is 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 **analyze the data [SEP-4]** that Ms. D had provided, **calculating [SEP-5]** per-capita consumption as the ratio of the emissions and population and then develop a poster to **communicate [SEP-8]** the differences to their classmates. Some student groups choose color-coding maps to compare per-capita consumption. Other groups superimpose on global maps pictorial ways to represent total consumption by a country or region. This representation helps them compare geographic size with consumption total. A less visually-oriented group creates a summary table (table 5.14).

**Table 5.14. Per-Capita Consumption**

<b>Region</b>  <b>(An example country)</b>	<b>Population</b>  <b>in 2013</b>  <i>number of people</i>	<b>Total CO<sub>2</sub> Emitted</b>  <b>in 2013</b>  <i>tons</i>	<b>Per-Capita</b> <b>Emission of CO<sub>2</sub></b>  <i>tons/person/year</i>
<b>Africa</b>  <b>(Nigeria)</b>	1,100 million  (174 million)	1,268 million  (96 million)	1  (0.5)
<b>Asia</b>  <b>(China)</b>	4,302 million  (1,357 million)	18,909 million  (10,246 million)	4  (8)
<b>East Europe</b>  <b>(Russia)</b>	295 million  (144 million)	2,713 million  (1,789 million)	9  (12)
<b>West Europe</b>	190 million	1,466 million	8

<b>(Germany)</b>	(81 million)	(759 million)	(9)
<b>South America</b>	401 million	1,188 million	3
<b>(Brazil)</b>	(196 million)	(502 million)	(3)
<b>Middle East</b>	251 million	1,716 million	7
<b>(Saudi Arabia)</b>	(30 million)	(543 million)	(18)
<b>North America</b>	352 million	5,660 million	16
<b>(USA)</b>	(316 million)	(5,184 million)	(16)

Table by Dr. Art Sussman, courtesy of WestEd with data from the Population Reference Bureau 2013 and Population Reference Bureau 2016

The whole class then does a gallery walk where they examine each of the posters and listen to the group's presentation about their chart. The students discuss the benefits and disadvantages of each representation of the data. Students ask questions, and write down notes about specific pieces of the data that they notice in each representation. After the gallery walk and while the charts are still visible, the whole class discusses the most important **patterns [CCC-1]** of per-capita consumption, and Ms. D invites students to propose **evidence-based claims [SEP-7]**. Some students notice a **pattern [CCC-1]** that some small countries, particularly in the Middle East, have the highest levels of per capita emission. For example, Kuwait had a per-capita emission rate of 37 tons of CO<sub>2</sub> per person per year. They make a claim that this extremely high rate results from Kuwait's large role as a producer, refiner and exporter of fossil fuel resources, and cite as **evidence [SEP-7]** correlations with other countries that produce and export large amounts of fossil fuels.

Throughout the year, Ms. D has posters along her wall with illustrations of *California's Environmental Principles* and she asks students to refer to them now. She asks her students which EP&Cs might apply to the data set they analyzed. One student suggests 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 facilitates a brief class discussion about the concepts associated with that principle. Several students observe 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’s systems, Ms. D introduces student group projects that will conclude their immersion in middle school science. Student teams will choose a specific human activity that has an environmental impact and explore it using all three dimensions of the CA NGSS as they experienced them throughout all three middle school grades. She organizes 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.

To help establish a shared background within and across the student groups, Ms. D provides 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 work in teams of two to initially process the information in one of the readings and then combine into larger groups focused on that reading. These groups then make presentations to the whole class, followed by discussions about the individual topics and how those topics connect with each other around the theme of human impacts on Earth systems. The five readings focus on **cause and effect [CCC-2]** and **stability and change [CCC-7]** as they relate 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 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 transitions to a focus on solutions by sharing seven brief readings from the *Living Planet Report 2014*. Each reading describes positive strategies that a specific community has implemented to preserve natural resources, produce better, and consume more wisely. While they were **evaluate information [SEP-8]** in these readings in teams and as a whole class, students begin to brainstorming potential solutions related to the impacts in the first set of readings. Student facilitators help summarize and display notes on these potential solutions.

