Chapter 8
High School Four-Course Model

2016 Science Framework

FOR CALIFORNIA PUBLIC SCHOOLS
Kindergarten Through Grade Twelve

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To view the remaining sections of the 2016 California Science Framework on the CDE website, go to: https://www.cde.ca.gov/ci/sc/cf/cascienceframework2016.asp

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

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

High School Four-Course Model

Introduction to Grades Nine Through Twelve

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

Before schools and districts can fully implement the CA NGSS, they must organize the high school grade-banded performance expectations into courses. This chapter describes ways in which the performance expectations for high school could be bundled together into instructional segments to form an appropriate sequence of courses. This chapter describes one of two high school course sequences: the High School Four-Course Model. The High School Three-Course Model is described in chapter 7. Additionally, appendix 4 in this framework outlines an integrated three-year high school model called Every Science, Every Year.

High School Four-Course Model Introduction

The High School Four-Course Model is based on the Science Domains Model in which one course is assigned to one domain of the CA NGSS: life science (LS), physical science (PS), and Earth and space science (ESS). The physical science performance expectations have been further subdivided to define a chemistry course and a physics course. The High School Three-Course Model contains the Living Earth, Chemistry in the Earth System, and Physics of the Universe courses. The three-course model combines all high school performance expectations into three courses. To highlight the nature of Earth and space sciences (ESS) as an interdisciplinary pursuit with crucial importance in California, the three courses present an integration of Earth and space science and one of the other high school disciplines.

Organization Within Courses

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

This framework provides examples and suggestions; it does not dictate requirements. The specific performance expectations in each instructional segment bundle presented in this chapter are only one example of the way performance expectations could be coherently organized. There are a variety of possible alternative paths and different interplays among overarching themes identified in each instructional segment bundle. Educators should consider their local context as they reflect upon these examples. Instructional sequences are most effective when they are designed to meet the needs of the specific students who will be participating in them.

The teaching of science and engineering content should be integrated with the teaching of the practices of scientists and engineers. It is through the integration of content and practices "that science begins to make sense and allows students to apply the material" (NGSS Lead States 2013b). The CA NGSS encourage teachers and students to engage with specific topics in depth, emphasizing critical thinking along with primary investigations such as in the context of case studies.

Essential Shifts in the CA NGSS

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

All Standards, All Students

The CA NGSS high school performance expectations are the assessable statements of what *all* students should know and be able to do by the end of grade twelve. In other words, the performance expectations represent the minimal assessable standards for which all high school students should be held accountable. Each of the performance expectations has assessment boundaries to guide those who construct standardized assessments. Thus, the performance expectations set a minimum goal, and high school science teachers should include additional expectations as appropriate for the goals of their courses. Teachers should pay close attention to the DCIs, SEPs, and CCCs and develop each to the depth appropriate for the goals of their class using the resources in the CA NGSS appendixes.

Course-Sequencing Discussion

California's high schools operate largely under local control. As such, course offerings and the order in which courses are offered for high school science are local education agency (LEA) decisions. As a result, this framework prescribes neither the courses to be offered nor the order in which they are offered. Instead, LEAs may consider multiple course sequences. The proposed Every Science, Every Year integrated model (appendix 4 of this framework) has a set sequence but the four-course discipline specific and three-course integrated Earth and space science models do not.

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

The order in which high school science courses have traditionally been offered—biology, chemistry, and then physics—has been in place for more than 100 years since the Committee of Ten first met. In our twenty-first century world, this may not make the most sense. As LEAs decide among the twenty-four permutations for course sequence in the four-course model and six possibilities for the three-course model, they need to be thoughtful about their choices and consider carefully the implications of the selected sequence. Strong arguments can be made for any of the sequences.

The questions and prompts below are meant to help LEAs with the decision:

- Is the goal to get students to take more science and science, technology, engineering and math (STEM) classes? If so, consider placing the most engaging and exciting classes as the first courses in the sequence. That may recruit more students into STEM and science classes (and possible STEM-related careers and college majors).
- What course(s) are viewed as most important to the community? Put those classes first because some percentage of students will take the minimum requirements for graduation.
- How many science classes are students in the LEA required to take in order to graduate? How many science classes do students in the LEA *typically* take? What science concepts and ideas does the LEA want to be sure that all students have if they do not take the full scope of CA NGSS? These questions all have implications for choosing which classes (and ideas) come earliest.
- What science ideas does the LEA think juniors and seniors are more developmentally ready to learn than freshmen and sophomores?
- What concepts and ideas does the LEA think are more concrete so should be placed earlier in the sequence, with more abstract ideas coming later in the learning process?
- As the LEA considers individual discipline focused classes, they should look at the performance expectations. Are there performance expectations from other disciplines that should be mastered for students to be successful in a particular course? If so, that has implications for sequencing.

The decision LEAs are being asked to make is not trivial. Therefore, LEAs should spend time on the decision and consult with their science teachers. Ultimately, the LEA needs to determine a two-, three- or four-year sequence of course offerings. Whichever course sequence is selected, the LEA needs to consider the learning that takes place in earlier classes that will support and impact learning that comes later. The purpose of science classes is not merely to prepare students for other courses, but to demonstrate that courses are interconnected and that disciplines overlap (think about those crosscutting concepts which underpin all of science). Ideas and concepts learned in one content area come into play when learning a new science discipline. These should be considered as the LEA determines in what order to place courses.

Biology Early or Late in the Sequence?

There are several good arguments for placing biology early in the sequence: (1) biology has a better track record of interesting girls in science (AAUW 2010; Baram-Tsabari and Yarden 2011); (2) some teachers are more comfortable with its earlier placement in the sequence; and (3) students are generally interested in themselves, so a course that helps them understand themselves could be a good starting point. However, modern biology requires understanding and applying chemistry and physics, and much of biology today explores and explains things at the molecular or cellular level. Therefore, the LEA should consider the following question: How could topics in high school biology be taught differently if chemistry, for example, were taken prior to biology as opposed to afterwards?

Chemistry Early or Late in the Sequence?

As mentioned above, modern biology is heavily influenced by chemistry. Therefore, having chemistry prior to biology may be instructionally efficient. For example, concepts already studied in a chemistry class should require less emphasis and subsequently less time, leaving room for more in-depth biology concepts. On the other hand, chemistry is rather abstract, dealing with phenomena unseen to the naked eye and frequently unintuitive to students. Knowing the students and community will help the LEA decide if students can handle the more abstract science ideas earlier in their academic career. An understanding of physics prior to chemistry could help students better understand atomic structure, electron shells and orbitals, and bonding. Just as comfort with mathematics is an argument used for determining where physics should be offered, it can be argued that chemistry also requires a level of mathematical competence.

Physics Early or Late in the Sequence?

Physics has traditionally been offered late in the sequence to a small population of students. Many argue having physics later in the course sequence allows concepts to be introduced through a more mathematically rigorous lens. Others argue having physics earlier in the sequence is approachable to students as the concepts are concrete and relate to students' everyday lives. Physics *prior* to chemistry or Earth and space sciences means students bring an understanding of the mechanisms for much of the physical world to their studies. Physics *after* chemistry or Earth and space sciences allows the opportunity to revisit ideas learned earlier. Physics early in the sequence, taken by all students, might attract more students to pursue the physical sciences—especially girls and underrepresented populations who traditionally avoid the physical sciences (Institute of Physics 2006).

Earth and Space Sciences Early or Late in the Sequence?

Modern Earth and space sciences comprise an integrated discipline, which uses life and physical sciences to understand the universe. Earth and space sciences as an early course can be grounded in California phenomena, serve as a teaser for future classes, and introduce students to concepts that will be developed in later science classes. However, as a later course it can be a culminating capstone-like experience tying together and using concepts from other disciplines as they apply to phenomena in our state and universe.

High School Four-Course Model: Life Science/Biology

Introduction to the Biology Course

According to the Next Generation Science Standards:

> Students in high school develop understanding of key concepts that help them make sense of life science. The ideas are building upon students' science understanding of disciplinary core ideas, science and engineering practices, and crosscutting concepts from earlier grades. There are five life science topics in high school: 1) Structure and Function, 2) Inheritance and Variation of Traits, 3) Matter and Energy in Organisms and Ecosystems, 4) Interdependent Relationships in Ecosystems, and 5) Natural Selection and Evolution. The performance expectations for high school life science blend core ideas with scientific and engineering practices and crosscutting concepts to support students in developing useable knowledge that can be applied across the science disciplines. While the performance expectations in high school life science couple particular practices with specific disciplinary core ideas, instructional decisions should include use of many practices underlying the performance expectations. The performance expectations are based on the grade-band endpoints described in A Framework for K–12 Science Education. (NGSS Lead States 2013e)

The study of life science spans from microscopic proteins to entire ecosystems and includes an understanding of human body systems. While biology emphasizes the relationship between structures and their functions, the scale of structures is perhaps less important than the processes and mechanisms of the functions. Students are finally able to explain patterns that they identified and asked questions about during their K–8 education. Some of these processes occur in the blink of an eye while others take millions of years to unfold. Despite the extreme spans in scale, students have tools to use evidence, evaluate claims, and develop models to interpret the unseen. Students begin with phenomena and use them to enhance their understanding of core ideas in biological science.

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

This example course is divided into instructional segments centered on questions about observations of a specific phenomenon. Different phenomena require different amounts of investigation to explore and understand, so each instructional segment should take a different fraction of the school year. As students achieve the performance expectations within the instructional segment, they uncover **disciplinary core ideas (DCIs)** from life science and engineering. Students engage in multiple practices in each instructional segment, not only those explicitly indicated in the performance expectations. Students also focus on one or two **crosscutting concepts (CCCs)** as tools to make sense of their observations and investigations; the CCCs are recurring themes in all disciplines of science and engineering and help tie these seemingly disparate fields together.

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

Example Course Mapping for a Life Science/Biology Course

Throughout the course, students consider what it means to be living and what characterizes life. The instructional segments in table 8.1 match the sequence in appendix K of the CA NGSS. The segments are grouped into four clusters that each build upon one another. The clusters could be rearranged in a different sequence to match a different conceptual flow, though the depth and complexity of each topic would have to be adjusted accordingly.

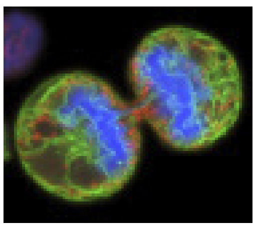
The example course ends with a culminating experience tying together how organisms maintain life from the single cell to the multicelled organism and how the environments they live in provide a rich integration of what students learned in their yearlong biology course. In this experience, students use the following **science and engineering practices (SEPs)** to illustrate how all living things maintain life: **evidence [SEP-7]**, **arguments [SEP-7]**, **explanations [SEP-6]**, and **design solutions [SEP-6]**.

Table 8.1. Overview of Instructional Segments for High School Biology

FROM MOLECULES TO ORGANISMS: STRUCTURES AND PROCESSES

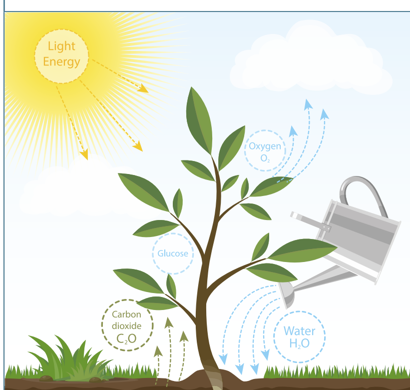
1 Structure and Function

All cells contain genetic information in the form of deoxyribonucleic acid (DNA) molecules. DNA provides the blueprint for building proteins so that cells can function. Cells are living organisms that can carry on life and can work together to become organs and organ systems. What happens when organs fail? How do diseases affect cells?



2 Growth and Development of Organisms

One characteristic of life is the growth of organisms. For organisms to grow, parent cells have to pass on their genetic information to daughter cells, which happens during cell division. Once cell division occurs, cells can then differentiate into specific cell types.



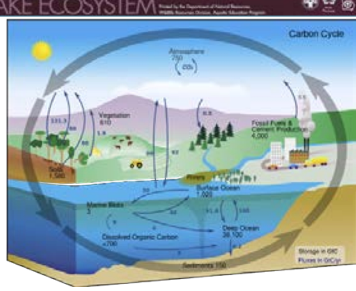
3 Organization for Matter and Energy Flow in Organisms

Students track the movement of matter and energy through plants and animals and relate the flow to photosynthesis and cellular respiration. These processes interact to provide energy for living systems (from the individual all the way to the ecosystem).

ECOSYSTEMS: INTERACTIONS, ENERGY, AND DYNAMICS

4 Interdependent Relationships in Ecosystems

Resources determine the carrying capacity of populations of organisms living in an ecosystem. Abiotic and biotic changes can alter resource availability and affect populations.



5 Cycles of Matter and Energy Flows in Ecosystems

Students model the cycling of matter in ecosystems (including the carbon and nitrogen cycles) and relate these cycles to energy transfer. Animals use most of the energy they consume for survival, and only about 10 percent is stored within their biomass.

6 Ecosystem Dynamics, Functioning, and Resilience

When resources are limited, all organisms in an ecosystem suffer. Humans often alter resource availability. Conservation biology examines ways to restore ecosystems that have been disrupted or destroyed.

7 Social Interactions and Group Behavior

This instructional segment focuses on the ability of gene pools in populations to be passed on as modeled in the survival of reproducing individuals, including individuals raising young (rather than having young), colonies and herds used for protecting young so traits are passed on, and other modes of group behavior.

HEREDITY: INHERITANCE AND VARIATION OF TRAIT

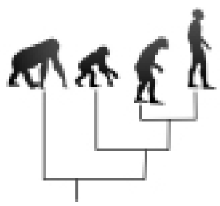
8 Inheritance of Traits

Students obtain information about the history of how the structure of DNA was understood. Students also learn that DNA provides a code that is transcribed into ribonucleic acid (RNA) and that this code is translated into a protein.

9 Variation of Traits

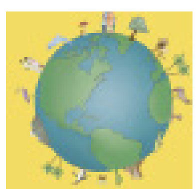
Traits are passed from generation to generation in an ordered way. Predictions of offspring traits can be made through Punnett squares. Even within the same family, organisms can have different combinations of traits.

BIOLOGICAL EVOLUTION: UNITY AND DIVERSITY



10 Evidence of Common Ancestry and Diversity
This instructional segment focuses on evidence of evolution through common ancestry, homologous and analogous structures, and commonalities of organisms.

11 Natural Selection
Darwin's observations and inferences led to our understanding of evolution. How can these be applied to all living things?



12 Adaptation and Biodiversity
This instructional segment provides a culmination of the course. Topics include how populations maintain diversity and what selective pressures mean for survival, all of which are tied to how organisms maintain life (the overarching question in biology).

Sources: PublicDomainPictures 2013; Wellcome Images 2011; Saff 2004; PollyDot 2014; Unsplash 2015; Cold Spring Harbor Laboratory n.d.; Debivort 2006; adapted from Tkgd2007 2008; Gould 1882; Environmental Management 2016 Wiki 2016

From Molecules to Organisms: Structures and Processes

Understanding the characteristics of life is the unifying theme of biology. Before starting IS1, teachers should assess what students know about the characteristics of life. For example, working in small groups, students can sort pictures of living and nonliving things into two categories and **support an argument [SEP-7]** for where they put each item. Objects can include plants, insects, mammals, electronics, plastic toys, as well as unusual examples and outliers such as a sponge, rock, lichen, tunicates, snakeskin, molds, and/or a skeleton. Students in a group come to a consensus as to what goes in each category and why. After presenting the group's thinking to the entire class and listening to the thinking of their classmates, students re-sort the items. Groups discuss the similarities and differences between the living organisms. Instructional segment 1 also builds on other key ideas in life science that students engaged in during the middle grades including (1) models of cells and how they interact in multicellular organisms (MS-LS1-1, MS-LS1-2 and MS-LS1-3) and (2) the ability to explain the role of genes and how changes in them (mutations) can cause a change in the proteins a cell constructs (MS-LS3-1 and MS-LS3-2). Formative assessments at the beginning of the course will help teachers determine what level of detail they will need to revisit to help students succeed.

Opportunities for ELA/ELD Connections

As part of the discussion to reach consensus on categorizing pictures of living and nonliving things, students develop “agree–disagree” statements and exchange ideas with one another about which pictures represent living or nonliving things, making sure they articulate their rationale. The teacher can post a sample agree statement and a sample disagree statement that model the language students are expected to use in this content area. For example, “I agree that a sponge is a living thing based on the criteria that anything that is, or ever has been, alive is a living thing” or “I disagree that a sponge is a living thing since the definition of living is something that is not dead—a sponge is dead.” As students share, the teacher can validate and guide students to self-correct their statements.

CA CCSS for ELA/Literacy Standards: SL.9–12.1

CA ELD Standards: ELD.PI. 9–12.3

IS1 Life Science/Biology Instructional Segment 1: Structure and Function

The performance expectations in the topic Structure and Function help students formulate an answer to the following question: How do the structures of organisms enable life’s functions? High school students are able to investigate explanations for the structure and function of cells as the basic units of life, the hierarchical systems of organisms, and the role of specialized cells for maintenance and growth. Students demonstrate understanding of how systems of cells function together to support the life processes. Students demonstrate their understanding through critical reading, using models, and conducting investigations. The crosscutting concepts of **structure and function [CCC-6]**, **matter and energy [CCC-5]**, and **systems and system models [CCC-4]** in organisms are called out as organizing concepts. (NGSS Lead States 2013e)

LIFE SCIENCE/BIOLOGY INSTRUCTIONAL SEGMENT 1: STRUCTURE AND FUNCTION

Guiding Questions

- How does the structure of DNA affect how cells look and behave?
- How do systems work in a multi-celled organism and what happens if there is a change in the system?
- How do organisms survive even when there are changes in their environment?

Performance Expectations

Students who demonstrate understanding can do the following:

HS-LS1-1. Construct an explanation based on evidence for how the structure of DNA determines the structure of proteins which carry out the essential functions of life through systems of specialized cells. [*Assessment Boundary: Assessment does not include identification of specific cell or tissue types, whole body systems, specific protein structures and functions, or the biochemistry of protein synthesis.*]

HS-LS1-2. Develop and use a model to illustrate the hierarchical organization of interacting systems that provide specific functions within multicellular organisms. [Clarification Statement: Emphasis is on functions at the organism system level such as nutrient uptake, water delivery, and organism movement in response to neural stimuli. An example of an interacting system could be an artery depending on the proper function of elastic tissue and smooth muscle to regulate and deliver the proper amount of blood within the circulatory system.] [*Assessment Boundary: Assessment does not include interactions and functions at the molecular or chemical reaction level.*]

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

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

Highlighted Science and Engineering Practices	Highlighted Disciplinary Core Ideas	Highlighted Crosscutting Concepts
[SEP-2] Developing and Using Models [SEP-3] Planning and Carrying Out Investigations [SEP-6] Constructing Explanations (for science) and Designing Solutions (for engineering)	LS1.A: Structure and Function	[CCC-4] Systems and System Models [CCC-6] Structure and Function [CCC-7] Stability and Change

CA CCSS for ELA/Literacy Connections: RST.11–12.1; WHST.11–12.2a–e, 7, 8, 9; SL.11–12.5

CA ELD Connections: ELD.PI.9–10.1, 5, 6a–b, 9, 10, 11a

Human skin cells have a lifespan of only a few weeks before they die off, but we do not really notice because the new ones look identical to the old ones. We see evidence for this skin loss as we scrape off dead skin. How do cells do this? Students can watch cells divide during a video and observe that the two cells at the end look identical. What is the mechanism for making such exact copies? Instructional segment 1 and instructional segment 2 help students answer these questions.