Students then start meeting in groups to develop projects. Groups share their initial ideas with each other and with the teacher. These ideas and the partnering of students are in flux for a while until they solidify into specific project teams. Four teams focus on climate change but have different geographical contexts (the Arctic, Pacific Atolls, and two in California). Another team focuses on protecting the California freshwater shrimp, an endangered species living in a stream near the school, while another team focuses on reducing the school's energy consumption. After Ms. D approves the request of students to broaden the topics to include other concepts they had covered in grade eight, two groups choose asteroid impact deflection to protect the planet, and a third group chooses genetic engineering as a general way to increase food supplies.

### ***Days 4-8 – Collaborative Work Sessions***

The schedule for the work on student projects include designated dates when groups share their current status with each other. This sharing greatly broadens the learning from the projects about the topics as well as expanding the feedback to the student groups. During these sessions, each group focuses on reporting about their project through the lens of one or two CCCs. The CCCs help 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 present posters of their projects at a school science evening program.

Some highlights from the projects include public outreach and monitoring water quality in a local stream to help protect the California freshwater shrimp. Students share 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 **h**abitat by building dams, and also **o**verharvesting timber and gravel along the stream banks. In addition, people have stocked streams

with invasive nonnative fish species and polluted the water. The students propose plans to increase public awareness related to stream overharvesting and pollutions practices, and identify constraints that need to be addressed in reducing these practices. (CA EP&C II; See the EEI unit “Extinction: Past and Present”

<http://californiaeei.org/framework/sci/Extinction> for more information and a lesson on HIPPO).

The genetic engineering group make an analogy between genetic code with the encoding involved in digital files. They claim that genetic code is neither analog nor digital, but instead was uniquely biological and provide 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 provide **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 (CA EP&C V).

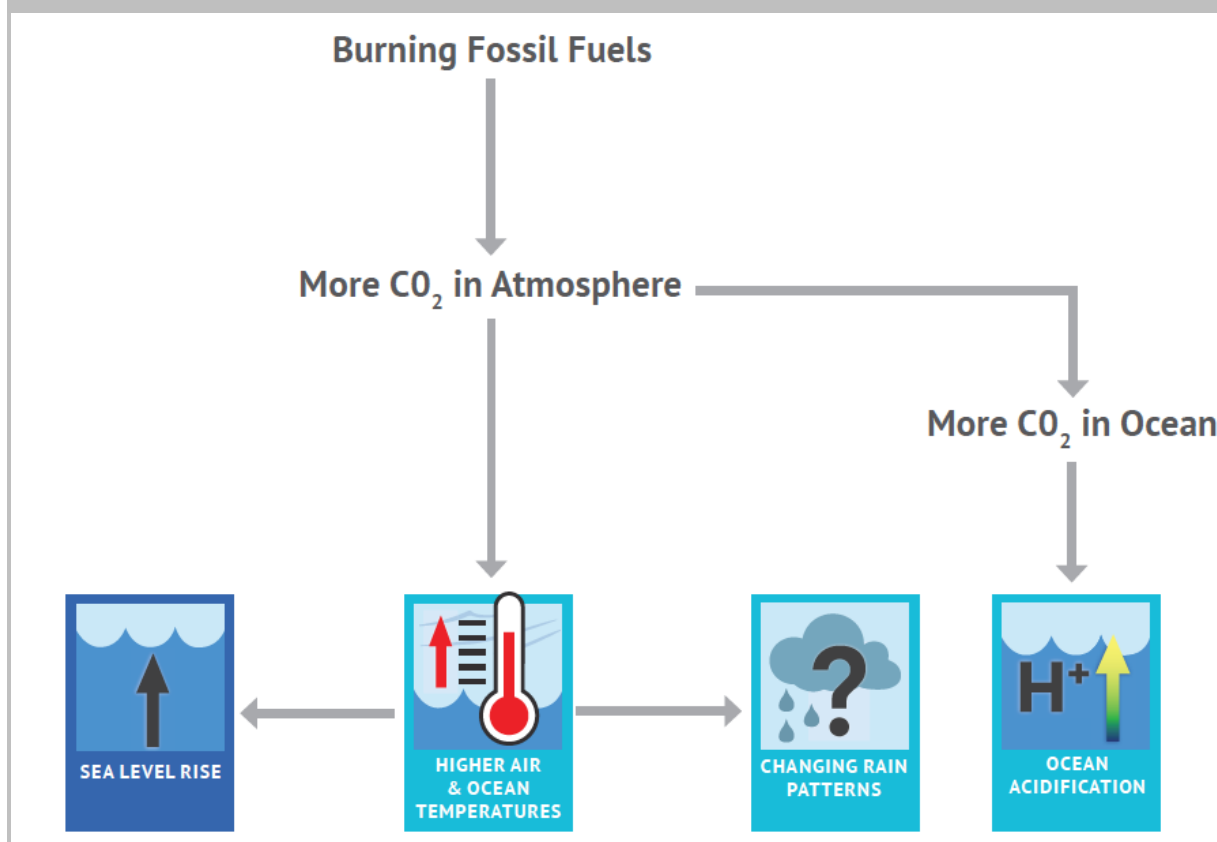
The school energy group visits a school in a different district that has been recognized as a “green school”. They **analyze and compare energy consumption data [SEP-4]** from their school and the “green school”, and make recommendations based on those analyses. In addition, they **share information [SEP-8]** about digital tools that schools use to monitor and reduce energy consumption by improving the efficiency of lighting and heating. The team identifies specific reduction goals as their criteria for success as well as detailed plans to achieve those goals. They identify a constraint that energy budgets and decisions are made at the district level rather than the school level. (California Environmental Principle V)

One of the asteroid impact teams change projects. They had remembered that the HHMI BioInteractive website about the impact crater had included remote digital data that had originally identified the crater in the Yucatan. While checking other links, they discover that the HHMI BioInteractive website includes conservation efforts at the Gorongosa National Park in Mozambique (<http://www.hhmi.org/biointeractive/gorongosa-national-park>). The students explain that this park provides a case study in ecology and conservation science. They are

particularly excited when they learn that park scientists use 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 use educational resources from the website to **explain [SEP-6]** factors that influence the park ecology, the conservation recovery plans and significant constraints that need to be addressed to promote successful restoration (CA EP&C V).

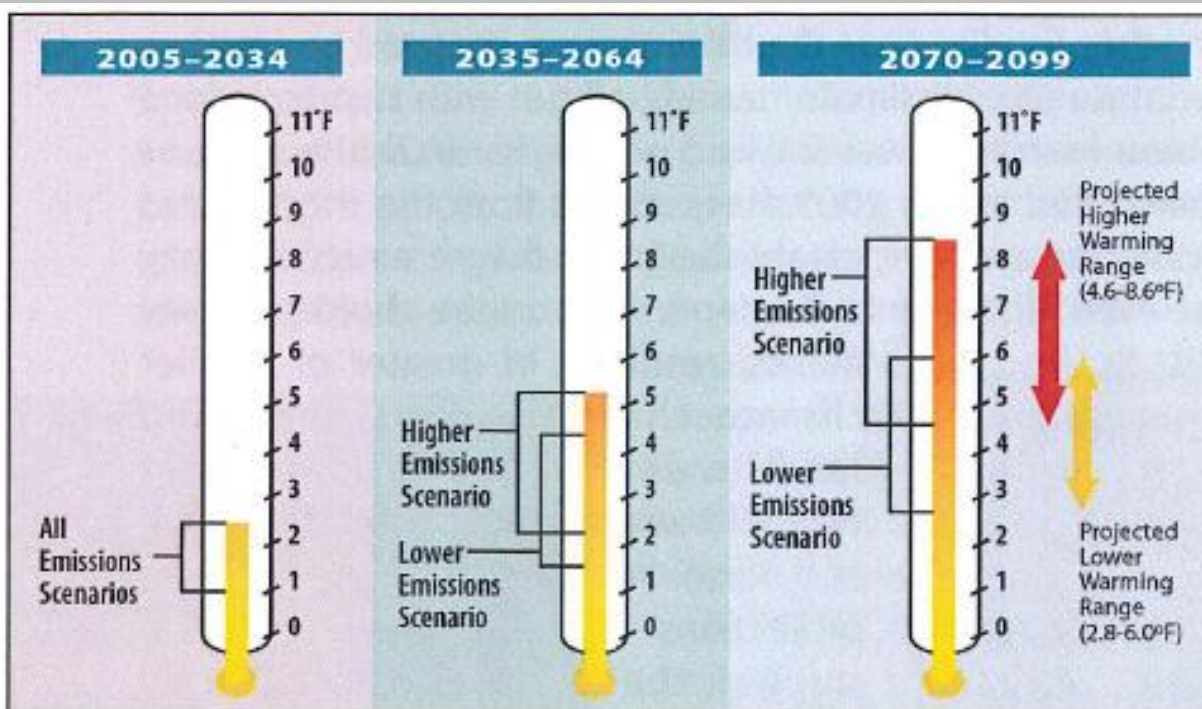
The different student groups working on climate change issues jointly identify as a constraint that people have a lot of confusion about global warming and climate change. They consult with their sixth grade science teacher who had taught them that global warming is the increase in air and ocean temperatures due to the increased greenhouse effect (MS-ESS3-5). She refers them to a PBS LearningMedia website (<http://www.pbslearningmedia.org/resource/pcep15-sci-ess-impacts/impacts-climate-change-pacific-region/>) that has a computer interactive explaining four main impacts of climate change (figure 5.59). Higher concentrations of atmospheric CO<sub>2</sub> 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 (CA 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 and Lisa Rosenthal, courtesy respectively of WestEd and WGBH.