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

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

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

Historically, most of these connections were made by looking at mutants, and now students can observe this by looking at loss of function in strains of bacteria[1] or mutant strains of fast-growing plants.[2] Mutation gene maps for model organisms are available

1. It is possible to buy safe bacteria strains that are resistant to antibiotics from many biological supply companies and compare those strains to ones that are not resistant or to ones that grow in the presence of lactose and ones that cannot breakdown lactose and therefore change color.
2. A search on the Internet should provide links to companies that maintain normal and mutant seed stocks.

and students can refer to these as they look at mutated phenotypes. Students can then gather **evidence [SEP-7]** to construct an **explanation [SEP-6]** for how a specific DNA sequence causes a specific loss of function, and can use this specific case to support the claim that there is a connection between DNA, the proteins cells produce, and the physical features of an organism (HS-LS1-1). In preparation for IS4 and IS11, students can **plan and carry out investigations [SEP-3]** to determine if mutants can grow in varying environments. Because students will need to refer back to their data to look at variations within populations and effects of environment on individuals within populations, teachers will need to introduce an organizational structure such as science notebooking or the twenty-first century version of a notebook—student-created Web pages that describe investigations using data stored in collaborative Web-based spreadsheets.

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

One of the ways that cells work together in tissues, organs, and finally organ systems is to maintain **stability [CCC-7]** through homeostasis. Maintaining homeostasis means that despite changes in the environment, an organism has the ability to maintain certain internal chemical and physical states. Students can measure their internal body temperature on a cold morning, a hot day, or after vigorous exercise. Even as the temperature outside spans as much as 40°C, a person's internal temperature only varies by a few degrees. How does this happen and why does the body work so hard to maintain a constant temperature? The significance is in the functioning of proteins, especially when considering enzymes, which usually have a fairly narrow range within their environment in which they can function correctly. For multicellular organisms, the first line of regulation is through their skin or outer layer (epithelium), which responds to stimuli in the environment. The brain then processes these stimuli and activates balancing feedback mechanisms to counteract the environmental change. When it is hot, mammals sweat or pant, and when it is cold, they shiver. Students can **plan and conduct investigations [SEP-3]** in which they change conditions for plants or animals and watch how they respond (HS-LS1-3). They can measure their own heart rate returning to normal after vigorous exercise, observe plants growing taller in the dark until they reach new light sources, or observe the behavioral response of Planaria (flatworms) as the amount of light changes. Students do not need to explain the specific mechanisms that accomplish these changes (e.g. photosensitivity, hormone distribution, avoidance, etc.), but they should gather evidence that organisms respond to changes and use that evidence to construct a conceptual **model [SEP-2]** that can predict outcomes of future experiments that vary parameters from their initial trials.

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

Opportunities for ELA/ELD Connections

Working with partners, students select a human disease to research and construct an explanation to answer the following questions: What are the multiple effects of (selected disease) on the human body? and What are the current treatments or solutions that modern medicine has found? Each pair will prepare a visual display to be used in a medical office to help patients understand the disease. They must research multiple print and digital sources, synthesize and summarize the key points, and present their findings using a visual display (e.g., poster, slides, handouts). As students work, the teacher can validate, encourage, and challenge students (particularly English learners) to use the appropriate academic lexicon in clear sentences

CA CCSS for ELA/Literacy Standards: WHST.9–12.7, 8; RST.9–12.1, 2, 7, 9
CA ELD Standards: ELD.PI. 9–12.6, 9

IS2 Life Science/Biology Instructional Segment 2: Growth and Development of Organisms

Students constructed explanations of how genetics and environment both contribute to the growth of organisms (MS-LS1-5), and supported an argument about how specific traits enable organisms to survive and reproduce (MS-LS1-4). In IS2, students develop a model of the specific mechanisms by which growth occurs. This model also helps explain the mechanisms by which successful traits get passed down from parent to offspring.

LIFE SCIENCE/BIOLOGY INSTRUCTIONAL SEGMENT 2: GROWTH AND DEVELOPMENT OF ORGANISMS

Guiding Questions

- How do organisms grow?
- How do cells create exact copies of themselves?

Performance Expectations

Students who demonstrate understanding can do the following:

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

HS-LS3-1. Ask questions to clarify relationships about the role of DNA and chromosomes in coding the instructions for characteristic traits passed from parents to offspring. [*Assessment Boundary: Assessment does not include the phases of mitosis or the biochemical mechanism of specific steps in the process.*] (Introduced but not assessed until IS8).

LIFE SCIENCE/BIOLOGY INSTRUCTIONAL SEGMENT 2: GROWTH AND DEVELOPMENT OF ORGANISMS

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

Highlighted Science and Engineering Practices	Highlighted Disciplinary Core Ideas	Highlighted Crosscutting Concepts
[SEP-1] Asking Questions and Defining Problems [SEP-2] Developing and Using Models	LS1.A: Structure and Function LS1.B: Growth and Development of Organisms LS3.A: Inheritance of Traits	[CCC-2] Cause and Effect: Mechanism and Explanation [CCC-4] Systems and System Models

CA CCSS Math Connections: F-IF.7.a–e; F-BF.1a–c; MP.2, MP.4

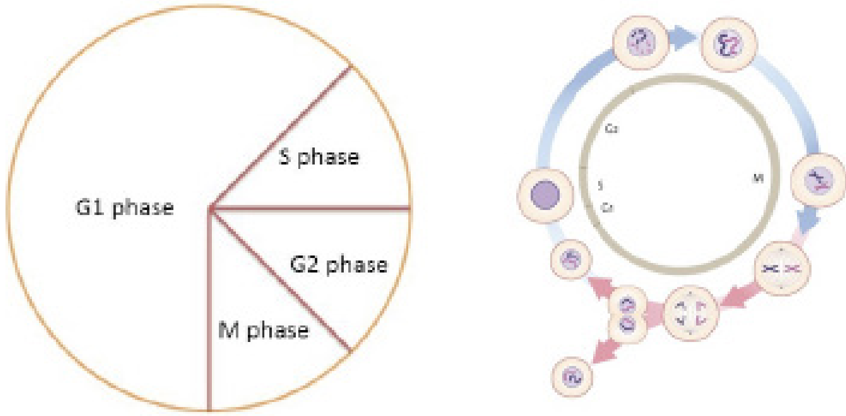
CA CCSS for ELA/Literacy Connections: RST.11–12.1, 9; SL.11–12.5

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

One of the characteristics of life is the ability to grow (whether as a single cell or as a multicellular organism). In the 1860s, Rudolf Virchow proposed that new cells arose from pre-existing cells. As microscope technology advanced in the late 1800s, scientists were able to gather direct evidence supporting Virchow's claim. To go from a single cell (fertilized egg) to a multicellular organism, cells produce more cells. As unicellular organisms reproduce, they also make more cells. In both cases, information gets copied from the parent to the daughter cells. From IS1, students know that DNA records this information, but how do cells duplicate DNA?

Cells, just like organisms, have a life cycle referred to as the cell cycle (figure 8.1). The cell cycle is a conceptual model that describes the essential events in a cell's life. The assessment boundaries for HS-LS1-4 and HS-LS3-1 are clear that rote memorization of different stages of the cell cycle or mitosis is not the goal of the CA NGSS. One of the common consequences of differentiating between these stages is that students think of them as separate and independent events rather than a continuous process. Students should be able to describe the events and sequence of the cell-cycle model. They should be able to describe how the stages contribute to the overall goal of the process. In particular, students should ensure that their model includes the idea that organisms that reproduce sexually (involving meiosis) contain two sets of genetic material, one set from each parent. Students should begin to ask questions about how these duplicate copies of DNA determine which traits offspring inherit from their parents (HS-LS3-1). Students should be able to use their model of the cell cycle to explain how organisms grow, how multicellular organisms copy the same genetic code but differentiate into different cell types, and how organisms replace dead cells with new ones (HS-LS1-4). Students can also apply their model to predict what happens when there are mistakes in this process. For example, what would happen if the stages of mitotic cell division do not occur in order (i.e. if cytokinesis occurs before mitosis)? Students can also use the model to explain cancer[3] and the effects of unchecked, out-of-control cell division on normal cell function.

Figure 8.1. Two Pictorial Models of the Stages of the Cell Cycle



Stages of the cell cycle. On the left, the size of the pie is proportional to the time spent in each phase. On the right, the icons visually depict what happens at each stage. *Source*: V. Vandergon; Genomics Education Programme 2014
Long description of Figure 8.1.

Cell division is the first part in the growth of an organism and as new cells are formed in multicellular organisms, they differentiate into specific cell types. These specific cell types then participate in the formation of a tissue, which then forms organs that are often parts of a physiological system in multicellular organisms (this links back to IS1). Many multicellular organisms stop growing once they reach adulthood, but mitosis does not stop. Some cells die off as they reach the end of their life cycle and these dead cells are replaced. This replacement of dead cells occurs through mitosis of the remaining living cells. Extensions of this instructional segment might include discussions of stem cells that have not yet differentiated and have the ability to become a variety of types of cells, leading to new tissue and organ formation. Stem cells use in organ transplant is one way that scientists are helping decrease rejection of transplanted organs by the recipient of the donated organ.

3. Resources are available to look at cancer rates and types. See https://www.cde.ca.gov/ci/sc/cf/ch8.asp#link1, which has short YouTube videos as well as the latest on cancer research. Make sure to use reputable government supported research sites.

Stem cells can be used to generate signals for the recipient's body so that their immune system thinks that the organ belongs there.

Engineering Connection: Organ Donation

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

IS3

Life Science/Biology Instructional Segment 3: Organization for Matter and Energy Flow in Organisms

In the middle grades, students explained how energy and matter cycled into and out of organisms (MS-LS1-6) and created a model describing how chemical reactions deconstruct food molecules in organisms, rearrange them, and reconstruct them to make biomass and obtain energy (MS-LS1-7). Now, they look at the chemical reactions in more detail, modeling them as chemical equations and tracking the flow of energy and matter within an organism.

LIFE SCIENCE/BIOLOGY INSTRUCTIONAL SEGMENT 3: ORGANIZATION FOR MATTER AND ENERGY FLOW IN ORGANISMS

Guiding Questions

- How do living things acquire energy and matter for life?
- How do organisms store energy?
- How are photosynthesis and cellular respiration connected?
- How do organisms use the raw materials they ingest from the environment?

Performance Expectations

Students who demonstrate understanding can do the following:

HS-LS1-5. Use a model to illustrate how photosynthesis transforms light energy into stored chemical energy. [Clarification Statement: Emphasis is on illustrating inputs and outputs of matter and the transfer and transformation of energy in photosynthesis by plants and other photosynthesizing organisms. Examples of models could include diagrams, chemical equations, and conceptual models.] [*Assessment Boundary: Assessment does not include specific biochemical steps.*]

LIFE SCIENCE/BIOLOGY INSTRUCTIONAL SEGMENT 3: ORGANIZATION FOR MATTER AND ENERGY FLOW IN ORGANISMS

HS-LS1-6. Construct and revise an explanation based on evidence for how carbon, hydrogen, and oxygen from sugar molecules may combine with other elements to form amino acids and/or other large carbon-based molecules. [Clarification Statement: Emphasis is on using evidence from models and simulations to support explanations.] [*Assessment Boundary: Assessment does not include the details of the specific chemical reactions or identification of macromolecules.*]

HS-LS1-7. Use a model to illustrate that cellular respiration is a chemical process whereby the bonds of food molecules and oxygen molecules are broken and the bonds in new compounds are formed resulting in a net transfer of energy. [Clarification Statement: Emphasis is on the conceptual understanding of the inputs and outputs of the process of cellular respiration.] [*Assessment Boundary: Assessment should not include identification of the steps or specific processes involved in cellular respiration.*]

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

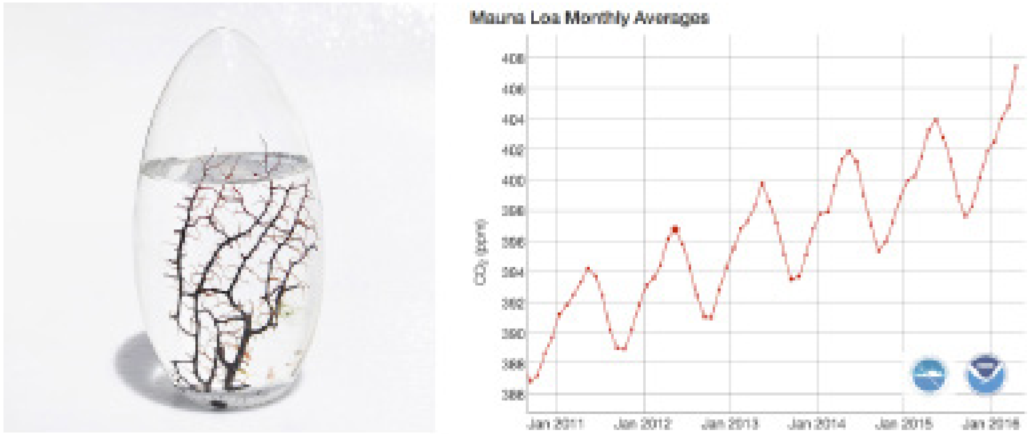
Highlighted Science and Engineering Practices	Highlighted Disciplinary Core Ideas	Highlighted Crosscutting Concepts
[SEP-2] Developing and Using Models [SEP-6] Constructing Explanations (for science) and Designing Solutions (for engineering)	LS1.C Organization for Matter and Energy Flow in Organisms	[CCC-5] Energy and Matter: Flows, Cycles, and Conservation

CA CCSS for ELA/Literacy Connections: RST.11–12.1; WHST.9–12.2.a–e, 5, 9; SL.11–12.5

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

Students can consider the phenomenon of a sealed glass sphere that supports the survival and growth of both algae and brine shrimp (figure 8.2, left). How do they survive without air flowing in? On a more advanced level, they can observe how the global atmospheric CO_2 concentrations on Earth follow a distinctive **pattern [CCC-1]** each year (figure 8.2, right; caused by the fact that there is more land in the Northern Hemisphere and therefore more respiration during the growing season of the Northern Hemisphere summer). They should be able to explain and model each of these processes by the end of this instructional segment.

Figure 8.2. Phenomena Illustrating Relationship Between Photosynthesis and Respiration



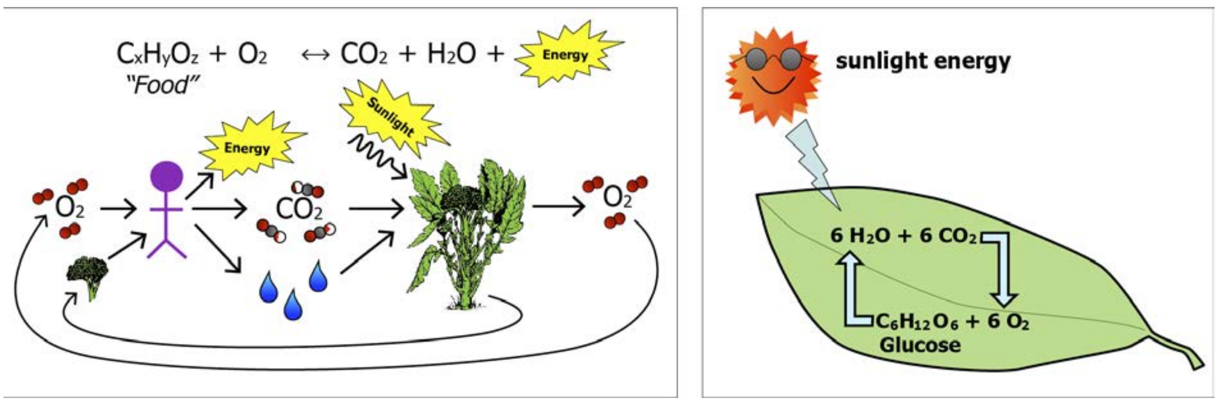
A sealed sphere that supports survival of both brine shrimp and algae (left). CO_2 levels are highest in June each year and cycle annually (right). *Source*: Ecosphere Associates Inc. 2013 and National Oceanic and Atmospheric Administration (NOAA) 2016
Long description of Figure 8.2.

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

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

The products of photosynthesis are used as the reactants for cellular respiration and vice versa. Students can create **models [SEP-2]** of these processes using chemical equations or pictorial models that emphasize the **energy and matter [CCC-5]** inputs and outputs from each process (HS-LS1-5, HS-LS1-7; figure 8.3). Sometimes both processes occur in the same organism, and sometimes the respiration occurs in a consumer after it has eaten the producer. With each cycle of organisms eating or being eaten, there is less usable energy available to the organism (a consequence of the second law of thermodynamics, HS-PS3-4). In this way, ecosystems are constantly losing usable energy and therefore rely on the Sun to provide a constant influx of energy.

Figure 8.3. Models of Photosynthesis and Respiration



Examples of models showing how photosynthesis and respiration are mirrors of one another, involving the same basic ingredients. Matter cycles within the Earth system between the two processes, but energy must constantly flow in as sunlight to replace the energy put to work by organisms to grow and survive. Diagrams by M. d'Alessio and V. Vandergon
Long description of Figure 8.3.

Students can build a physical **model [SEP-2]** of a glucose molecule and show how to split it up (with an emphasis on the components needed to build the glucose and the components left after the breakdown of the glucose). They should start with the atoms of carbon, hydrogen, and oxygen and make the simple molecules of CO_2, H_2O, and O_2 and then trace the movement of these molecules, much like they did in MS-LS1-7 but with added detail about what happens at each stage in the process. For example, the carbon dioxide and water are raw ingredients to photosynthesis and then are released as waste again in cellular respiration. Because of CO_2's role in both processes, photosynthesis and respiration are crucial parts of the global carbon cycle. Students can begin to explain the graph in figure 8.2 and teachers can draw connections to Earth science disciplinary core ideas.

A detailed model of photosynthesis and respiration can include the unique chemical properties of carbon. Carbon is structurally important to building all biological molecules including the glucose molecule. What is so special about carbon? Due to its electron structure and configuration, carbon can covalently bond to four other atoms and form single and double bonds with other atoms. The same raw materials can be recombined in different configurations with different chemical potential energy, allowing carbon-based molecules to store or release energy during these changes. Students should be able to use computer simulations of this process to help them construct explanations about how organisms build a wide range of organic molecules such as amino acids (HS-LS1-6).

Since photosynthesis and respiration are key aspects of the **flow of matter and energy [CCC-5]** in ecosystems, students are now ready to extend their model of the molecular scale processes to the scale of organisms in the next section of the course. Before they do, they can revisit the images in figure 8.2 and **explain [SEP-6]** how photosynthesis and respiration remain approximately balanced within these closed systems.

Ecosystems: Interactions, Energy and Dynamics

According to the Next Generation Science Standards:

> The performance expectations in LS2: Ecosystems: Interactions, Energy, and Dynamics help students formulate an answer to the questions, “How and why do organisms interact with their environment, and what are the effects of these interactions?” The LS2 Disciplinary Core Idea includes four sub-ideas: Interdependent Relationships in Ecosystems, Cycles of Matter and Energy Transfer in Ecosystems, Ecosystem Dynamics, Functioning, and Resilience, and Social Interactions and Group Behavior. High school students can use mathematical reasoning to demonstrate understanding of fundamental concepts of carrying capacity, factors affecting biodiversity and populations, and the cycling of matter and flow of energy among organisms in an ecosystem. These mathematical models provide support for students’ conceptual understanding of systems and their ability to develop design solutions for reducing the impact of human activities on the environment and maintaining biodiversity. The crosscutting concepts of systems and system models play a central role in students’ understanding of science and engineering practices and core ideas of ecosystems. (NGSS Lead States 2013d)

IS4 Life Science/Biology Instructional Segment 4: Interdependent Relationships in Ecosystems

Conservation is getting nowhere because it is incompatible with our Abrahamic concept of land. We abuse land because we regard it as a commodity belonging to us. When we see land as a community to which we belong, we may begin to use it with love and respect.

— Aldo Leopold, author, ecologist, and environmentalist

LIFE SCIENCE/BIOLOGY INSTRUCTIONAL SEGMENT 4: INTERDEPENDENT RELATIONSHIPS IN ECOSYSTEMS

Guiding Questions

- How and why do populations change over time?
- How do populations change when their resources become scarce?

Performance Expectations

Students who demonstrate understanding can do the following:

HS-LS2-1. Use mathematical and/or computational representations to support explanations of factors that affect carrying capacity of ecosystems at different scales. [Clarification Statement: Emphasis is on quantitative analysis and comparison of the relationships among interdependent factors including boundaries, resources, climate, and competition. Examples of mathematical comparisons could include graphs, charts, histograms, and population changes gathered from simulations or historical data sets.] [Assessment Boundary: Assessment does not include deriving mathematical equations to make comparisons.]

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

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-5] Using Mathematics and Computational Thinking	LS2.A: Interdependent Relationships in Ecosystems LS2.C: Ecosystem Dynamics, Functioning, and Resilience	[CCC-3] Scale, Proportion, and Quantity [CCC-5] Energy and Matter: Flows, Cycles, and Conservation

LIFE SCIENCE/BIOLOGY INSTRUCTIONAL SEGMENT 4: INTERDEPENDENT RELATIONSHIPS IN ECOSYSTEMS

Highlighted California Environmental Principles and Concepts:

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

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

CA CCSS Math Connections: N-Q.1–3; MP.2, MP.4

CA CCSS for ELA/Literacy Connections: RST.11–12.7; WHST.11–12.2a–e, 9

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

As Aldo Leopold implies, understanding the community as both biotic (living) and abiotic (nonliving) gives insight into how ecosystems work and the importance of all aspects of an ecosystem. In the middle grades, students defined populations and what affects changes in environment have on those populations (MS-LS2-4). Students also developed a model of how **matter cycles and energy flows [CCC-5]** through ecosystems (MS-LS2-5) and interpreted data about populations when resources are limited (MS-LS-2-1). Now, they are ready to quantify the relationship between resources and populations in ecosystems. Since the biological definition of a population (a group of individuals from the same species living together in the same geographical area at the same time), teachers should formatively assess student knowledge about populations (perhaps describing some scenarios and asking them how many separate populations they can identify).

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

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

they can describe the population changes **mathematically [SEP-5]** (HS-LS2-2). Initially growth will be exponential, but students should be able to recognize the point on the graph when competition for resources begins to dramatically impact the population size.

Students can use simulations to recognize two general types of factors that limit population growth: density-dependent factors and density-independent factors. Many factors are density dependent such as food resources, space, nesting sites, and water, meaning that the amount of these resources required depends on the population size. Density-independent factors alter the number of individuals in a population regardless of how many individuals already exist. Weather pattern changes or catastrophic events (e.g., hurricanes, floods, landslides, and volcanoes) are examples of density-independent factors. Addressing these two factors can help students understand how **proportion and quantity [CCC-3]** are essential to describing in density-dependent cases but not relevant in density-independent cases.

Many times, humans alter the availability of resources and change the landscape. For example, if a new freeway divides a population's territory in half and limits its migration, how will this cause both density-dependent and density-independent changes to the ecosystem? Human-induced changes to climate also cause changes. The Education and the Environment Initiative (EEI) Curriculum *Ecosystem Change in California*, which focuses on changes in a grassland ecosystem in the state, provides guidance teaching EP&Cs II and IV as students obtain information about both the positive and negative ways humans influence ecosystem resources. (https://www.cde.ca.gov/ci/sc/cf/ch8.asp#link2).

IS5

Life Science/Biology Instructional Segment 5: Cycles of Matter and Energy Transfer in Ecosystems

In the middle grades, students used food webs to model the flow of energy and matter in ecosystems (MS.LS1.C, LS2.A, and LS2.B). Now, they make quantitative estimates of the flow of energy, trace the flow of carbon specifically, and explain the differences between energy flow in aerobic (with oxygen) versus anaerobic (without oxygen) environments. They build on their models of respiration from IS3 and ecosystem interactions from IS4.

LIFE SCIENCE/BIOLOGY INSTRUCTIONAL SEGMENT 5: CYCLES OF MATTER AND ENERGY TRANSFER IN ECOSYSTEMS

Guiding Questions

- Why is the cycling of matter and energy important?
- How are matter and energy linked in ecosystems?

Performance Expectations

Students who demonstrate understanding can do the following:

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

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

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

LIFE SCIENCE/BIOLOGY INSTRUCTIONAL SEGMENT 5: CYCLES OF MATTER AND ENERGY TRANSFER IN ECOSYSTEMS

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

Highlighted Science and Engineering Practices	Highlighted Disciplinary Core Ideas	Highlighted Crosscutting Concepts
[SEP-2] Developing and Using Models [SEP-5] Using Mathematical and Computational Thinking [SEP-6] Constructing Explanations (for science) and Designing Solutions (for engineering)	LS2.B: Cycles of Matter and Energy Transfer in Ecosystems PS3.D: Energy in Chemical Processes	[CCC-4] Systems and System Models [CCC-5] Energy and Matter: Flows, Cycles, and Conservation

Highlighted California Environmental Principles and Concepts:

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

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

CA CCSS Math Connections: N-Q.1–3; MP.2, MP.4

CA CCSS for ELA/Literacy Connections: RST.11–12.1, WHST.11–12.2a–e, 5

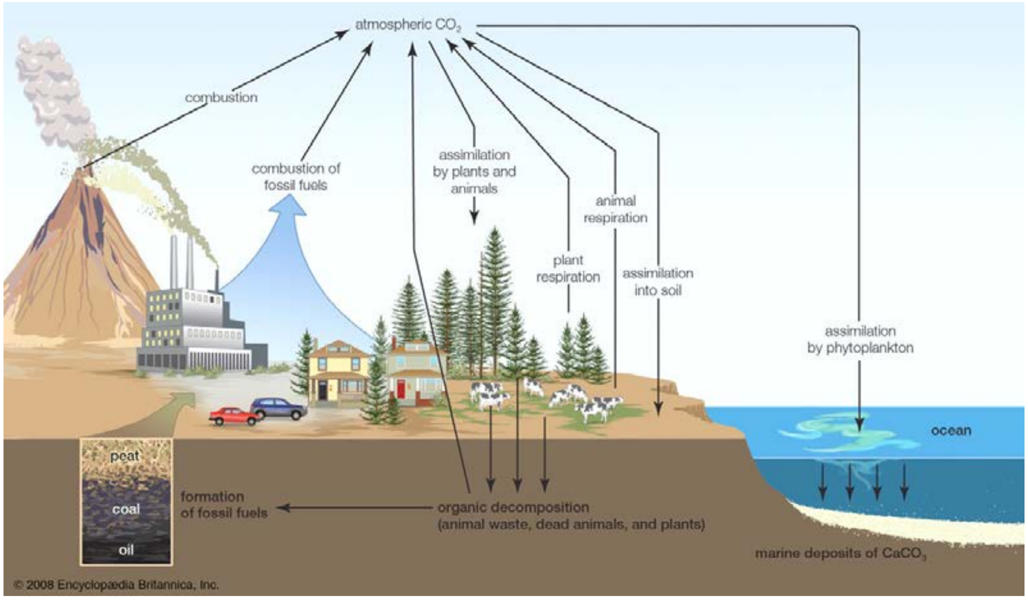
CA ELD Connections: ELD.PI.11–12.1, 5, 6a–b, 9, 10, 11a

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

Using the conceptual **model [SEP-2]** of this energy pyramid, students find that very large populations of producers are required to support much smaller populations of tertiary consumers for the ecosystem to remain **stable [CCC-7]**. This concept links to the laws of thermodynamics. Mathematical **models [SEP-2]** use this principle to predict the sizes of populations given the sizes of populations at other trophic levels. Students can explore many computer simulations and hands-on demonstrations so that they can support claims about the relative amounts of energy in different trophic levels (HS-LS2-4).

Energy flows from abiotic (nonliving) forms to biotic (living) forms, starting with sunlight or other light sources and inorganic compounds in producers and moving through consumers and decomposers. Nutrients (matter) cycle in the same manner. They can exist in forms that are largely abiotic such as carbon dioxide (CO_2) and nitrogen (N_2) and move into living organisms (biotic) in a different form such as glucose ($C_6H_{12}O_6$) or starch (many joined glucoses) and nitrates (NO_3-). The movement from abiotic to biotic molecular forms involves living processes. For carbon (figure 8.4), these processes are photosynthesis and cellular respiration (as in IS3). For nitrogen, "nitrogen-fixing" bacteria change nitrogen gas into nitrates while bacterial decomposers change ammonia and nitrates back into nitrogen. In some cases, abiotic processes can do a similar job. When a lightning bolt travels through the atmosphere, its energy can break apart molecules of nitrogen in the air; free nitrogen atoms bond with oxygen to create nitrate that gets carried to the soil by raindrops. Other nutrients are involved in similar cycles (such as the phosphorous cycle as it relates to DNA or the way climate change alters the calcium cycle by affecting hard-shelled marine organisms), but the clarification statement for HS-LS2-4 emphasizes carbon, nitrogen, oxygen, and hydrogen. Students can develop **models [SEP-2]** on paper, with technology, using their body moving around the room to represent the flow through different processes, or as a chemical model using organic chemistry molecule kits. The models show how simple inorganic molecules are made into larger organic molecules and then how they cycle back to the simple inorganic molecules.

Figure 8.4. The Carbon Cycle includes Biotic and Abiotic Processes



Source: Encyclopædia Britannica 2008. Courtesy of Encyclopaedia Britannica, Inc., copyright 2008; used with permission
Long description of Figure 8.4.

With these models of nutrient cycles in mind, students can write an **explanation [SEP-6]** of how the exchange of matter between the atmosphere and biosphere relates to the cycling of energy in an ecosystem. Students can literally feel the effects of these exchanges in their own bodies when they get a cramp during exercise or feel their muscles burn after a vigorous workout. In these cases, their bodies do not get enough oxygen but still need energy to do work. Students have evidence that a different chemical process must exist for respiration that requires less air. They can **perform investigations [SEP-3]** varying the amount of oxygen available to an organism such as yeast to see the effects on their productivity and survival. Using their observations they can begin to develop their own models of the differences between aerobic and anaerobic respiration (systems of chemical equations, diagrams, etc.) and identify differences between the processes. They can refine these models by evaluating models from textbooks or media. With this new understanding, they can return to their original explanation about exchanges in the biosphere and atmosphere and revise it to include the new information about anaerobic processes (HS-LS2-3).

Engineering Connection: Wastewater Treatment Facilities

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

While carbon and nitrogen are essential nutrients, toxic material also cycles through the ecosystem. Humans are major sources of disruptions to nutrient cycles, including adding toxins. Students can **obtain information [SEP-8]** about how mercury accumulates in certain fish species and learn about the impacts this can have on human health. Human activities such as coal-powered plants have added significant amounts of mercury to the environment (EP&Cs III and IV). Students will investigate more of these human disruptions to ecosystems next in IS6.

High School Three-Course Model Living Earth Snapshot 8.1: How Did We Eradicate Diseases in the US?

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

Mr. H. introduced a historical case study about the different factors that go into eradicating diseases. Even though students may not remember it, most children admitted to school in California are tested for TB. Despite this common practice, it's likely that many students have never met anyone who had TB and may not even know that it stands for tuberculosis. So why all the fuss with TB tests? Mr. H told students that if he were teaching 200 years ago, the class would have lived in fear of this disease. During the nineteenth century, TB caused as many as 20 percent of the deaths in some years. Today, fewer than 250 people in all of California die of the disease in an average year (California Department of Public Health 2015). How did society accomplish this change?

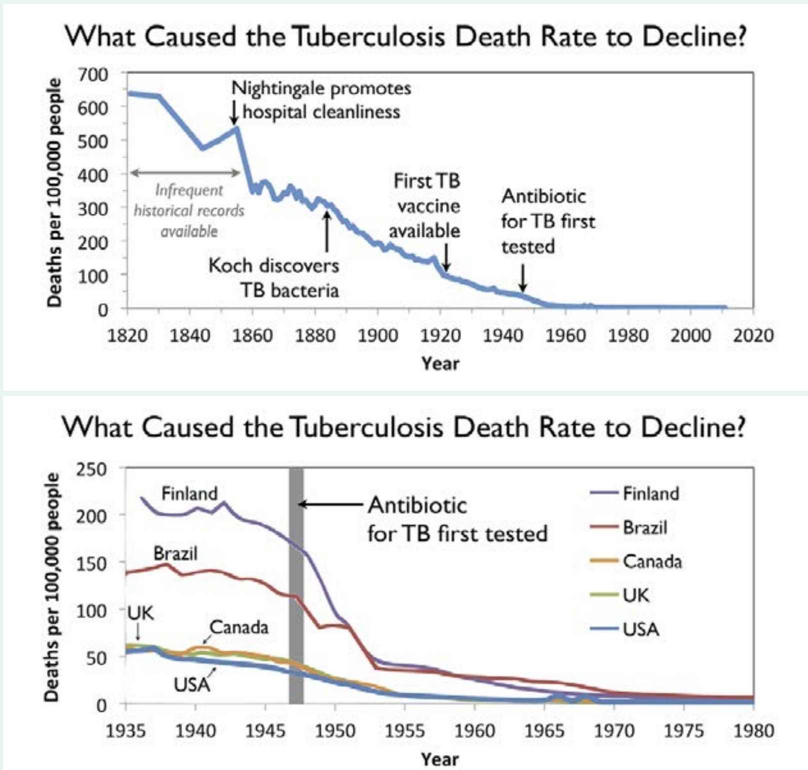
Mr. H divided the class into two groups that **obtain and evaluate information [SEP-8]** from different articles that introduce historical case studies of two major scientific innovations: (1) the origin of modern germ theory, including the discovery of tuberculosis bacteria by R. Koch in 1882; and (2)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

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

Mr. H provided each group with a graph (figure 8.5) showing how death rates changed around the time of the events described in their article. Students **analyzed the graphs [SEP-4]**, identifying **trends [CCC-1]** and looking for evidence of possible **cause and effect relationships [CCC-2]** between events labeled on the graph and changes in the death rate. Students reorganized in jigsaw style—two students from the group that discussed Koch's investigation **communicated [SEP-8]** their findings to two students that discussed the antibiotic trial (and then they switched). Students had to present an **argument [SEP-7]** about whether or not their group's innovation led to a significant decline in TB-related death rates (using their group's graph as evidence). Students realized that there was evidence that both sets of innovations may have helped, but also that rapid declines in death rates seem to happen even before some of the major events.

High School Three-Course Model Living Earth Snapshot 8.1: How Did We Eradicate Diseases in the US?

Figure 8.5: Two Graphs of the Decline of Tuberculosis



Charts by M. d'Alessio with data from Antunes and Waldman 1999; United States Census Bureau 1975; Official Statistics of Finland 2010; Public Health England n.d.; Gallant, Ogunnaike-Cooke, and McGuire 2014; Wikipedia 2016
Long description of Figure 8.5.

Mr. H wanted his high school students to move beyond the simple understanding of linear **cause and effect relationships [CCC-2]** from elementary school. According to the progression of CCCs in appendix 1 of this framework, high school students should recognize that changes in systems may have various causes that may not have equal effects. This is especially true when it comes to the health revolution that eradicated so many diseases like TB (Aiello, Larson, and Sedlak 2007). Innovations in medicine (drawn directly from scientific discoveries) influenced cultural norms for sanitation (such as hand washing) and led to changes in public policy and land use. These innovations occurred within the context of new technologies such as water filtration and sewage treatment that enhanced the standard of living in the United States and other western countries. Students watched a short video highlighting some of these key advances that dramatically increased life expectancy. Monitoring efforts, including the TB tests taken by most

High School Three-Course Model Living Earth Snapshot 8.1: How Did We Eradicate Diseases in the US?

California students, are part of this process. No individual factor is the singular cause of this health revolution. Mr. H led a whole-class discussion during which they generated a collaborative concept map representing society as a **system [CCC-4]** in which changes to different components result in the revolutionary overall system behavior where infectious disease no longer dominates our lives and deaths.

IS6

Life Science/Biology Instructional Segment 6: Ecosystem Dynamics, Functioning, and Resilience

In the middle grades, students constructed arguments that change, either physical or biological, to an ecosystem can lead to a change in populations living in that ecosystem (MS-LS2-4). Now, students must accomplish a nearly identical performance expectation but at a higher level that involves more sophisticated ecosystem interactions and more detailed evidence (HS-LS2-6). As in the middle grades (MS-LS2-5), students must complete a design challenge to maintain biodiversity but must now refine their solutions (not just evaluate them) and focus specifically on human-induced changes to ecosystems (HS-LS2-7).

LIFE SCIENCE/BIOLOGY INSTRUCTIONAL SEGMENT 6: ECOSYSTEM DYNAMICS, FUNCTIONING, AND RESILIENCE

Guiding Questions

- What types of interactions cause changes in ecosystems that ultimately affect populations?
- To what extent can humans “undo” their negative impact on the environment?