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 research predictions related to climate change and wildfires. They learn that average temperatures in California are projected to generally keep increasing throughout this century (figure 5.60). They note that reductions in emissions of greenhouse gases could reduce the amount of heating. They also learn that communities could engage in individual and collective actions that increase the fire safety of homes.

**Figure 5.60. Projected Changes to California's Average Temperature**

Projected increases in statewide annual temperatures during this century. Source: Moser, Ekstrom, and Franco 2012.

The Pacific Atoll climate change group report about the Marshall Islands, which had been a territory of the United States. They share information about its geography, and using digital tools to video conference with a school on the island of Majuro. The group explains 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 communicate with each other, a King Tide causes serious flooding in the area of the Majuro School. The group presentation includes **explanations [SEP-6]** of how climate change **causes [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 focuses on ways communities can protect beaches and homes from rising sea levels. Like the other student groups, they want 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” <http://californiaeei.org/framework/sci/Greenhouse> provide additional resource materials on climate change and greenhouse gases.)

### **Day 10 – Synthesis**

In each of the three middle school grades, students learned about the EP&Cs that had been adopted by the California State Board of Education. For the final lesson related to the student projects, students form groups that consist of students who had worked on at least three of the different projects. Each of these new groups then discuss what they had done or heard about that relates to each of the EP&Cs. Students then share their ideas in a whole class discussion. They are surprised how many of them identify 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 conclude that decisions affecting resources and natural systems are definitely based on a wide range of considerations and decision-making processes.

### **Vignette Debrief**

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 CA CCSS and the EP&Cs:

*SEPs.* Scientists typically use all SEPs to fully understand a new phenomena, 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 phenomena and have the time to fully pursue it, students should fully employ all SEPs. For this reason, Ms. D explicitly organizes her project criteria around all the SEPs.

*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 Design (Defining and Delimiting Engineering Problems). Different project groups focused on problems that were more

closely related to DCIs in one or two disciplines, though the project criteria required that students consider human impacts (ESS3), include digital technology (PS4.C), engineering design (ETS).

CCCs. The CCC's are a series of big, overarching issues that scientists consider when they approach a new phenomenon. Since the students will be engaging in a very big science and engineering problem that is new to them, the CCCs provide a critical scaffold. Presentations during the collaborative work sessions on Days 4-8 focus on viewing the projects through individual CCCs.

*CA CCSS ELA, Math, and CA ELD.* The capstone projects and surrounding structure in the vignette are 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 analyze data, calculating the per-capita consumption as the ratio of the emissions and population. They look for patterns in the data and make evidence-based claims about what they observe (8.SP.2,4). The entire project is structured to promote student discourse in small groups and in formal presentations (SL.8.1, 4, 6). Students then create written and visual communications products that summarize 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 is designed to draw together all of the EP&Cs. Even though this framing is intentional, Ms. D still devotes specific time on Day 1 and again on Day 10 to identifying which EP&Cs apply to the situations.