Performance Expectations

Students who demonstrate understanding can do the following:

HS-LS2-6. Evaluate the claims, evidence, and reasoning that the complex interactions in ecosystems maintain relatively consistent numbers and types of organisms in stable conditions, but changing conditions may result in a new ecosystem. [Clarification Statement: Examples of changes in ecosystem conditions could include modest biological or physical changes, such as moderate hunting or a seasonal flood; and extreme changes, such as volcanic eruption or sea level rise.]

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

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

LIFE SCIENCE/BIOLOGY INSTRUCTIONAL SEGMENT 6: ECOSYSTEM DYNAMICS, FUNCTIONING, AND RESILIENCE

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

Highlighted Science and Engineering Practices	Highlighted Disciplinary Core Ideas	Highlighted Crosscutting Concepts
[SEP-6] Constructing Explanations (for science) and Designing Solutions (for engineering) [SEP-7] Engaging in Argument from Evidence	LS2.C: Ecosystem Dynamics, Functioning, and Resilience LS4.D: Biodiversity and Humans ETS1.B: Developing Possible Solutions	[CCC-7] Stability and Change

Highlighted California Environmental Principles and Concepts:

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

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

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

CA CCSS for ELA/Literacy Connections: RST.9–10.8, RST.11–12.7, 8; WHST.11–12.7

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

Students investigate complicated interactions in ecosystems to determine how the interactions affect populations, in particular noting how these interactions **change [CCC-7]** when one component of the ecosystem changes. If a change results in competition for resources, food, or shelter, then the impact on population size will be density dependent. For example, if the population is large and there is very little food, then some of that population will not survive. The members of the population that are more fit will out-compete less fit members for resources, and this competition can damage ecosystems if the more fit members deplete or eliminate the resource. The depletion of a resource can make it difficult for the ecosystem to recover to its original state, and the ecosystem may be permanently transformed. Students can observe these changes through data-rich case studies and through computer simulations. Once they have developed conceptual models of ecosystem changes, they should be able to **evaluate different claims [SEP-7]** about the impacts of a new, hypothetical change (HS-LS2-6).

Many human-induced changes in ecosystems have unintended consequences, meaning humans did something to an ecosystem for one reason without realizing that there would be changes to other components of the ecosystem. For example, humans clear-cut the tropical rainforests to provide more land for farming. When this happens, they disrupt the cycle of matter in the forest; the soil becomes infertile and is unable to sustain farming for long. Students can learn about some of these changes within California by obtaining information about different habitat zones in the state and the pressures facing each of them (EP&Cs III & IV) (see EEI Curriculum, *Biodiversity: The Keystone to Life on Earth* https://www.cde.ca.gov/ci/sc/cf/ch8.asp#link3.) Students can track changes in land use or observe changes in plant productivity after major environmental changes using freely available LandSat imagery. Teachers can download LandSat data directly from https://www.cde.ca.gov/ci/sc/cf/ch8.asp#link4 or use Google's free EarthEngine at https://www.cde.ca.gov/ci/sc/cf/ch8.asp#link5, which has a wide range of LandSat data preloaded and easy to explore. Students can even engage in citizen science activities to "adopt a pixel" of LandSat imagery to document the changes happening around them (see https://www.cde.ca.gov/ci/sc/cf/ch8.asp#link6).

Engineering Connection

Within ecosystem science, some aspects of conservation biology are a form of engineering that focuses on developing processes that save endangered and threatened species (both animal and plant species). Conservation biologists help preserve these species by (1) supporting the use of wildlife corridors, which link large areas of land to other large areas so animals can migrate safely; (2) developing breeding programs for protecting endangered species; (3) identifying specific hotspots of species-rich regions worthy of extra protection and determining plans that provide sufficient protection; (4) arguing for the maintenance of larger environment regions instead of habitat fragmentation; (5) observing genetic diversity in small populations; and (6) monitoring the effects of climate change on all ecosystems. Students can investigate one specific environmental change that threatens biodiversity and **propose a solution [SEP-6]**. As they **obtain more information [SEP-8]**, including the needs of people as well as plants and other animals, they refine their solution (EP&C V; HS-LS2-7).

IS7 Life Science/Biology Instructional Segment 7: Social Interactions and Group Behaviors

Students have been developing a model of how group behavior helps organisms survive starting as far back as kindergarten when they looked at animal families. Now, they evaluate many competing arguments about how group behavior actually enables animals to survive, which may be driven by different factors in different situations.

LIFE SCIENCE/BIOLOGY INSTRUCTIONAL SEGMENT 7: SOCIAL INTERACTIONS AND GROUP BEHAVIOR

Guiding Questions

- How do populations ensure that their gene pool gets passed on?
- What affects a population's chance of survival?

Performance Expectations

Students who demonstrate understanding can do the following:

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

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

Highlighted Science and Engineering Practices	Highlighted Disciplinary Core Ideas	Highlighted Crosscutting Concepts
[SEP-7] Engaging in Argument from Evidence	LS2.D: Social Interactions and Group Behavior	[CCC-2] Cause and Effect: Mechanism and Explanation

CA CCSS for ELA/Literacy Connections: RST.9–10.8; RST.11–12.1, 7, 8, 9

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

Some animals are completely solitary while others group together in flocks or herds with thousands of individuals. What are the advantages and disadvantages of each? Students obtain information about multiple group and cooperative behaviors in the animal kingdom. They might watch video clips of humpback whales trying to protect a grey whale calf from a pod of killer whales. What motivates them to put their own lives on the line to protect a calf from another species? How does this exceptional case relate to other more commonly observed group behaviors?

Students will look closely at the behaviors of populations to assess their impact on survivability. For a population to succeed and not become a genetic dead end, the gene pool (the set of all the different genes) of the population must be passed on to the next generation. Producing a new generation of healthy offspring capable of successful reproduction is important for a population's survival.

Viable individuals within populations have the ability to better compete for resources such as food and protected living spaces. Though they still may not have ample food or safety, they have some food and safety and are able to reproduce and pass on their alleles. Individuals within some populations rally around the young to help in raising and protecting them. It is important that some of the members of the population reproduce but not all need to as long as others help "raise" the young and keep the gene pool going. These individuals are known as *altruistic*. This type of behavior is seen in bees and ants working in colonies and other animals in herds, flocks, and schools surrounding their young to protect them from predators. This is even seen in human populations where extended family (family members who are biologically related) help raise the young. There may be a kin selection process occurring with these examples where the more genetically related an individual is to the offspring the more likely the individual will "help" (perhaps driven by the instinct to enable some of its genetic code to persist). Or, it may be that group selection does not require an actual kinship relationship but instead involves other factors. The actual mechanism that promotes altruism is debated but is definitely based on a cost-to-benefit ratio where the individual ultimately receives some direct or indirect benefit for its effort. Altruism is seen mostly in species that live in social population groups, but there are definitely many populations that are not altruistic. Regardless of the theoretical basis for altruism, students can directly observe populations working together (having an ant colony in the classroom or watching videos that demonstrate the hunting and herding behaviors in animals) to gather **evidence [SEP-7]** that organisms within a population work together so that they survive and reproduce. Students then use the evidence to write or present an **argument [SEP-7]** that altruistic behavior is an important part of survival for some populations.

Life Science/Biology Snapshot 8.2: Does Living as a Group or Individual Help You Survive?

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

Mr. T started class showing a short video clip on prairie dogs and how they sound alarms to protect their family units against snakes (for example, NatGeoWild, Prairie Dog Snake Alarm: http://www.cde.ca.gov/ci/sc/cf/ch8.asp#link7). He then asked the students to do a quickwrite on what behavior the prairie dogs used to protect themselves and how that behavior helped their family.

Later, the students played a game that was actually a physical **model [SEP-2]** of individual and group behavior. Students used their bodies to represent components in a **system [CCC-4]** with a predator-prey relationship. He needed an even number of students as prey; since Mr. T had 30 students, he designated two students to act as predators, leaving 28 students to act as prey. Mr. T randomly handed each prey a white index card that had a color code on it, with each color representing a different genotype. Mr. T set up the cards ahead of time so that there were four cards for each color (i.e., four blue cards, four yellow cards, four green cards, four red cards, etc.).

For the first round (prey living as *individuals*) the predators and prey did not have knowledge about the individual's genetics (in other words they did not know who was genetically related to whom). Mr. T instructed the 28 prey to randomly wander around the open area and after one minute he signaled the predators to attack. The predators then tagged a prey. That individual stepped out of the group and the rest of the students continued wandering; again Mr. T signaled for attack and again each predator tagged an individual who dropped out of the group. After seven attacks, half the prey (14 individuals) had been tagged. At that point, a recorder tallied all the colors left on a shared class spreadsheet showing how many of each genotype survived (for example, 0 blue, one yellow, etc.).

Next Mr. T assigned two different students to act as predators and told them to go sit in the corner and hide their eyes while he redistributed the index cards to the remaining 28 students who were again the prey. This time he told the prey students to quietly (so the predators don't know) find the other students who shared their color. These four students had the same genotypes and represented a kin group. The second round (*altruistic prey in groups*) began. Since Mr. T had a big open area, he blindfolded the predators. This was so they would not know about genotypes and relatives within the prey groups. The group units now randomly wandered in the space and again Mr. T signaled the predators to attack. Each kin group could surround an individual so that when they were tagged the individual prey was saved and did not get eliminated. Each genotype/color group received only one save in this round, after that save had been used, anyone

Life Science/Biology Snapshot 8.2: Does Living as a Group or Individual Help You Survive?

in the group who was tagged again, was eliminated. This rule is designed to simulate the cost to benefit ratio of altruism. Saving a member of your group incurs an individual cost because it means your group will not be able to save you during the next attack. The benefit is that the group to which you belong is more likely to survive as a whole. The game continued for a total of seven attacks. This time there were fewer than 14 individuals eliminated because some individuals were saved by the herding effect of their group. Then a recorder used the shared class spreadsheet to tally the number of individuals left in each color group.

Mr. T reassigned the roles of each student (picking new predators and shuffling the genotype cards) to prevent learning by predators. The class enacted each scenario one more time.

After the class completed the four rounds of the game, Mr. T had the students look at the whole class data that had been recorded. He defined the terms *individual fitness* (your ability to pass on your genes) and *inclusive fitness* (your individual fitness plus indirect fitness when you belong to a group that herds to save individuals). Mr. T then asked the students to use these terms to describe the similarities and differences they saw between the two scenarios and **explain [SEP-6]** how inclusive behavior (group behavior) could be advantageous for some populations (HS-LS2-8). Mr. T wanted the students to specifically address what the action of saving an individual meant in the altruistic group scenario. Students were expected to use examples of animals that they knew that used *inclusive fitness behaviors*. The students talked about the prairie dogs (as in the video), dolphin pods, rabbit colonies, bird flocks, monkey troops, and other social, family, or group behavior. Mr. T ended class with a video clip showing how water buffalo work as a group to counter-attack lions that have surrounded an individual water buffalo (for example, NatGeoWild, Buffalo Herd Counter Attack: https://www.cde.ca.gov/ci/sc/cf/ch8.asp#link8). What was the individual fitness of the animal being attacked? How does its fitness change because of the behavior of the group?

Heredity: Inheritance and Variation of Traits

IS8 Life Science/Biology Instructional Segment 8: Inheritance of Traits

The performance expectations in LS3: Heredity: Inheritance and Variation of Traits help students formulate answers to the questions: "How are characteristics of one generation passed to the next? How can individuals of the same species and even siblings have different characteristics?" The LS3 Disciplinary Core Idea from the NRC Framework includes two sub-ideas: Inheritance of Traits and Variation of Traits. Students are able to ask questions, make and defend a claim, and use concepts of probability to explain the genetic variation in a population. Students demonstrate understanding of why individuals of the same species vary in how they look, function, and behave. Students can explain the mechanisms of genetic inheritance and describe the environmental and genetic causes of gene mutation and the alteration of gene expression. Crosscutting concepts of patterns and cause and effect are called out as organizing concepts for these core ideas. (NGSS Lead States 2013e)

LIFE SCIENCE/BIOLOGY INSTRUCTIONAL SEGMENT 8: INHERITANCE OF TRAITS

Guiding Questions

- How are characteristics of one generation passed to the next?
- What allows traits to be transmitted from parents to offspring??

Performance Expectations

Students who demonstrate understanding can do the following:

HS-LS3-1. Ask questions to clarify relationships about the role of DNA and chromosomes in coding the instructions for characteristic traits passed from parents to offspring. [*Assessment Boundary: Assessment does not include the phases of meiosis or the biochemical mechanism of specific steps in the process.*]

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	LS1.A: Structure and Function LS3.A: Inheritance of Traits	[CCC-2] Cause and Effect: Mechanism and Explanation

LIFE SCIENCE/BIOLOGY INSTRUCTIONAL SEGMENT 8: INHERITANCE OF TRAITS

CA CCSS for ELA/Literacy Connections: RST.11–12.1, 9

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

In IS1, students built upon their model of genetics from the middle grades to model the physical mechanisms by which organisms use their genetic codes to produce cells with specific functions. Now, they return to DNA in more detail to ask specific questions about how DNA enables organisms to pass on their genetic codes to their offspring.

One way to help students meet HS-LS3-1 and better appreciate the nature of science is through a historical approach. Students obtain information about the study of DNA, learning about what scientists knew, what questions they asked, and how they designed investigations to answer those questions. Discussing the scientists themselves shows that science is a human endeavor. The historical approach also illustrates how ideas have unfolded over time, showing that scientific knowledge is open to revision in light of new evidence. See chapter 11 on instructional strategies for specific advice about teaching science through historical case studies.

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

The next question was What was that “transforming agent”? Avery, MacLeod, McCarty attempted to answer that question. They discovered that DNA was the transforming agent, which they concluded after testing individual components of the bacteria cell in a cell-culture system. However, scientists were not entirely convinced; therefore, Alfred Hershey and Martha Chase radioactively labeled parts of viruses and provided even more evidence that DNA was being transported into hosts’ cells and transforming those host cells into virus-making machines. It was also around this time that Erwin Chargaff and his students who, while working on isolating nucleotides from different organisms, noticed that adenine and thymine were always in equal amount to each other as were guanine and cytosine. They also noticed that the total amount of adenine and thymine was *not* equal to the total amount of guanine and cytosine. A final piece of the puzzle was the X-ray photograph of DNA that Rosalind Franklin generated that showed the regular pattern and the helix formation of the molecule. These experiments, along with other evidence gathered during this time, led to the building of the **model [SEP-2]** of DNA by Watson and Crick.

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

Much of the work done in the first half of the twentieth century looked at the effect mutations had on phenotypes. If a genetic disease resulted, it gave the geneticists evidence of the function of that gene, though they could not “see” the genotype (see IS1). In the latter half of the twentieth century and into the twenty-first century, techniques and tools have improved so that scientists can actually test how specific changes in a gene sequence alter phenotypes (see IS9). Technology has also enabled scientists to map out entire genomes of a large variety of organisms, and large online databases exist that students can browse freely (see National Center for Biotechnology Information at https://www.cde.ca.gov/ci/sc/cf/ch8.asp#link9). Students can select a specific region of DNA and create **models [SEP-2]** of different levels that mirror the different steps of how DNA is used in organisms, such as a word code that transcribes into a physical code (colored building blocks) that then is ordered into a structure (for example, a building or a bridge). This modeling process can help students grasp how cells go from a written code to protein.

Once scientists started mapping out entire genomes, they realized that the simple relationships between DNA sequences and phenotypes were more complicated than originally thought. Genomes contain far fewer gene sequences than scientists originally thought and many phenotypes are the result of more than one gene. Students can look at phenotype studies and **ask questions [SEP-1]** regarding what changes in DNA result in changes in phenotypes of humans (or other living organisms) and the effect of DNA changes on individuals. Students can go to National Center for Biotechnology Information at https://www.cde.ca.gov/ci/sc/cf/ch8.asp#link10 and link to case studies done in humans by looking at the Online Mendelian Inheritance in Man (OMIM) link or they can expand the exercise and look at other animals or plants.

Students can return to the concept of organ and tissue donation from IS1 by **obtaining information [SEP-8]** about how doctors use genotypes to find successful matches for people who need new organs or tissue. The success of these transplants is much higher when the doctors can find a genotype match for certain traits (for additional information visit Organdonor.gov (https://www.cde.ca.gov/ci/sc/cf/ch8.asp#link11). Which genes are most important for identifying the right match? What other traits are influenced by those genes?

IS9 Life Science/Biology Instructional Segment 9: Variation of Traits

This instructional segment melds classic Mendelian genetics with molecular genetics. Students have documented variations in the traits of populations in the middle grades, and now they explain the mechanisms by which these variations arise. They look in detail at both variations caused by new genetic combinations during meiosis and variations caused by mutations from different sources.

LIFE SCIENCE/BIOLOGY INSTRUCTIONAL SEGMENT 9: VARIATION OF TRAITS

Guiding Questions

- How do genes determine traits?
- What is the chance of a trait being passed from one generation to another?
- What happens if there is a mutation in a gene?
- What contributes to phenotypes?

Performance Expectations

Students who demonstrate understanding can do the following:

HS-LS3-2. Make and defend a claim based on evidence that inheritable genetic variations may result from: (1) new genetic combinations through meiosis, (2) viable errors occurring during replication, and/or (3) mutations caused by environmental factors. [Clarification Statement: Emphasis is on using data to support arguments for the way variation occurs.] [*Assessment Boundary: Assessment does not include the phases of meiosis or the biochemical mechanism of specific steps in the process.*]

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

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-4] Analyzing and Interpreting Data [SEP-7] Engaging in Argument from Evidence	LS3.B: Variation of Traits	[CCC-2] Cause and Effect: Mechanism and Explanation [CCC-3] Scale, Proportion, and Quantity

LIFE SCIENCE/BIOLOGY INSTRUCTIONAL SEGMENT 9: VARIATION OF TRAITS

Highlighted California Environmental Principles and Concepts:

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

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

CA CCSS Math Connections: MP.2

CA CCSS for ELA/Literacy Connections: RST.11–12.1; WHST.11–12.1.a–e

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

Students can begin by **obtaining information [SEP-8]** about a range of genetic diseases (see National Human Genome Research Initiative, "Specific Genetic Disorders" at https://www.cde.ca.gov/ci/sc/cf/ch8.asp#link12). Students might read that about 1 in 12 African Americans has sickle cell disease that is inherited within families while skin cancer, which has a clear environmental trigger, can be more common in people with a specific gene on chromosome 9. A much more rare disease resulting in Turner syndrome cannot be inherited specifically because it leads to infertility in women. What determines who ends up with these diseases and who does not? To answer these fundamental questions, students must extend their model of inheritance to explain the source of all genetic variation.

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

Linking back to IS1, mutations in DNA can result in a change in genotype. Some mutations result in viable cells and can produce new genes that are then inherited by the next generation, others result in cell death, and still others in uncontrolled replication that leads to cancerous tumors. Sometimes, the traits caused by mutations result in a viable cell that somehow lacks certain functionality, and we refer to these mutations as genetic diseases. A single nucleotide change in the gene sequence for hemoglobin results in sickle cell anemia. A similar mutation in the gene that leads to formation of proteins that build a channel for movement of particles into and out of cells produces the condition known as cystic fibrosis (though it should be noted that there can be several single changes that result in the cystic fibrosis phenotype). Errors copying the X chromosome can lead to Turner syndrome. Students should be able to use evidence from these genetic diseases to construct an argument that variations are caused by genetic code that is inherited or altered either during DNA replication or by environmental factors (HS-LS3-2). Students should also be able to relate this argument not only to genetic disease but also to any variation in traits.

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

Once students understand how variation can occur, they can predict what combinations are possible in offspring. Punnett squares are a simple and common model used to predict traits, but they are cumbersome to use for predicting multiple traits. For example, predicting the outcome of a tri-hybrid cross requires a cumbersome eight-by-eight Punnett square. Instead, students can use statistical tools that include the product and sum rules of probabilities (CA CCSSM S.CP.7–8). Pedigrees are another model used to look at patterns of inheritance across generations. Students can evaluate possible genetic combinations and predict the chance of traits appearing in individual offspring. Students can use interactive computer simulations to create phenotypes of an organism by looking at combinations of genotypes and again predict what combinations are plausible. Students should be able to use information from genetics and their ability to calculate probabilities of different traits to explain the distribution of particular traits within a population (HS-LS3-3).

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

Biological Evolution: Unity and Diversity

According to the Next Generation Science Standards:

> The performance expectations in LS4: Biological Evolution: Unity and Diversity help students formulate an answer to the question, What evidence shows that different species are related? The LS4 Disciplinary Core Idea involves four sub-ideas: Evidence of Common Ancestry and Diversity, Natural Selection, Adaptation, and Biodiversity and Humans. Students can **construct explanations [SEP-6]** for the processes of natural selection and evolution and **communicate [SEP-8]** how multiple lines of evidence support these explanations. Students can **evaluate evidence [SEP-8]** of the conditions that may result in new species and understand the role of genetic variation in natural selection. Additionally, students can apply concepts of probability to explain trends in populations as those trends relate to advantageous heritable traits in a specific environment. The crosscutting concepts of **cause and effect [CCC-2]** and **systems and system models [CCC-4]** play an important role in students' understanding of the evolution of life on Earth. (NGSS Lead States 2013e)

IS10 Life Science/Biology Instructional Segment 10: Evidence of Common Ancestry and Diversity

Evolutionary scientist Theodor Dobzhansky made the now-famous quote, "Nothing in Biology makes sense except in the light of evolution." This course has been slowly building to the concept of evolution as students have investigated inheritance, natural selection, and ecosystem changes. Now, they bring these ideas together to construct an evidence-based account of how evolution occurs.

LIFE SCIENCE/BIOLOGY INSTRUCTIONAL SEGMENT 10: EVIDENCE OF COMMON ANCESTRY AND DIVERSITY

Guiding Questions

- What evidence shows that different species are related?
- How did modern-day humans evolve?

Performance Expectations

Students who demonstrate understanding can do the following:

HS-LS4-1. Communicate scientific information that common ancestry and biological evolution are supported by multiple lines of empirical evidence. [Clarification Statement: Emphasis is on a conceptual understanding of the role each line of evidence has relating to common ancestry and biological evolution. Examples of evidence could include similarities in DNA sequences, anatomical structures, and order of appearance of structures in embryological development.]

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-8] Obtaining, Evaluating, and Communicating Information	LS4.A: Evidence of Common Ancestry and Diversity	[CCC-1] Patterns

CA CCSS Math Connections: MP.2

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

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

Despite the fact that different organisms on Earth are so diverse, striking similarities provide evidence of common ancestry. From IS1, all organisms use the same basic DNA code. From IS3, organisms as different as plants and humans have surprising similarity in their metabolic processes (including the specific biochemical molecules they use). In this instructional segment, students build upon their background knowledge from the middle grades and earlier in this course to clearly communicate the lines of evidence that organisms have evolved over time from a common ancestor.

Students can begin by collecting examples of evidence supporting evolution that they learned about in the middle grades: patterns in fossils (MS-LS4-1), anatomical similarities (MS-LS4-2), and embryological similarities (MS-LS4-3). In each case, they can make the evidence more in depth. The goal for high school is to understand these concepts well enough to communicate these lines of evidence effectively. To help students meet HS-LS4-1, curriculum can focus on the SEP of **communicating information [SEP-8]**, which includes writing, oral presentations, and especially visual displays (e.g., diagrams, charts, annotated photos). Students can compare multiple depictions and **evaluate [SEP-8]** which ones illustrate the common ancestry most effectively. What are the elements of an effective communications product?

The fossil record provides much of the evidence to support evolution because it includes transitional life forms as well as organisms that no longer exist. Many life forms alive today (including humans) are not found very far back in the fossil record, implying that they are newer and have evolved from other species. Effective communication of this evidence shows progressions of species and identifies where species appear or disappear in the fossil record.

Looking at structures that are *homologous* (features that originate from the same structure within a common ancestor) and *analogous* (features that arise because two species use a similar structure to accomplish the same function) also provides evidence of how, over time, parts of organisms have changed in both **structure and function [CCC-6]**. Effective communication of this evidence shows comparisons of structures side-by-side and highlights the similarities.

Students can look at a variety of skeletons of vertebrates from the major classes and identify **patterns [CCC-1]**, noting that all these animals share the same basic skeletal structure noting only small variations such as the placement and usage of forelimbs or hind limbs. For example, a dog foreleg, human arm, and seal forelimb are all fore limbs of mammals (homologous) but serve very different functions (so they are not analogous). On the other hand, a dog and a horse have homologous forelimbs that they both use to walk. Students should be able to **construct arguments [SEP-7]** that two organisms share a common ancestor using homologous structures as evidence. Similarly, they should use the observation that homologous structures are used in diverse ways as evidence that natural selection accentuates certain favorable traits over generations, leading to a gradual evolution.

Are all structures with similar functions caused by genetic similarity and common ancestry? In high school, students develop a nuanced understanding of **cause and effect [CCC-2]** in which they evaluate evidence to determine which cause (or causes) most likely explains a given observation. For example, penguins and dolphins both have streamlined bodies that allow them to swim in the water. This feature is not the result of common ancestry, but rather an example of convergent evolution. Both these organisms independently evolved their body shapes from separate ancestors. Students can identify examples from the plant kingdom as well. The modified leaves in a Venus flytrap and pitcher plant demonstrate a homologous trait used to help the plants catch insects (all of these plants share a common ancestor). Thorns and spines, however, are a common analogous trait, which evolved in a wide range of plants through convergent evolution, which protects plants from herbivores. As students develop arguments that two organisms share common ancestry, they need to consider whether to present evidence of homology, analogy, both, or neither.

Because of the changes in organisms over time, some organs/structures no longer have a use in the modern-day organism, but there is evidence that the structure was once functional in the ancestor; these traits are now called vestigial organs/structures. Some classic examples of *vestigial organs/structures* are the remnants of hipbones in snakes and whales and the remainder of the tip of a tailbone (the coccyx) in humans.

Opportunities for ELA / ELD Connections

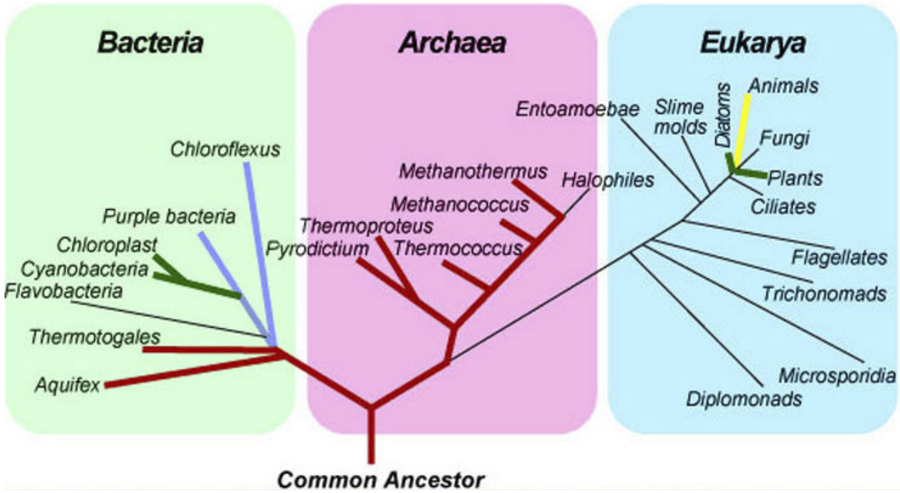
Students should be able to **communicate [SEP-8]** evidence both graphically and in writing. Students can design Venn diagrams or tables to communicate commonalities and differences. They can use diagrams and sequences of pictures or photos to illustrate commonalities in DNA, RNA, ribosomes, ATP, macromolecules, ability to use energy, cell division, and so on.

CA CCSS for ELA / Literacy Standards: WHST.9–12.4: RST.9–12.7

CA ELD Standards: ELD.PI. 9–12.2, 6

Evolution itself is not a linear process but rather a branching process in which some members of populations of an historical species changed and branched off into two new descendant species from a common ancestor (see IS12). These descendent species underwent more changes and could have possibly branched again and again over geological time. Visual depictions of this tree of life (figure 8.6) summarize our understanding of how life evolved from single-cell organisms to the modern-day species we see on earth today. The tips of the tree represent these modern-day species. These trees were developed using studies of fossils and have been refined using investigations of the similarities and differences in DNA. What makes these diagrams effective at communicating evolutionary history? How can they be improved?

Figure 8.6. Tree of Life



A tree diagram showing the relationship of all living species on Earth. All branches relate to the common ancestor at the base, which diverged into three main branches: bacteria; microbes known as Archaea; and a group of multicellular organisms called Eukarya, which includes humans. Longer branches indicate a more significant change in DNA from its common ancestor. *Source*: Farmer 2000
Long description of Figure 8.6.

Ideally, students should do an indepth investigation of one species and obtain information about the evidence of its evolutionary history. One possible example is the history of modern humans. Using genome studies on DNA sequences as well as fossil evidence, scientists estimate that the common ancestor for humans and great apes lived over seven million years ago. Since that time, each branch has undergone further evolution. Students can use interactive tools to examine fossils and arrange them on a timeline based on **patterns [CCC-1]** that document human evolution.[5]

5. See the HHMI-Howard Hughes Medical Institute at https://www.cde.ca.gov/ci/sc/cf/ch8.asp#link14. This Web site is free, kept up to date, and has excellent resources for evolution as well as other science topics designed by experts in the field for use by teachers and students.

High School Four-Course Model Life Science/Biology 8.3: Human Evolution

Anchoring phenomenon: Several other species of hominin existed, but our species, *Homo sapiens*, is the only one that survived to today.

Evolution is driven by natural selection favoring some new traits over others. But which new traits or selective pressures allowed our species, *Homo sapiens*, to thrive while several other early hominin species died off? Mrs. B recently saw the September 2014 issue of *Scientific American* https://www.cde.ca.gov/ci/sc/cf/ch8.asp#link13) that addresses that very question. Each article offers a different argument supported by different evidence. One article focuses on specific anatomical features (structure and function, LS1.A), several articles on group behavior (LS2.D) including mating for life, cooperative hunting, and the power of culture, one article on information processing (LS1.D), and one article emphasizes the role of ancient climate change on evolution (ESS2.E, ESS3.D).

Mrs. B assigned different students to read different articles in a classic jigsaw. Then she organized the students so that each group discussed a common article. Each student group created a collaborative presentation about its article that summarized the argument made in the paper. Students had to identify the claim, describe the evidence, and tie it all together with reasoning. The students needed to pay particular attention to fossil evidence (ESS1.C), which was described more in some articles than others. Then, the student groups were reorganized, with one expert on each article in each group. Each expert presented the collaborative presentation about the article to his or her small group. Then, the group laid out a large sheet of butcher paper and created a comprehensive concept map illustrating the possible explanations of how humans evolved and then connected those explanations to other key course ideas. For example, students knew that the pace of present-day climate change is much faster than a climate shift 160,000 years ago that one article mentioned may have been a selective pressure that favored larger brains. It is unlikely that humans or other species can adapt quickly enough to keep pace with modern changes happening on the scale of decades. Mrs. B emphasized the fact that today we do not have enough evidence to distinguish between these different possibilities, but one day somebody might discover key evidence that allows us to rule out some of the possibilities or provides direct evidence of a cause and effect relationship for others. Mrs. B added, “And the person who will make that discovery might be in this room right now.”

IS11

Life Science/Biology Instructional Segment 11: Natural Selection

This instructional segment begins historically with Darwin's original formulation of the principles of evolution but quickly moves to analyzing large data sets to provide evidence from statistics and probability that largely support his original ideas. Students build on the mathematical models they made in the middle grades that showed how natural selection can alter the traits within a population (MS-LS4-6).

LIFE SCIENCE/BIOLOGY INSTRUCTIONAL SEGMENT 11: NATURAL SELECTION

Guiding Questions

- What processes influence natural selection?
- What evidence did Darwin provide that became the foundation for the study of evolution?

Performance Expectations

Students who demonstrate understanding can do the following:

HS-LS4-2. Construct an explanation based on evidence that the process of evolution primarily results from four factors: (1) the potential for a species to increase in number, (2) the heritable genetic variation of individuals in a species due to mutation and sexual reproduction, (3) competition for limited resources, and (4) the proliferation of those organisms that are better able to survive and reproduce in the environment. [Clarification Statement: Emphasis is on using evidence to explain the influence each of the four factors has on number of organisms, behaviors morphology, or physiology in terms of ability to compete for limited resources and subsequent survival of individuals and adaptation of species. Examples of evidence could include mathematical models such as simple distribution graphs and proportional reasoning.] [*Assessment Boundary: Assessment does not include other mechanisms of evolution, such as genetic drift, gene flow through migration, and co-evolution.*]

HS-LS4-3. Apply concepts of statistics and probability to support explanations that organisms with an advantageous heritable trait tend to increase in proportion to organisms lacking this trait. [Clarification Statement: Emphasis is on analyzing shifts in numerical distribution of traits and using these shifts as evidence to support explanations.] [*Assessment Boundary: Assessment is limited to basic statistical and graphical analysis. Assessment does not include allele frequency calculations.*]

LIFE SCIENCE/BIOLOGY INSTRUCTIONAL SEGMENT 11: NATURAL SELECTION

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

Highlighted Science and Engineering Practices	Highlighted Disciplinary Core Ideas	Highlighted Crosscutting Concepts
[SEP-4] Analyzing and Interpreting Data [SEP-6] Constructing Explanations (for science) and Designing Solutions (for engineering)	LS4.B: Natural Selection LS4.C: Adaptation	[CCC-1] Patterns [CCC-2] Cause and Effect: Mechanism and Explanation

Highlighted California Environmental Principles and Concepts:

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

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

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

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

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

Students can now interpret Darwin's original ideas from the mid-1800s using modern understanding from the previous sections of this course. Charles Darwin spent his adult life collecting and analyzing data. His most famous voyage on the HMS Beagle was an expedition to map landforms and geology, but Darwin's observations on that journey formed the foundation of his ideas on evolution. On that trip, Darwin noticed that organisms have the potential to reproduce many more offspring than will survive (for example a spider will lay hundreds of eggs). Despite this possibility for exponential growth, most populations remain fairly constant in numbers over generations. Darwin concluded that there had to be competition for resources and that was part of what helped keep population numbers **stable [CCC-7]** over time. He also noticed that while fossils and modern living organisms differed from place to place, in the same area the fossils and modern living organisms were very similar to one another. For example, Darwin saw that several bird species in the Galápagos Islands looked very similar to one species found on the continent of nearby South America. He also knew that offspring looked like their parents but there was slight variation. He understood how animal breeders manipulate the traits in the population of their livestock or dogs by selectively breeding to reinforce or eliminate certain traits. It was all these observations that helped him identify the idea of natural selection—individuals in a population have certain traits that allow them to effectively compete for and obtain the resources they need so that they are able to reproduce and pass on their traits to their offspring. If no individuals reproduce in a population, then that population ceases to exist and any unique traits within that population are eliminated. Darwin originally summarized his findings into four postulates (table 8.2).

Table 8.2. Darwin's Four Postulates

DARWIN'S POSTULATE	EXAMPLE
Individual organisms in a population vary in the traits they possess.	The size of their heads or the length of a taproot
Some of this variation is passed from parent to offspring.	Seeds from plants with purple flowers grow into new plants with purple flowers; insects with long wings produce offspring with long wings.
Individuals within a population have the ability to produce a lot of offspring.	Number of seeds produced by a flowering tree, the ability of some bacteria to reproduce every 20 minutes, the number of spores released by a mushroom.
The individuals that leave living offspring are the individuals with certain traits that help them survive and reproduce, thus they are the individuals that are selected naturally by the environment.	Birds that can break open nuts that grew harder in a drought year could acquire enough food and survive the environmental change (drought) so they then could go on to reproduce. For an example of one type of organism, refer to the work of Rosemary and Peter Grant on the Darwin Finches in the Galápagos Islands (Grant and Grant 2003).

Students should observe examples of evolution in all living systems (e.g., plants, fungi, animals, prokaryotes, etc.). Students can collect data on individuals in a population and look for the **patterns [CCC-1]** that are present. They can measure individual skulls or beaks or shells that have been gathered to represent a specific species. There are datasets available that extend from generation to generation and students can use these to mathematically **analyze [SEP-4]** the changes they observe. They can begin to **construct an explanation [SEP-6]** based on this evidence of the conditions that are necessary for evolution to occur (HS-LS4-2). Extensions of this data collection can include some generations that survived after a change in their environment (e.g., what happens to the size of beaks after a drought or what happens to the size of shells after the introduction of a non-native species that eats the shelled organism). From these observations, students notice that interactions in the environment influence evolution (EP&Cs I, II).

Natural selection acts on the phenotype of an individual, for example the size of a shell or beak. The selective pressure that favors one size over another will translate into a change in proportion of individuals with the favored size in the next generation—if the change is a result of inheritance. In other words, the individuals that have the favorable phenotype reproduce and pass on the favorable genetic code that generated that phenotype. The frequencies of "favored" traits are ultimately what change from generation to generation. Students can **model [SEP-2]** these changes using computer simulations of populations (see Howard Hughes Medical Institute "Color Variation Over Time in Rock Pocket Mouse Populations" at https://www.cde.ca.gov/ci/sc/cf/ch8.asp#link15) and use **probabilities [SEP-5]** to determine whether or not there is evidence of changes in populations over time (see Howard Hughes Medical Institute "Stickleback Evolution Virtual Lab" at https://www.cde.ca.gov/ci/sc/cf/ch8.asp#link16) (HS-LS4-3). Using these simulations as examples, students should be able to tie together their knowledge in the course to construct an explanation of how organisms evolve (HS-LS4-2). Their explanation should note how 1) organisms can reproduce to grow in numbers; 2) offspring of organisms are slightly different from their parents due to the processes of mutations and sexual reproduction; 3) organisms compete for limited resources; and 4) organisms with traits that enable them to survive and obtain resources are most likely to reproduce and pass on their traits such that the population increases in the proportion of these successful traits.