### **Vignette Resources**

Moser, Susanne, Julia Ekstrom, and Guido Franco. 2012. *Our Changing Climate 2012*. Sacramento: California Climate Change Center.

World Wildlife Fund. 2014. *Living Planet Report 2014*. Gland, Switzerland. WWF International.

## References

- Achieve. 2010. *International Science Benchmarking Report: Taking the Lead in Science Education: Forging Next-Generation Science Standards*. Washington, D.C.: Achieve.
- American Geophysical Union. 2011. "New Paper on Landslide-Dams and Genetic Change in Fish." <http://blogs.agu.org/landslideblog/2011/11/15/new-paper-on-landslide-dams-and-genetic-change-in-fish/> (accessed September 30, 2016).
- Bakas, Christos, and Tassos A. Mikropoulos. 2003. "Design of Virtual Environments for the Comprehension of Planetary Phenomena Based on Students' Ideas." *International Journal of Science Education* 25 (8).
- Beccario, Cameron. 2016. Earth. <https://earth.nullschool.net/> (accessed September 6, 2016).
- Benda, Lee, and Thomas Dunne. 1997. "Sediment Routing by Debris Flow." *Erosion and Sedimentation in the Pacific Rim* (Proceedings of the Corvallis Symposium, August 1987). IAHS-AISH publication 165: 213–223.
- California Department of Water Resources. 2015. California Data Exchange Center. <http://cdec.water.ca.gov/cdecstation/> (accessed October 26, 2016).
- Callaham, Robert Z. 1962. "Chapter 20: Geographic Variability in Growth of Forest Trees." In *Tree Growth*, edited by Theodore T. Kozlowski. New York: Ronald Press Company: 311–325. <http://www.treearch.fs.fed.us/pubs/32866> (accessed September 13, 2016).
- Cambridge College Primary Science. 2017. <https://cambridgecollegeprimaryscience.wikispaces.com/>
- Chau, Kevin. 2016. "A Search Gone Cold." *SQ Online* (2015-16). <https://sqonline.ucsd.edu/2016/05/a-search-gone-cold/>
- Climate Charts. 2007. Average Annual Temperature. <http://www.climate-charts.com/World-Climate-Maps.html#temperature> (accessed July 28, 2016).
- Cornwell, Paige. 2014. "State, Tribal Officials Keep Watch on Mudslide's Effect on Fish." *The Seattle Times*. <http://www.seattletimes.com/seattle-news/state-tribal-officials-keep-watch-on-mudslidersquos-effect-on-fish/> (accessed September 30, 2016).
- Cowan, Richard. 2000. "Tracking the Course of Evolution: The K-T Extinction." In *History of Life*, by Richard Cowan. Boston: Blackwell Science.

Cretekos, Chris J., Ying Wang, Eric D. Green, NISC Comparative Sequencing Program, James F. Martin, John J. Rasweiler IV, and Richard R. Behringer. 2008. "Regulatory Divergence Modifies Limb Length between Mammals." *Genes and Development* 22 (2): 141–151.

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

———. 2011b. *Making Sense of SCIENCE: Force and Motion*. San Francisco: WestEd.

Daehler, Kirsten, and Jennifer Folsom. 2015. *Making Sense of SCIENCE: Genes and Traits*. San Francisco: WestEd.

———. 2013. *Making Sense of SCIENCE: Earth Systems*. San Francisco: WestEd.

Darling-Hammond, Linda. 2000. "Teacher Quality and Student Achievement: A Review of State Policy Evidence." *Education Policy Analysis Archives* 8 (1).

Environmental Management 2016 Wiki. 2016. <https://y9-environmental-management-sg.wikispaces.com/>

Exploratorium Teacher Institute. 2016. Science Snacks: Gas Model. <https://www.exploratorium.edu/snacks/gas-model>

Falstad, Paul. N.d. Virtual Ripple Tank. <http://www.falstad.com/ripple/> (accessed September 6, 2016).