Curricular materials should specifically force students to confront the common misconception that natural selection causes individual organisms to change and pass these changes on to their offspring. Variation must exist in the population before any environmental selection can occur. The environmental change does not "cause" beaks or shells to get bigger or smaller; individuals that have these traits simply are more likely to survive in the new environment. While environmental factors certainly do affect the expression of traits (such as plant height or animal weight), these traits are not passed on to offspring and this mechanism is not part of the explanation of evolution by natural selection.

Living Earth Snapshot 8.4: Simulating Evolution of Antibiotic-Resistant Bacteria

Everyday phenomenon: When you get a prescription antibiotic from the pharmacy, the symptoms go away in a few days but the instructions always say to keep taking the drug for as long as two weeks.

Mr. K asked students if they had ever had an ear infection and had to take antibiotics. Did they have a nasty tasting liquid or a huge pill to swallow? But did they get better? How long did it take? He then asked them if they remember how long they took the medicine. He passed around an empty antibiotic bottle (with patient information removed) and projected a picture of the label on the screen so that everyone could see how long the instructions say to take the drug. Could they just stop taking the antibiotic when they start feeling better?

Investigative phenomenon: Bacteria can become resistant to antibacterial drugs.

Evolution appears to be slow because **changes [CCC-7]** happen in populations over many, many generations. Bacteria reproduce every few hours, so humans can actually observe their evolution. Mr. K's class simulated the effects of antibiotics on bacteria populations using colored index cards or foam packing peanuts (NSTA https://www.cde.ca.gov/ci/sc/cf/ch8.asp#link17). Each index card represented an individual bacteria organism; most cards were white, but two red cards represented individuals of the same species that were somehow resistant to the antibiotic. During each round, an antibiotic was applied that killed three out of four of the white cards but none of the resistant red cards. After each round, the bacteria reproduced, so students collected another card of the same color. Students graphed the number of bacteria and identified the **trend [CCC-1]** that the population had evolved to become resistant to antibiotics.

Mr. K asked students to formulate the rules of the index card game as a **computational algorithm [SEP-5]**. Students then wrote their own computer code and used it to predict what happened to the population of bacteria when a person with an infection stopped taking antibiotics before the end of the prescription. They culminated by constructing an **explanation [SEP-6]** about how the use of antibacterial agents can cause bacteria to evolve into superbugs (HS-LS4-4). They watched a video to **obtain information [SEP-8]** about how resistant bacteria are impacting behaviors and health at local hospitals. Mr. K then pretended to be one student's father who wanted to throw out his antibiotic when his symptoms went away but before the prescription ended. He asked the student to **convince him using evidence [SEP-7]** that he should keep taking the medication.

IS12

Life Science/Biology Instructional Segment 12: Adaptation and Biodiversity

In IS12, students tie together ideas of natural selection and evolution. They use computer simulations to predict how populations will change when abiotic or biotic factors change within the ecosystem.

LIFE SCIENCE/BIOLOGY INSTRUCTIONAL SEGMENT 12: ADAPTATION AND BIODIVERSITY

Guiding Questions

- How does natural selection lead to adaptation in populations?
- How do changes in ecosystems influence populations?

Performance Expectations

Students who demonstrate understanding can do the following:

HS-LS4-2. Construct an explanation based on evidence that the process of evolution primarily results from four factors: (1) the potential for a species to increase in number, (2) the heritable genetic variation of individuals in a species due to mutation and sexual reproduction, (3) competition for limited resources, and (4) the proliferation of those organisms that are better able to survive and reproduce in the environment. [Clarification Statement: Emphasis is on using evidence to explain the influence each of the four factors has on number of organisms, behaviors morphology, or physiology in terms of ability to compete for limited resources and subsequent survival of individuals and adaptation of species. Examples of evidence could include mathematical models such as simple distribution graphs and proportional reasoning.] [*Assessment Boundary: Assessment does not include other mechanisms of evolution, such as genetic drift, gene flow through migration, and co-evolution.*]

HS-LS4-3. Apply concepts of statistics and probability to support explanations that organisms with an advantageous heritable trait tend to increase in proportion to organisms lacking this trait. [Clarification Statement: Emphasis is on analyzing shifts in numerical distribution of traits and using these shifts as evidence to support explanations.] [*Assessment Boundary: Assessment is limited to basic statistical and graphical analysis. Assessment does not include allele frequency calculations.*]

HS-LS4-4. Construct an explanation based on evidence for how natural selection leads to adaptation of populations. [Clarification Statement: Emphasis is on using data to provide evidence for how specific biotic and abiotic differences in ecosystems (such as ranges of seasonal temperature, long-term climate change, acidity, light, geographic barriers, or evolution of other organisms) contribute to a change in gene frequency over time, leading to adaptation of populations.]

HS-LS4-5. Evaluate the evidence supporting claims that changes in environmental conditions may result in (1) increases in the number of individuals of some species, (2) the emergence of new species over time, and (3) the extinction of other species. [Clarification Statement: Emphasis is on determining cause and effect relationships for how changes to the environment such as deforestation, fishing, application of fertilizers, drought, flood, and the rate of change of the environment affect distribution or disappearance of traits in species.]

LIFE SCIENCE/BIOLOGY INSTRUCTIONAL SEGMENT 12: ADAPTATION AND BIODIVERSITY

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

*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-4] Analyzing and Interpreting Data [SEP-5] Using Mathematics and Computational Thinking [SEP-6] Constructing Explanations (for science) and Designing Solutions (for engineering) [SEP-7] Engaging in Argument from Evidence	LS4.B: Natural Selection LS4.C: Adaptation LS4.D: Biodiversity and Humans ETS1.B: Developing Possible Solutions	[CCC-1] Patterns [CCC-2] Cause and Effect: Mechanism and Explanation

Highlighted California Environmental Principles and Concepts:

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

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

CA CCSS Math Connections: MP.2, MP.4

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

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

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

When enough adaptations build up in a population, sometimes that population changes to the point that some of its members no longer can mate and reproduce with other members of the species. This isolates the members into two populations that thereby become two different species. These two species had a single parent species from which they evolved: this is how speciation is defined. Speciation events occur when populations within a species change to the point that they can no longer mate with other individuals from the same species. In most organisms, speciation takes a very long time and preserving species that have developed is therefore a high priority. These species contribute biodiversity to ecosystems so that even if one species disappears, there are other surviving species that can continue the cycling of matter and flow of energy in the ecosystem. While changes can cause species to become extinct, human influences have accelerated these changes. Students can engage in engineering design challenges to minimize human impacts on species or to reverse some of these impacts.

Engineering Connection

When humans sprayed the pesticide DDT on farm fields in California, it accumulated in animal tissues and affected the viability of many bird eggs, including eggs of the California condor. The condor populations plummeted until the pesticide was banned in 1972 due to concerns over its impact on bird populations (EP&C II, IV). By that point, the condor population had dwindled so far that only a few dozen birds remained. Students can develop or revise a computer simulation (HS-LS4-6) of a condor captive breeding and release program like the one implemented in California (Ventana Wildlife Society n.d.). How quickly can the population expect to recover? How many breeding pairs should be captured initially to ensure a diverse enough gene pool? Students can track the variation in traits of offspring from one generation to the next and use that to estimate the susceptibility to selective pressures such as disease or drought.

The high school biology course should culminate with a project in which students apply what they have learned about how organisms maintain life. For example, students could compare and contrast how a few different organisms maintain life (e.g., human, redwood tree, and E. coli). The students should use **evidence [SEP-7]** to support their **explanations [SEP-6]** and they should effectively **communicate [SEP-8]** their **models [SEP-2]**.

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Performance Expectations

Students who demonstrate understanding can do the following:

HS-LS4-2. Construct an explanation based on evidence that the process of evolution primarily results from four factors: (1) the potential for a species to increase in number, (2) the heritable genetic variation of individuals in a species due to mutation and sexual reproduction, (3) competition for limited resources, and (4) the proliferation of those organisms that are better able to survive and reproduce in the environment. [Clarification Statement: Emphasis is on using evidence to explain the influence each of the four factors has on number of organisms, behaviors morphology, or physiology in terms of ability to compete for limited resources and subsequent survival of individuals and adaptation of species. Examples of evidence could include mathematical models such as simple distribution graphs and proportional reasoning.] [*Assessment Boundary: Assessment does not include other mechanisms of evolution, such as genetic drift, gene flow through migration, and co-evolution.*]

HS-LS4-3. Apply concepts of statistics and probability to support explanations that organisms with an advantageous heritable trait tend to increase in proportion to organisms lacking this trait. [Clarification Statement: Emphasis is on analyzing shifts in numerical distribution of traits and using these shifts as evidence to support explanations.] [*Assessment Boundary: Assessment is limited to basic statistical and graphical analysis. Assessment does not include allele frequency calculations.*]

HS-LS4-4. Construct an explanation based on evidence for how natural selection leads to adaptation of populations. [Clarification Statement: Emphasis is on using data to provide evidence for how specific biotic and abiotic differences in ecosystems (such as ranges of seasonal temperature, long-term climate change, acidity, light, geographic barriers, or evolution of other organisms) contribute to a change in gene frequency over time, leading to adaptation of populations.]

HS-LS4-5. Evaluate the evidence supporting claims that changes in environmental conditions may result in (1) increases in the number of individuals of some species, (2) the emergence of new species over time, and (3) the extinction of other species. [Clarification Statement: Emphasis is on determining cause and effect relationships for how changes to the environment such as deforestation, fishing, application of fertilizers, drought, flood, and the rate of change of the environment affect distribution or disappearance of traits in species.]

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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-4] Analyzing and Interpreting Data [SEP-5] Using Mathematics and Computational Thinking [SEP-6] Constructing Explanations (for science) and Designing Solutions (for engineering) [SEP-7] Engaging in Argument from Evidence	LS4.B: Natural Selection LS4.C: Adaptation	[CCC-1] Patterns [CCC-2] Cause and Effect: Mechanism and Explanation

Highlighted California Environmental Principles and Concepts:

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

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: S-IC.1, 3, 4; S-ID.7

CA CCSS for ELA/Literacy Connections: SL.9–12.1, 2; RST.11–12.1, 2, 7–10; WHST.9–12.1a–b, 2a, 6–10

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

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Introduction

This vignette describes how students developed an understanding of how variation, genotype, and phenotype play a role in evolution by addressing the following overarching questions: What processes influence natural selection? How much can humans cause changes that influence natural selection (EP&C II)? What do changes in **patterns [CCC-1]** of phenotypes mean? How do **changes [CCC-7]** in the environment **cause [CCC-2]** changes in the variation in populations?

Length and position in course: This vignette builds on background knowledge of life science DCIs from the middle grades. It illustrates one approach to teaching sections of IS11 and IS12 of this course. Students need to know how to obtain raw data and construct graphs, both by hand and using spreadsheets on the computer. There is a bit of guidance in some of the documents used for the vignette, but it assumes that students already have some experience with graphing.

This vignette also illustrates students using one-to-one electronic devices to edit online collaborative documents (e.g., Google documents and spreadsheets). The vignette debrief at the end describes how to adapt the lesson without technology or limited technology.

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

Day 1: Looking for Patterns

Students ask questions about height variations in human populations. They measure and record data about students in their class and look for patterns in the height of professional athletes.

Day 2: Identifying Variation

Students practice recognizing variation in pinto beans and birds on the Galápagos Islands.

Days 3–4: Bird-Beak Simulations

Students use their bodies to make a physical model that simulates how different beak shapes are adaptations for different conditions. Students then analyze the data they collect, identifying cause and effect linkages about beak shape and survival.

Days 5–6: Darwin's Observations

Students obtain information about Darwin and make a concept map summarizing the inferences he drew from his data. Students share their concept maps with other students, asking questions and evaluating their peers' maps in gallery a walk.

Days 7–8: Analyzing Beak Data

Students graph wing length, body mass, and beak depth from finches on the Galápagos islands both prior to and following a drought. They prepare and give presentations supporting claims about cause and effect relationships they interpret from the data.

Day 9: Simulating Natural Selection

Students make a physical model in which they act as predators eating different color prey (simulated by different color dots of paper scattered on a colored fabric background). They watch as the population shifts from one generation to the next.

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Day 10: Selection Pressure

Students obtain information about different types of selection pressures and discuss how human activities affect different populations.

Day 11: Case Study

Students work in groups to evaluate a case study about biodiversity and human impacts on species survival.

Day 12: Case Study Culmination

Students present their findings about the case study.

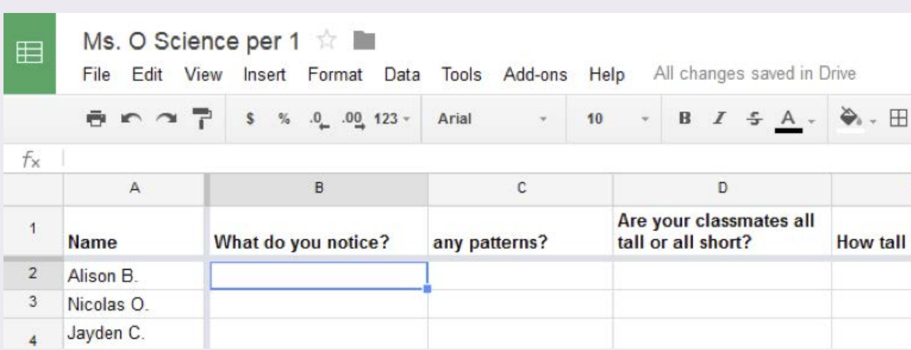
Day 1: Looking for Patterns (Engage)

Anchoring phenomenon: Height variation exists in the classroom.

As the students entered the classroom, Ms. O handed each of them an index card and told them to put down their books and go with a partner to a station and measure both their heights in inches and in centimeters. Each person wrote measurements for both partners on the index card. Ms. O then asked them to enter their own data into the class online spreadsheet. The students also indicated their gender, but they left their names off.

Ms. O projected a graph of the data from the entire class on the screen. She displayed the data in a table format with male/female as one column and inches in another and centimeters in the last column. She asked the students a few questions: "What did you notice? Were there any **patterns [CCC-1]** to this distribution? Were your classmates all tall or all short? How tall is tall? How short is short?" She wanted all students to be able to respond simultaneously, so she had them log into an electronic quickwrite (a collaborative online spreadsheet with each student's name as a row header and the question as a header in the column closest to their name. The students are familiar with this protocol, which they have used since the beginning of the school year. See example below—figure 8.7.)

Figure 8.7. Example of a Quickwrite Using an Interactive Online Spreadsheet



Source: Screenshot of Google Sheets by V. Vandergon

Long description of Figure 8.7.

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Ms. O then highlighted some of the commonalities between different students' answers and asked students the next guiding question: "You all noticed that there were differences in the heights of your classmates. We call this variation. Why was there variation in height? Answer on the quickwrite."

To review essential concepts in genetics, Ms. O asked students to form a sentence in the quickwrite that described the relationship between genotype, phenotype, height, and nutrition. She highlighted a few answers that described how height is a phenotype that relates to both genotype and environmental factors like nutrition.

Investigative phenomenon: The average height of baseball and basketball players today is taller than it was 100 years ago.

She then asked, "Do you think humans' average height has changed over the years? Are people today taller than they were 100 years ago?" Ms. O asked students to submit their responses in the quickwrite and explain their thinking.

"Now we are going to look at data on height and weight of baseball and basketball players in the last century." Ms. O then had the students open the class Web site and click on the link for Baseball (McLennan 2010) and Basketball (Basketball-Reference n.d.) statistics. Working in established pairs or groups of three, the students wrote down observations of the trends they saw over time in the height data. Then she asked them, "What stands out for you in this data?"

Ms. O led the students through an analysis of the data, identifying the overall trend including the direction and the shape (is it linear?). For homework, she asked students to write an **explanation [SEP-6]** that **interprets the data [SEP-4]** in terms of genetics and environmental factors. She asks them to speculate about which factor might have changed most during 100 years, genetics or environment.

Day 2: Identifying Variation (Engage)

Investigative Phenomenon: There is variation in beans even when they are the same type.

Ms. O's goal on the second day was to have the students recognize that there is variation in many different populations (not only in humans), including in pinto beans and birds.

Ms. O led a discussion of the evidence from the previous day that showed the average height and weight of baseball and basketball players had increased over the years. While there was a general trend, there was still variation between players during every year, just like there was variation in student heights in the class.

The class focused on variation today, starting with variation in beans. Ms. O handed out two to three pinto beans to each student and asked them to write down a few observations

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about what each looked like. They were allowed to measure and draw what they saw. Ms. O encouraged them to look at their neighbors' beans too. Then, she collected all the beans and put them into a few bowls that had some additional beans in them too. Ms. O asked the students within the groups to pick out their beans from among the beans in the bowls. Were the variations large enough to tell the beans apart? Had the students recorded the variations with enough detail to recognize their beans?

Ms. O. asked the students if variation is part of all populations. She asks students to call out a few variations that bird populations might have, guiding the students to think about beaks, body size, and wingspan. Then she introduced and showed a 15-minute video on variation in the Galápagos Island finches (HHMI Biointeractive 2014).

Before class ended, Ms. O explained that tomorrow they would each play the part of a bird with a different beak in a physical simulation of variation on different islands. She assigned roles and handed out instructions about the parts students would play. She told them that they needed to be prepared to start the simulation as soon as class begins or they would "starve." She assigned a short online quiz as homework to ensure that students knew their roles well enough.

Day 3: Bird-Beak Simulations (Explore)

Investigative phenomenon: Birds with different-shaped beaks survive when different- shaped food morsels are available.

Ms. O's expectation for the students was to collect as much high-quality data as possible. They would analyze the data the following day.

Before class, Ms. O set up eight stations around the room representing different islands with different food sources. Students entered class ready to start at their stations and pick up their assigned beak tool (tweezers, a pair of tongs, a spoon, and a toothpick). Each island had "food" with a different shape and their goal was to pick up as many of the food items as possible using their assigned beak tool. They could not use their hands. Once Ms. O called time, they recorded the number of food morsels "eaten" at each station and reset the station for the next group before rotating to the next "island" with food of a different shape. As the students performed the tasks at each station, Ms. O walked around helping the students stay on task and making sure the supplies were adequate.

Students' homework was to enter their data into the cloud-based class spreadsheet that Ms. O had linked to the class Web site and to answer the questions for each of the stations they had completed. Ms. O made it clear that they would receive points based on data input before class started.