Folsom, Jennifer, and Kirsten Daehler. 2012. *Making Sense of SCIENCE: Land and Water*. San Francisco: WestEd.

Gemini Observatory. 2008. Twin Galaxies in a Gravitational Embrace. <http://www.gemini.edu/twinspiral> (accessed September 19, 2016).

Genetic Science Learning Center, University of Utah. N.d. Homeotic Genes and Body Patterns. <http://learn.genetics.utah.edu/content/basics/hoxgenes/> (accessed October 21, 2016).

Geology Cafe. 2012. Precipitation and Relief Map of California. [http://geologycafe.com/california/maps/california\\_precipitation&relief1.htm](http://geologycafe.com/california/maps/california_precipitation&relief1.htm) (accessed October 20, 2016).

Gewin, Virginia. 2003. "Genetically Modified Corn—Environmental Benefits and Risks." *PLoS Biology* 1 (1): e8.



Grant, Peter R., and B. Rosemary Grant. 2014. *40 Years of Evolution: Darwin's Finches on Daphne Major Island*. Princeton: Princeton University Press.

Howard Hughes Medical Institute. 2014. The Origin of Species: The Beak of the Finch. <http://www.hhmi.org/biointeractive/origin-species-beak-finch> (accessed February 8, 2017).

InquireBotany. N.d. "Can You See the Difference between Wind Pollinated and Insect Pollinated Flowers?" [http://www.inquirebotany.org/uploads/files/lesson%20plan\\_wind%20and%20insect%20pollination\(NBGB\).pdf](http://www.inquirebotany.org/uploads/files/lesson%20plan_wind%20and%20insect%20pollination(NBGB).pdf) (accessed September 13, 2016).

Intergovernmental Panel on Climate Change (IPCC). 2014. *Climate Change 2014: Impacts, Adaptation, and Vulnerability: Working Group II Contribution to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*. New York: Cambridge University Press.

Janulaw, Al, and Judy Scotchmoor. 2011. UCMP Lessons: Clipbirds. <http://www.ucmp.berkeley.edu/education/lessons/clipbirds/> (accessed October 24, 2016).

Keeley, Page, Francis Eberle, and Joyce Tugel. 2007. *Uncovering Student Ideas in Science: Vol. 2, 25 More Formative Assessment Probes*. Arlington, VA: NSTA Press.

Keller, Gerta. 2011. "The Cretaceous–Tertiary Mass Extinction: Theories and Controversies." *SEPM Special Publication* 100: 7–22.

Klausmeyer, Kirk, and Katherine Fitzgerald. 2012. *Where Does California's Water Come From? Land Conservation and the Watersheds that Supply California's Drinking Water*. A Science for Conservation Technical Brief. An unpublished report of The Nature Conservancy. San Francisco, CA.

Lawson, Ruth. 2007. "Anatomy and Physiology of Animals Various Vertebrate Limbs." Posted at *Wikimedia Commons*, [https://commons.wikimedia.org/wiki/File:Anatomy\\_and\\_physiology\\_of\\_animals\\_Various\\_vertibrate\\_limbs.jpg](https://commons.wikimedia.org/wiki/File:Anatomy_and_physiology_of_animals_Various_vertibrate_limbs.jpg) (accessed September 7, 2016).

Lim, Elliot. 2008. "Age of Oceanic Lithosphere." Posted at *Wikimedia Commons*, [https://commons.wikimedia.org/wiki/File:2008\\_age\\_of\\_ocean\\_plates.png](https://commons.wikimedia.org/wiki/File:2008_age_of_ocean_plates.png)

Mackey, Benjamin H., Joshua J. Roering, and Michael P. Lamb. 2011. "Landslide-Dammed Paleolake Perturbs Marine Sedimentation and Drives Genetic Change in Anadromous Fish." *Proceedings of the National Academy of Sciences of the United States of America* 108 (47): 18905–18909. <http://www.pnas.org/content/108/47/18905> (accessed October 20, 2016).

Media College. N.d. Sound Waves. <http://www.mediacollege.com/audio/01/sound-waves.html> (accessed July 26, 2016).

Meléndez, A. and Molina, E. 2008. “The Cretaceous-Tertiary (KT) Boundary.” In *Contextos Geológicos Españoles*, edited by Angel García-Cortés, José Águeda Villar, Jaime Palacio Suárez-Valgrande, and Carlos I Salvador González. Madrid: Publicaciones del Instituto Geológico y Minero de España, 107–113. <http://wzar.unizar.es/perso/emolina/pdf/MelendezMolina2008chapter9IGME.pdf> (accessed September 14, 2016).

Meyer, Walter H. 1938. “Yield of Even-Aged Stands of Ponderosa Pine.” U.S. Department of Agriculture Technical Bulletin 630. [http://www.fire.ca.gov/resource\\_mgt/downloads/forestry/yield\\_tables/YieldTableEvenAgedPonderosaPineMeyer.pdf](http://www.fire.ca.gov/resource_mgt/downloads/forestry/yield_tables/YieldTableEvenAgedPonderosaPineMeyer.pdf) (accessed September 13, 2016).

NASA. 2008. Chapter 4. Angle of Light Rays and Surface Distribution: A Structured-Inquiry Activity. [https://www.nasa.gov/centers/langley/pdf/245895main\\_MeteorologyTeacherRes-Ch4.r3.pdf](https://www.nasa.gov/centers/langley/pdf/245895main_MeteorologyTeacherRes-Ch4.r3.pdf) (accessed September 7, 2016).

———. 2014. All Dry on the Western Front. <http://earthobservatory.nasa.gov/IOTD/view.php?id=82910> (accessed September 12, 2016).

———. 2016. GISS Surface Temperature Analysis (GISTEMP). <http://data.giss.nasa.gov/gistemp/> (accessed September 7, 2016).

NASA/Goddard Space Flight Center. 2008. “Blue Marble (Planet Earth).” Posted at Flickr by woodleywonderworks, <https://www.flickr.com/photos/wwwworks/2222523486/>

National Research Council. 1995. *Effects of Past Global Change on Life*. Washington, D.C.: National Academies Press.

Netburn, Donna. 2016. “Dinosaurs were in Decline Long before the Chicxulub Asteroid Finished Them off.” <http://www.latimes.com/science/sciencenow/la-sci-sn-dinosaur-decline-before-asteroid-20160418-story.html> (accessed February 8, 2017).

NGSS Lead States. 2013. Appendix F – Science and Engineering Practices in the NGSS. <http://www.nextgenscience.org/sites/default/files/Appendix%20F%20%20Science%20and%20Engineering%20Practices%20in%20the%20NGSS%20-%20FINAL%20060513.pdf> (accessed October 20, 2016).



- Ninjatacoshell. 2009. "Keichousaurus Hui Fossil." Posted at *Wikimedia Commons*, [https://commons.wikimedia.org/wiki/File:Keichousaurus\\_hui\\_fossil.JPG](https://commons.wikimedia.org/wiki/File:Keichousaurus_hui_fossil.JPG)
- Pearce, Andrew J., and Alex John Watson. 1986. "Effects of Earthquake-Induced Landslides on Sediment Budget and Transport over a 50-yr Period." *Geology* 14 (1): 52–55.
- Pittsburgh City Photographer. 1917. *15 Years of Typhoid*. <http://historicpittsburgh.org/islandora/object/pitt%3A715.174433.CP> (accessed September 7, 2016).
- Population Reference Bureau. 2013. World Population Data Sheet. [http://www.prb.org/pdf13/2013-population-data-sheet\\_eng.pdf](http://www.prb.org/pdf13/2013-population-data-sheet_eng.pdf) (accessed January 4, 2017).
- . 2016. World Population Data Sheet. <http://www.prb.org/pdf16/prb-wpds2016-web-2016.pdf> (accessed January 4, 2017).
- Rathbun, J.A., J.R. Spencer, A.G. Davies, R.R. Howell, and Lionel Wilson. 2002. "Loki, Io: A Periodic Volcano." *Geophysical Research Letters* 29. (10): 84-1–84-4.
- Rohde, Robert A., and Richard A. Muller. 2005. "Cycles in Fossil Diversity." *Nature* 434 (7030): 208–210.
- Roth, Mitchel. 1997. "Cholera, Community, and Public Health in Gold Rush Sacramento and San Francisco". *Pacific Historical Review* 66 (4): 527–551.
- Ruggerone, Gregory. 2008. "Evaluation of Salmon and Steelhead Migration after a Landslide on the Sultan River. Phase I: Fish Passage Assessment." Prepared for Snohomish County Public Utility District 1.
- Sadler, Philip, Gerhard Sonnert, Harold P. Coyle, Nancy Cook-Smith, Jaimie L. Miller. 2013. "The Influence of Teachers' Knowledge on Student Learning in Middle School Physical Science Classrooms." *American Educational Research Journal*. 50 (5): 1020–1049.
- Sherriff, Robert. 2015. "Middle School Madness Part 2: Integrated Science versus Coordinated Science." *California Classroom Science* 28: 10/11.
- Summey, Barbara. N.d. The Hadley Effect. Southwest Climate Network. From the NASA Goddard Visualization Analysis Lab. [http://www.southwestclimatechange.org/figures/hadley\\_cells](http://www.southwestclimatechange.org/figures/hadley_cells)
- Sussman, Art. 2000. *Dr. Art's Guide to Planet Earth*. White River Junction, VT: Chelsea Green Publishing Company.