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Day 4: Analyzing Bird-Beak Simulation Results (Explore)

The class objective this day was to **analyze and interpret data [SEP-4]** collected the previous day to identify cause and effect relationships between beak characteristics and survival on different islands.

Students entered class and took out their electronic devices and their worksheets. Ms. O called the class together and projected the data students had entered into the spreadsheet for homework. Ms. O asked some guiding questions about the data. She collected some of the answers on the class quickwrite so that all students could respond. Ms. O asked, “Which beaks worked best for each island? Is there any beak type that worked well on more than one island? Why or why not? What causes one beak to work better than the others?” She had the students input their responses and then talked within their groups to decide if they wanted to improve on their answers.

For the last 15 minutes of the class, she gave the students a formative assessment. Students filled out an online form (this would ensure individual responses were gathered as students could not see other students’ responses). They looked at the spreadsheet that Ms. O had projected. She did not let the students look at the sheet on their devices as she wanted to see what they knew not what their partners knew.

The questions for the assessment were:

1. What overall patterns did you observe in the use of the beak tools on each island? Give evidence from the data to support your answer.
2. Did there seem to be a “best” tool for every island? Why or why not? Use data to support your answer.
3. Now that you have had a chance to look at data collected for each island, write a few sentences on how variation affects the ability of birds to gather food. Provide examples of cause and effect. What will happen to the separate bird populations over time? Provide evidence for your explanations. Use class data to support your observations. (Note: this question was asked already but before the discussion, so students should now have more evidence to support their answers).

Ms. O assigned homework for the students that involved reading the section of their textbook on Darwin’s observations and inferences.

Days 5–6: Darwin’s Finches (Explain)

Investigative phenomenon: Different islands of the Galápagos had different populations of finch species, and the birds came in a variety of sizes on each island.

Ms. O expected students to produce a concept map outlining Darwin’s observations and the inferences he made. They then connected these observations to the activities done in class already. She modified this activity from Passmore et al. (2013

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Working in groups, students discussed Darwin's observations and the inferences he drew from them. Ms. O traveled to each group to answer any questions and/or clarify for the students anything about Darwin's findings. Students then worked together to create a concept map that included each of Darwin's observations with links to each of his inferences (Ms. O encouraged them to be creative. They could use pictures, drawings, or sketches). As she circulated, she ensured that each group had included all four of Darwin's key points:

1. Individuals within populations are variable.
2. The variation among individuals is, at least in part, passed from parent to offspring.
3. In every generation, some individuals are more successful at surviving and reproducing then others.
4. The survival and reproduction of individuals is not random; instead they are tied to the variation among individuals. The individuals with the most favorable variations, those who are better at surviving and reproducing, are naturally selected. (Darwin 1859, 459)

Ms. O instructed the students to add another layer to their maps that drew connections to the activities already done in this instructional segment. Ms. O expected these concept maps to be completed halfway through the second day of the activity.

Students displayed their maps around the room, and students did a gallery walk to view the work of their peers. They wrote at least one question or comment on a sticky note and attached it to each concept map. After the gallery walk, groups returned to their own posters and reviewed the feedback that was given to them. They made improvements based on the feedback. Ms. O then took a photo that she uploaded to the class Web site. The students continued to add information to these posters over the next week.

Ms. O assigned homework for the students to read pages 965–968 of an article posted on the class Web site (Grant and Grant 2003). This paper was a review of the work featured in the HHMI video shown on day 2.

Days 7–8: Analyzing Finch Data (Explain and Elaborate)

Investigative phenomenon: The average size of birds on one island changed in the years following a severe drought.

At the end of days 7 and 8, Ms. O expected students to analyze real data collected by the Grants and use it as evidence to support a claim about how a drought had affected one local finch population. Ms. O modified this activity from one by HHMI.

Ms. O introduced the spreadsheet showing data (HHMI 2016) recorded by the scientists students had read about in their homework. She oriented students by showing the columns with wing length, body mass, and beak depth, taken from a sample of 100 medium ground

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finches (*Geospiza fortis*) living on the island of Daphne Major in the Galápagos Islands. She projected the picture of a ground finch so that students had an image of what the bird looked like (figure 8.8). All the finches in this study had hatched between the years of 1973 and 1976. Before the students looked at the data, Ms. O asked a quickwrite question, "What do you think will happen to birds after a drought and why?" Then, Ms. O told the students to look at the data and she asked, "Do you see any patterns in this data before you graph it? Are all the birds of similar size? What measurements seem to vary the most from individual to individual? Why do you think the sample only includes adult birds? Is there a best approach to graphing beak depth measurements?"

Figure 8.8. A Ground Finch

Source: John van de Graaff 2010

Once students recognized that half of the measurements were from finches that died in 1977 (the year of the drought) and that half of the measurements were from finches that survived the drought, Ms. O asked them to graph the two groups on separate graphs as histograms. After the students generated their graphs, Ms. O had the students **analyze and interpret the data [SEP-4]**. To help scaffold students up to the point where they could support a strong claim, she asked them to work in pairs to complete an online form. The questions included the following:

1. What observations can you make about the overall shape of each graph? (Imagine that you are drawing a line that connects the tops of the vertical bars).
2. What do the shapes of the two graphs indicate about the distribution of beak-depth measurements in these two groups of medium ground finches?
3. Compare the distribution of beak depths between survivors and non-survivors. In your answer, include the shape of the distributions, the range of the data, and the most common measurements.
4. Based on what you saw in the film last week (it is linked to the class Web site if you want to refer back to it), think about how changes in the environment may have affected which birds survived the drought. Propose a hypothesis to explain differences in the distribution of beak depths between survivors and non-survivors. Use evidence from what you have learned about natural selection.

As a quick formative assessment she asks the following questions:

1. Are there any differences in average wing span between survivors and non-survivors?

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2. Are there any differences in average body mass between survivors and non-survivors?
3. Back to the graphs on beak depth are there any differences between survivors and non-survivors?
4. If there are differences, what do you think caused these differences? If there are no differences, why do you think that is so?
5. Which trait seems to have the most differences and what effect will that have on the finch population over time? Why?

On day 8, Ms. O addressed student's common ideas (including some that are inconsistent with the data). The students shared their results and added new information and observations to their concept map.

Day 9: Simulating Natural Selection (Explore and Explain)

Students used their bodies as physical models to simulate how variation within populations can occur over time due to natural selection.

Ms. O set out two types of fabric. One-half of the room had swatches of one type of fabric, and the other half had swatches of another type. Students worked in their assigned groups of four. Each group also received a bag containing 20 dots each of six different colors made out of construction paper that has been hole-punched (red, green, yellow, blue, black, pink). She also put a bag of additional dots at each of the stations (these had lots of each color in them, no specific number is counted). She also set up a cloud-based class spreadsheet with color-coded columns where the students input their data.

Ms. O welcomed the students and told them that half of them were going to be birds again, but this time they would all have the same beak type: their forefinger and their thumb. One person in the group was the timer; another person in the group was a "producer" who spread the colored dots from the baggie onto the fabric, and the other two individuals were birds of prey. The individual who was the timer was also the data entry person, entering data into the class spreadsheet throughout the experiment. Before beginning, this person recorded that the first generation began with 20 dots of each color. When Ms. O said "start," the birds turned their back and the producer spread the dots on the fabric. When the timer said "go," the two birds of prey turned around and picked up dots one at a time, for 20 seconds, using just their thumb and forefinger. They dropped the dots into a petri dish. After they were done, each member of the group helped count the dots. Ms. O asked them to figure out the number of dots that were left on the fabric by subtracting the number of prey captured from the initial number. Now using a baggie that has "extra" prey in it, the team members count out the new offspring. For every dot left on the fabric, two more dots of that color were added. If 12 green dots were left, they counted out 24 more green dots. Before the next round started, the data entry person recorded the starting number for each color under "second generation." The students repeated the actions of the first round with the producers spreading the dots on the

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fabric and the birds picking up dots with their forefingers and thumbs for 20 seconds. Again the team counted the dots and calculated how many dots were left, they again added two offspring per dot remaining and entered the total number of each color for the start of "third generation." Then the students could create line graphs of their data showing the evolution of each color over successive generations. After all students had generated their graphs, Ms. O had them complete an online form answering the following questions, which required them to **analyze and interpret data [SEP-4]** and **engage in argument from evidence [SEP-7]**:

1. Which, if any, colors of paper dots survived better than others in the second- and third-generation beginning populations of paper dots?
2. What might be the reason that predators did not select these colors as much as they did other colors? Use evidence from your results and what you know about natural selection to support your reason.
3. What effect did capturing a particular color dot have on the numbers of that color in the following generations? How does this relate to what you know about natural selection?
4. How well does the class data support your team's data and conclusions? Again use evidence from your results and what you know about natural selection to support your reason.

If the students ran out of time, they finished these questions as homework.

Day 10: Selection Pressure (Elaborate)

Investigative phenomenon: Different marine organisms have different features/ adaptations.

In this lesson students elaborated on what they had learned about natural selection as they applied it to selection pressures on marine organisms. Ms. O modified this lesson for days 10–12 from the Education and the Environment Initiative (EEI) curriculum *Differential Survival of Organisms*.

Each group received one of the following Selection Pressure Cards (https://www.cde.ca.gov/ci/sc/cf/ch8.asp#link18). Within their groups, they discussed the card, added their own examples, and then created a five-word poster (they could use drawings and symbols but only five words, besides the title) that **communicates [SEP-8]** the pressure and characteristics that might exist in organisms. Students share their posters so that all teams have a solid grasp of the different factors that can lead to successful reproduction.

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Selection Pressures Cards (copied from the EEI teacher pages)	
Need for Energy Examples of survival traits: teeth that can grasp prey, large eyes that help find prey, sensitive noses to smell prey	**Predation** Examples of survival traits: speed for escaping from predators, camouflage to hide from predators, hard exoskeleton
Abiotic Environmental Factors Examples of survival traits: layers of fat to protect from cold, feathers that shed water, feet that help running through sand	**Need to Reproduce** Examples of survival traits: ability to sing to find mates, pouches to carry young, nest-building behavior

After asking if there are any questions or clarifications that were needed, Ms. O distributed marine organism information cards (https://www.cde.ca.gov/ci/sc/cf/ch8.asp#link19) to each team. Each card depicted a marine organism and described several adaptations the organisms had. Students then had to identify how the adaptation gave the organism an advantage for one (or more) of the selection pressures. In each case, the students had to recognize both the **structure and its function [CCC-6]**.

After discussing these selection pressures as a class, students read an article from the same EEI unit *Differential Survival of Organisms* (https://www.cde.ca.gov/ci/sc/cf/ch8.asp#link20) to **obtain information [SEP-8]** about how human activities had affected the population of sea otters. Students discussed how these activities altered selection pressures.

As an exit ticket, all students completed two questions in an online form: What selective pressures have led to the characteristics commonly seen in sea otters? If sea otters are threatened again by human activities, as they were a century ago, how would this influence the differential survival of the otters and other species? Use evidence from natural selection and what you learned about today in class.

Students tied the ideas from the most recent lessons to the other ideas on their concept maps. They were asked to consider how each example related to Darwin's original ideas. Ms. O then took a new picture of the concept maps and re-uploaded them to the class presentation Web site.

Days 11–12: Case Study on Biodiversity and Human Impacts (Evaluate)

Investigative phenomenon: The number of crown-of-thorns sea stars in the Great Barrier Reef tends to be higher in years with more rainfall.

Students applied the knowledge gained during this instructional segment to analyzing a case study, (*Case Study of the Great Barrier Reef in Australia* found in the EEI unit, *Differential Survival of Organisms*.)

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Students worked in small groups to read through the short case study (https://www.cde.ca.gov/ci/sc/cf/ch8.asp#link21) and began to answer the questions on the worksheet provided in the unit (https://www.cde.ca.gov/ci/sc/cf/ch8.asp#link22). In addition to the questions on the worksheet, Ms. O asked students to apply their models of natural selection from previous days to explain what was happening in the case. Students were encouraged to create concept maps, graphs, or other supporting material.

On day 11, students completed the worksheet and prepared arguments about how to diminish the effects of human activities on the survival of coral populations on the Great Barrier Reef. On day 12, each group was given three minutes to make the case for their solution to the decreasing population of coral.

Vignette Debrief

The instructional plan described in this vignette was specifically designed to take into account the three dimensions of learning identified in the CA NGSS. Additionally, because of the **cause and effect [CCC-2]** relationship between environmental conditions and the selection pressures that directly influence natural selection, this series of lessons provided a wide array of opportunities to reinforce students' understanding of California's Environmental Principles and Concepts (EP&Cs).

SEPs. There were four practices highlighted in this vignette. The most frequently used was **analyzing and interpreting data [SEP-4]** which was applied after each hands-on activity that used data (for example, the Island Beak lab). In the finch raw data lesson, students used **mathematics and computational thinking [SEP-5]** to fully analyze the data. The students **constructed explanations [SEP-6]** when they described what happened during the dot-and-fabric activity as well as when they observed the selective pressure on the marine organisms. Throughout the vignette the students were asked to **engage in argument from evidence [SEP-7]** to justify their claims, which is an important part of the final assessment on day 12.

DCIs. The main disciplinary core idea for this vignette was natural selection, and it was fully addressed throughout the vignette. The other DCI that was partially addressed was adaptation, especially in the EEI lesson on marine organisms.

CCCs. Students recognized **patterns [CCC-1]** and used them to infer **cause and effect [CCC-2]** relationships on day 1 when they looked for patterns in human height and during each of the data analysis activities following the two simulations and the real finch data set.

EP&Cs. This vignette incorporated part of the EEI curriculum into the lessons and used a case study as the final assessment for the unit. This instructional plan provided an opportunity to reinforce three of California's EP&Cs, including 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; and, Principle IV: The exchange of matter between natural systems and human societies affects the long-term functioning of both. The Environmental Principles are emphasized on day 12.

HIGH SCHOOL FOUR-COURSE MODEL LIFE SCIENCE/BIOLOGY VIGNETTE 8.1: NATURAL SELECTION

CA CCSS Connections to English Language Arts and Mathematics. Throughout the vignette students were collecting, recording, and analyzing data. They used the data to examine change over time and to evaluate possible causes for the changes (S-IC-1, 3, 4; S-ID.7). The students held small-group and class discussions as they analyzed data and performed bird-beak simulations (SL.9-12.1, 2; RST.9-12.3). The students also produced several small informal pieces of writing throughout the vignette (WHST.9-12.7-10)

Note on technology use in the classroom. This vignette integrated many uses of technology within the daily lessons. If the students did not have one-to-one technology, they used lab notebooks or index cards for quickwrites and guiding questions. A teacher could ask students to record data in their notebook first and then for homework enter it into cloud-based spreadsheets or take the students to a computer lab the next day. Also, some teachers had access to a few computers and could use these with lab groups, eliminating the need for one-to-one access to technology.

Resources:

Basketball-Reference. n.d. NBA League Averages. https://www.cde.ca.gov/ci/sc/cf/ch8.asp#link23.

BSCS. 2016. BSCS 5E Instructional Model. https://www.cde.ca.gov/ci/sc/cf/ch8.asp#link24.

California Education and the Environment Initiative. 2010. https://www.cde.ca.gov/ci/sc/cf/ch8.asp#link25.

Darwin, Charles. 1859. *On the Origins of Species by Means of Natural Selection*. London: Murray.

Grant, Rosemary B., and Peter R. Grant. 2003. “What Darwin’s Finches Can Teach Us about the Evolutionary Origin and Regulation of Biodiversity.” *Bioscience* 53 (10): 965–975.

Howard Hughes Medical Institute (HHMI). 2016. “BioInteractive Lesson, Evolution in Action: Data Analysis.” https://www.cde.ca.gov/ci/sc/cf/ch8.asp#link26.

HHMI Biointeractive. 2014. “Galápagos Finch Evolution—HHMI BioInteractive Video.” Posted at *YouTube*, https://www.cde.ca.gov/ci/sc/cf/ch8.asp#link27.

McLennan, Jim. 2010. “Baseball Players: Does Size Matter?” https://www.cde.ca.gov/ci/sc/cf/ch8.asp#link28.

Passmore, Cynthia, and Jim Stewart. 2002. “A Modeling Approach to Teaching Evolutionary Biology in High Schools.” *Journal of Research in Science Teaching* 39 (3): 185–204.

Passmore, Cynthia, Elizabeth Coleman, Jennifer Horton, and Heather Parker. 2013. “Making Sense of Natural Selection: Developing and Using the Natural Selection Model as an Anchor for Practice and Content.” *The Science Teacher* 80 (6): 43.

Concept Map of Life Science Disciplinary Core Ideas

In meeting the performance expectations selected for this instructional segment, instructors must introduce some DCIs as well as build on the DCIs introduced in the middle grades. Figure 8.9 shows a concept map with the relationships between DCIs introduced during the middle grades and high school level. This concept map is *not* a conceptual flow with a specific order or sequence, nor is it a comprehensive illustration of all ideas that should be taught in the courses. Nor does it illustrate interdisciplinary connections that should be drawn. It may, however, be helpful in identifying how DCIs build from middle grades to high school and relate to one another. This map is explicitly placed at the end of the unit so that readers view it with a full appreciation of how these DCIs must be explored using the other two dimensions of CA NGSS as outlined in the course above. The concept map is limited only to DCIs, so even if students had a full appreciation of the content of these maps, they also need practice in doing science and engineering (SEPs) and identifying big-picture relationships to other disciplines (CCCs).