———. 2006. *Dr. Art's Guide to Science*. San Francisco: Jossey-Bass.

Swanson, F.J., R.L. Fredriksen, and F.M. McCorison. 1982. "Material Transfer in a Western Oregon Forested Watershed." In *Analysis of Coniferous Forest Ecosystems in the Western United States*, by Robert L. Edmonds. Stroudsburg, Pa: Hutchinson Ross Publishing Company, 233–266.

Thebiologyprimer. 2015. "Relationship between Latitude vs. Temperature and Precipitation." Posted at *Wikimedia Commons*, [https://commons.wikimedia.org/wiki/File:Relationship\\_between\\_latitude\\_vs.\\_temperature\\_and\\_precipitation.png](https://commons.wikimedia.org/wiki/File:Relationship_between_latitude_vs._temperature_and_precipitation.png) (accessed September 13, 2016).

Tkgd2007. 2008. "Human Evolution." Posted at *Wikimedia Commons*, [https://commons.wikimedia.org/wiki/File:Human\\_evolution.svg](https://commons.wikimedia.org/wiki/File:Human_evolution.svg)

United States Geological Survey (USGS). 1988. "Landslides, Floods, and Marine Effects of the Storm of January 3-5, 1982, in the San Francisco Bay Region, California." USGS Professional Paper 1434.

———. 1995. Inventory of Landslides Triggered by the 1994 Northridge, California Earthquake. USGS Open File Report 95-213. <http://pubs.usgs.gov/of/1995/ofr-95-0213/> (accessed September 29, 2016).

———. 1999. Snider-Pellegrini Wegener Fossil Map. <http://pubs.usgs.gov/gip/dynamic/continents.html> (accessed October 20, 2016).

University of Wisconsin. 2010. UW Extension AG Weather. <http://agwx.soils.wisc.edu/>

U.S. Energy Information Administration. 2012. International Energy Statistics. <http://www.eia.gov/cfapps/ipdbproject/IEDIndex3.cfm?tid=90&pid=44&aid=8> (accessed October 20, 2016).

Viégas, Fernanda, and Martin Wattenberg. 2016. Wind Map. <http://hint.fm/wind/> (accessed September 6, 2016).

Wegener, Alfred. 1912. "The Origins of Continents." Translated by Roland von Huene. *International Journal of Earth Sciences* 91: S4–S17.

Zimmer, Carl. 2016. "From Fins into Hands: Scientists Discover a Deep Evolutionary Link." [https://www.nytimes.com/2016/08/18/science/from-fins-into-hands-scientists-discover-a-deep-evolutionary-link.html?\\_r=1](https://www.nytimes.com/2016/08/18/science/from-fins-into-hands-scientists-discover-a-deep-evolutionary-link.html?_r=1) (accessed February 8, 2017).