Figure 8.9. Relationship of DCIs in Biology including High School and Middle Grades Content

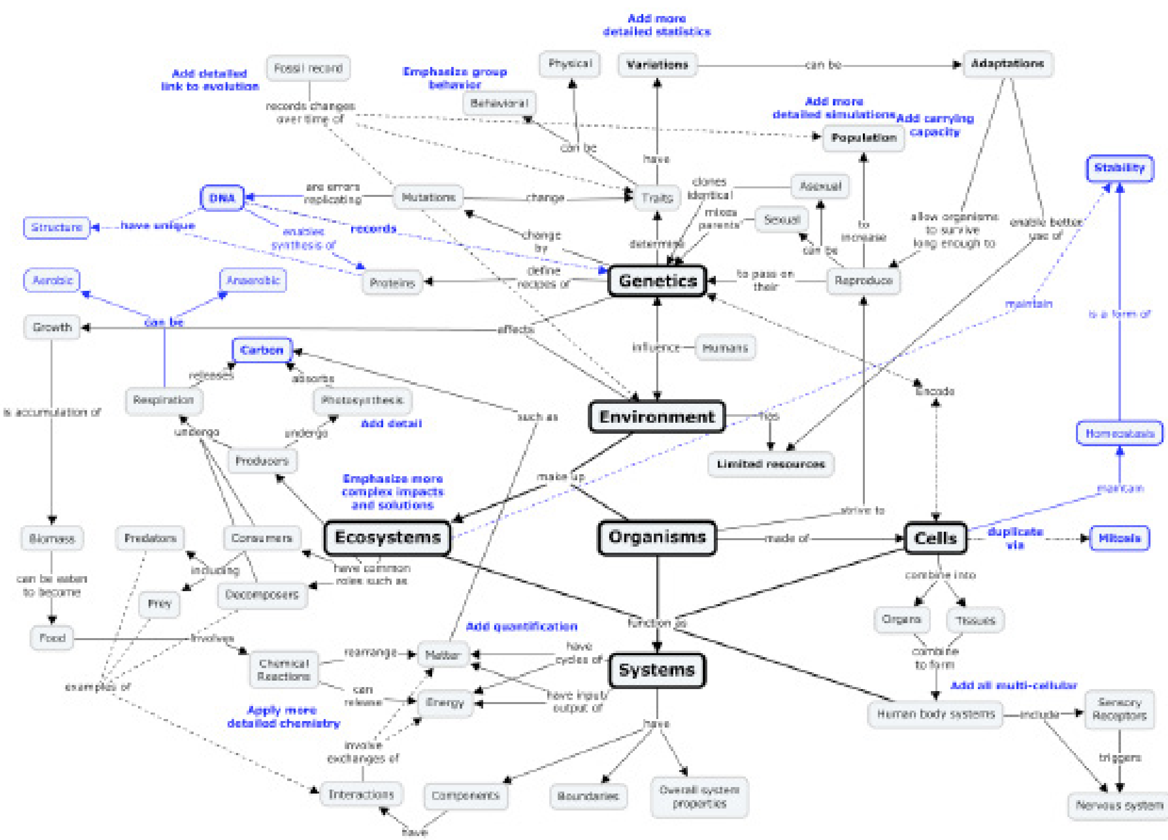


Diagram by M. d'Alessio

Black = Middle Grades Concepts; Blue = High School Concepts

Long description of Figure 8.9.

High School Four-Course Model: Chemistry

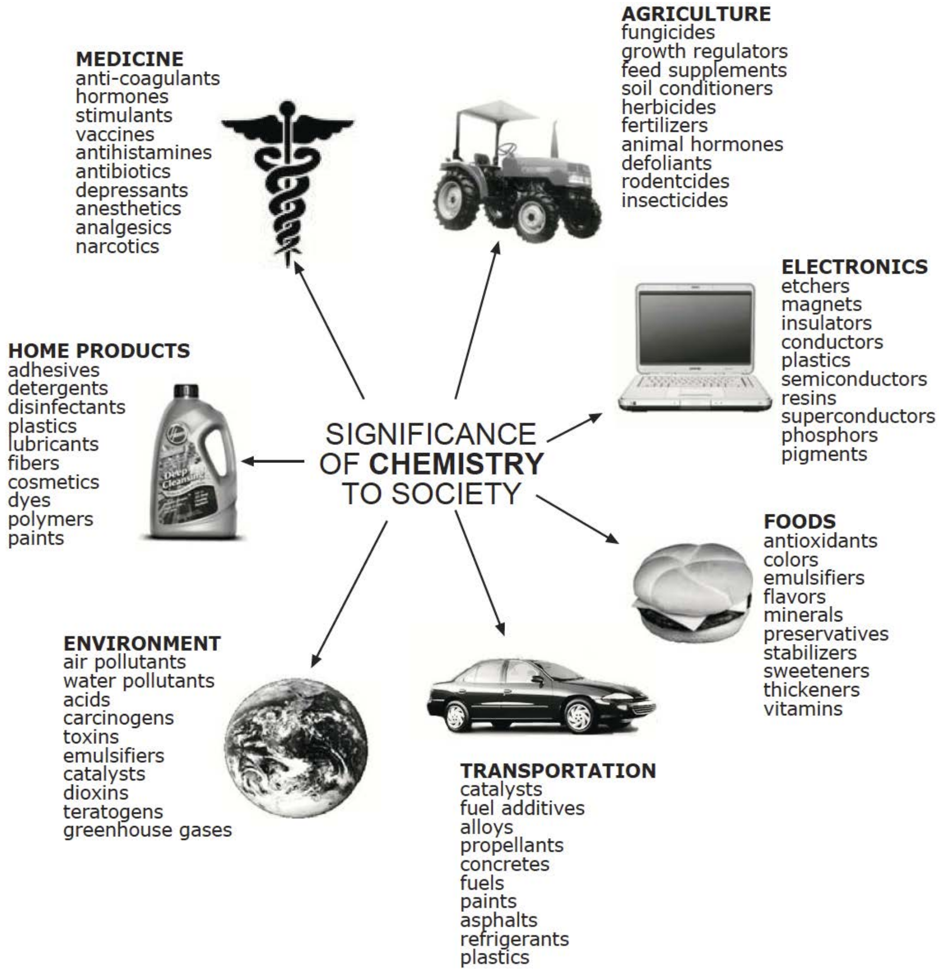
Introduction to the Chemistry Course

According to the Next Generation Science Standards:

> Students in high school continue to develop their understanding of the four core ideas in the physical sciences. These ideas include the most fundamental concepts from chemistry and physics, but are intended to leave room for expanded study in upper-level high school courses. The high school performance expectations in Physical Science build on the middle school ideas and skills and allow high school students to explain more indepth phenomena central not only to the physical sciences, but to life and Earth and space sciences as well. These performance expectations blend the core ideas with **scientific and engineering practices (SEPs)** and **crosscutting concepts (CCCs)** to support students in developing useable knowledge to explain ideas across the science disciplines. In the physical science performance expectations at the high school level, there is a focus on several scientific practices. These include developing and using models, planning and conducting investigations, analyzing and interpreting data, using mathematical and computational thinking, and constructing explanations; and to use these practices to demonstrate understanding of the core ideas. Students are also expected to demonstrate understanding of several engineering practices, including design and evaluation. (NGSS Lead States 2013f)

Chemical processes are a part of everyday life in California (figure 8.10). All students in California should have the opportunity to **investigate [SEP-3]** phenomena **caused [CCC-2]** when matter interacts, and to create **models [SEP-2]** of these interactions at the atomic **scale [CCC-3]**.

Figure 8.10. Chemistry in Everyday Life



Students can brainstorm the variety of ways that chemistry, and the products of chemical research and development, are relevant to society and their everyday lives. *Source*: Herr 2008, 285
Long description of Figure 8.10.

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. Many of the phenomena selected illustrate California's EP&Cs, which are an essential part of the CA NGSS (see chapter 1 of this framework). However, the phenomena chosen for this statewide document will not be ideal for every classroom in a state as large and diverse as California. Teachers are therefore encouraged to select phenomena that will engage their students and use this chapter's examples as inspiration for designing their own instructional sequence.

For example, the course could be restructured around contemporary issues of health or ecosystem change faced by a local community.

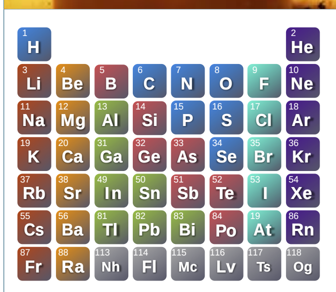
This example course is divided into instructional segments centered on questions about observations of a specific phenomenon. Different phenomena require different amounts of investigation to explore and understand, so each instructional segment should take a different fraction of the school year. As students achieve the performance expectations within the instructional segment, they uncover **disciplinary core ideas (DCIs)** from physical science and engineering. Students engage in multiple practices in each instructional segment, not only those explicitly indicated in the performance expectations. Students also focus on one or two CCCs as tools to make sense of their observations and investigations; the CCCs are recurring themes in all disciplines of science and engineering and help tie these seemingly disparate fields together.

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

Example Course Mapping for a Chemistry Course

This example course is divided into five instructional segments that group together related component ideas within the DCIs (table 8.3).

Table 8.3. Overview of Instructional Segments for High School Chemistry

	**1 Properties of Matter** Students observe and quantify the bulk properties of matter and how they change during chemical reactions.
	**2 Structure of Matter** Students recognize patterns in bulk properties and use them to develop a model of the internal structure of atoms. They apply these model atoms and how they interact through electrical attractions to bond together.
	**3 Chemical Reactions** Students use their model of the inner working of the atom to explain the rates of chemical reactions and whether energy is stored or released during interactions between atoms.
	**4 Modifying Chemical Reactions** In many situations, a dynamic and condition-dependent balance between a reaction and the reverse reaction determines the numbers of all types of molecules present.
	**5 Conservation of Energy and Energy Transfer** Students perform investigations of the basic laws of thermodynamics and relate these to important societal issues related to fuels and energy supply.

Sources: Giardino 2006; M. d'Alessio; Amitchell125 2011; A.M. Lebow; O'Sullivan 2009

IS1 Chemistry Instructional Segment 1: Properties of Matter

According to the NGSS storyline:

> The performance expectations in the topic Structure and Properties of Matter help students formulate an answer to the question, "How can one explain the structure and properties of matter?" Two sub-ideas from the *NRC Framework* are addressed in these performance expectations: the structure and properties of matter, and nuclear processes. Students are expected to develop understanding of the substructure of atoms and provide more mechanistic explanations of the properties of substances … *The crosscutting concepts of patterns, energy and matter, and structure and function* are called out as organizing concepts for these disciplinary core ideas. In these performance expectations, students are expected to demonstrate proficiency in developing and using models, planning and conducting investigations, and communicating scientific and technical information; and to use these practices to demonstrate understanding of the core ideas. (NGSS Lead States 2013f)

CHEMISTRY INSTRUCTIONAL SEGMENT 1: PROPERTIES OF MATTER

Guiding Questions

- How can we describe and measure the bulk properties of matter?
- What causes different materials to have different bulk properties?
- How can we infer the structure of matter at the atomic scale from properties of matter observed at the bulk scale?

Performance Expectations

Students who demonstrate understanding can do the following:

HS-PS1-3. Plan and conduct an investigation to gather evidence to compare the structure of substances at the bulk scale to infer the strength of electrical forces between particles. [Clarification Statement: Emphasis is on understanding the strengths of forces between particles, not on naming specific intermolecular forces (such as dipole-dipole). Examples of particles could include ions, atoms, molecules, and networked materials (such as graphite). Examples of bulk properties of substances could include the melting point and boiling point, vapor pressure, and surface tension.] [*Assessment Boundary: Assessment does not include Raoult's law calculations of vapor pressure.*] (Introduced here but not assessed in IS3)

CHEMISTRY INSTRUCTIONAL SEGMENT 1: PROPERTIES OF MATTER

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

Highlighted Science and Engineering Practices	Highlighted Disciplinary Core Ideas	Highlighted Crosscutting Concepts
[SEP-3] Planning and Carrying Out Investigations	PS1.A: Structure and Properties of Matter PS2.B: Types of Interactions	[CCC-1] Patterns [CCC-2] Cause and Effect: Mechanism and Explanation [CCC-4] Systems and System Models

CA CCSS Math Connections: N-Q.1–3

CA CCSS for ELA/Literacy Connections: RST.11–12.1; WHST.11–12.7, 9

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

Chemistry is the study of matter, the properties of matter, and the way matter interacts to form new substances. Many consider chemistry to be a challenging subject because it deals with infinitesimally small particles and abstract concepts, yet our understanding of chemistry has been derived from observable properties of matter at the bulk scale. Performance expectation HS-PS1-3 requires learners to make inferences about the strength of electrical forces between particles using observable properties such as melting point, boiling point, vapor pressure, and surface tension. Thus, students are asked to make inferences and models about atomic-scale objects and forces on the basis of what can be seen and observed, in much the same way that chemists have done throughout history. We introduce this performance expectation in the first instructional segment of this high school chemistry course so that students come to learn the power of reasoning and the inductive nature of science.

For students to succeed in this performance expectation, they must build upon their existing knowledge of matter and its interactions as learned through everyday life, as well as through academic experiences in elementary and middle grades. Students have interacted with both physical and chemical properties of bulk matter as long as they have been alive, and have developed naive but important understandings about the nature of matter. For example, when students describe the volume of a soft drink, texture or one's hair, or color of the sky, they are describing physical properties of matter at the bulk scale.

Similarly, when they describe the way wood burns, iron rusts, or silver tarnishes, they are describing chemical reactions at the bulk scale.

Before attempting performance expectation HS-PS1-3, students should become skilled at observing, describing, categorizing, and measuring physical and chemical properties at the bulk scale through a variety of activities and investigations. One such activity is to make as many observations, descriptions, and measurements as possible about a burning candle, patterned after a classic science lesson introduced by Michael Faraday. The teacher can introduce a list of things to observe (table 8.4).

Table 8.4. List of What to Observe in an Experiment of a Burning Candle Placed Under a Beaker

COMPONENTS OF THE SYSTEM	
flame	colors, shape, height in open air, initial rate of burning, rate of burning when wax melts, response to wind, response to water droplets, changes in color and height when a beaker is lowered over it, direction flame burns when candle is tilted at different angles, duration of smoke when extinguished, time flame burns under a 500 milliliter (ml) beaker versus a 1000 ml beaker
wick	position, color, structure, flow patterns of wax, rate wick burns when not in wax, rate wick burns when in candle
wax	color, texture, shape, rate consumed, appearance when melted, rate consumed if melted wax is drained, rate consumed if not drained
smoke	color, quantity, distribution, color bromthymol blue turns in smoke
condensate	appearance when placed under a beaker, conditions when it forms, location where it forms, rate of formation
deposits	color, texture, location, rate of formation, conditions under which deposits form
beaker	shape, size, changes during experiment
OTHER OBSERVATIONS (INCLUDING "SYSTEM PROPERTIES")	
odors	odors of unlit candle, burning candle, and extinguished candle
sound	sound produced by burning candle, sound when water is placed in well
temperature	top of flame, middle of flame, bottom of flame, at different distances away from the flame

All but the last three items in this list are objects that are components of a **system [CCC-4]**. Students can also make observations of the relationships between the components, noticing which objects interact directly. These relationships give clues to **cause and effect [CCC-2]** mechanisms. The bottom portion of the table includes other observations that don't seem to be readily attributable to any specific component of the system (though an astute student may notice that the odor and the sound are directly related to unseen components of the system, particles and movements in the air). These might include so-called *system properties* that are properties and behaviors of the entire system that manifest only from the fully functioning interactions between all the components. Students will be studying chemical systems in this course that involve different interacting chemical species. The purpose of this or other such activities is to help students develop the observation and measurement skills necessary to build **models [SEP-2]** of those **systems [CCC-4]** and make inferences that relate those models to other behaviors of the natural world. When they are skilled at observing properties on the bulk scale, they are better prepared to make the observations and inferences required by HS-PS1-3.

Students entering high school chemistry not only have a wealth of practical experiences with the properties of bulk matter, but they also have received formal instruction in chemistry starting in the second grade. By fifth grade, students identified materials based on their properties (5-PS1-3), *performed investigations to show that matter is conserved* (5-PS1-2), and made models that describe how matter is made of particles too small to see (5-PS1-1). In the middle grades, students should be experienced making models of molecules with different structures (MS-PS1-1) and start to understand that atomic and molecular structures determine properties at the bulk level.

Scientists have been studying matter for centuries, examining the behavior and interactions of different materials long before they had a working model of atoms at the microscopic level. Through careful measurements before and after chemical reactions, Lavoisier determined the law of mass conservation. Cavendish recognized that materials seemed to combine together in definite proportions. Even after Dalton built on their work to infer the existence of atoms, it was nearly 100 years before Thomson's investigations with cathode rays suggested that atoms had an internal structure that might govern their behavior. In the intervening time, researchers around the world noticed **patterns [CCC-1]** in the behavior of materials. Mendeleev, who grew up in a poor household and probably did not learn his country's official language until high school, finally cracked the code by building an incredible knowledge base of the bulk properties and behavior of different elements. The purpose of the first part of this instructional segment is to provide students experience with the types of observations Mendeleev was using at the time he developed the basis for our modern periodic table.

Many of the early investigations in chemistry had the goal of purifying substances (driven in part by alchemists' ideological belief that discovering the secret to removing the impurities in substances would allow them to remove impurities in their souls). Beginning a chemistry course with **investigations [SEP-3]** into the bulk properties of matter in pure substances forces students to confront the fact that there must be some sort of process causing these behaviors that operates within the matter itself. This realization is the first stage in forming the bridge between macroscopic properties of matter and models of microscopic interactions between particles that make up that matter.

Opportunities for ELA/ELD Connections

To support students in effectively interpreting their investigations in chemistry, have them identify, define, and discuss key vocabulary and concepts. For example, provide students with a list of the properties of matter (e.g., crystal shape, hardness, cleavage, freezing point, melting point, etc.) and have them define each property, draw a picture or visual representation, and, during the investigation, explain how the properties change when heated or cooled.

CA CCSS for ELA/Literacy Standards: L.9–12.4, 6
CA ELD Standards: ELD.PI. 9–12.6

A wide range of activities can be used to explore the variety of bulk properties of matter (e.g., crystal shape, hardness, cleavage, freezing point, melting point, boiling point, color, flammability, heat of combustion, malleability, ductility, luster, odor, color). The special properties of water make it particularly well suited to early investigations. Its high heat capacity, low density in solid form, strong cohesion and adhesion, capillary action, high surface tension, and excellent ability to dissolve polar substances, are particularly important to biological, environmental, and chemical systems, and are determined by its unique structure. Students **investigate [SEP-3]** how these properties change as a function of heating and cooling, allowing them to apply their **model [SEP-2]** of matter as interacting particles developed in the middle grades (MS-PS1-4). Students should rely on the **patterns [CCC-1]** they observe to form the **questions [SEP-1]** that will lead to the **cause [CCC-2]** of such behaviors ("The more I heat water, the less dense it becomes. What is causing that to happen?"). Students should start making inferences about the spacing between particles/molecules in solids, liquids, and gases. They should also begin **asking questions [SEP-1]** about how that spacing might affect other bulk properties ("Does changing the temperature affect the surface tension of water?") and be able to **plan investigations [SEP-3]** to answer some of these questions (comparing warm and cold water in such experiments as the number of drops that can be held on a penny or the height which water climbs in a straw through capillary action). Students' mental **models [SEP-2]** of pure substances should include particles that push one another apart when they collide and yet have some other force that attracts them together. In solids, this attraction is quite strong and objects retain their shapes. The strength of attraction in liquids varies substantially based on the substance (students can examine the difference in properties of water and alcohol). In gases, there is very little attraction between particles at all. These attractions are caused by electrical forces between the particles. Much of this course focuses on the nature of these forces, which govern the structural and electrostatic forces within and among atoms and molecules.

Water's unique properties also make it an excellent platform for observing the behavior of other pure substances and simple interactions between substances. After mixing different compounds with water, students observe their solubility, their ability to conduct electricity, and any changes in temperature that might occur. When choosing compounds, students should study multiple types that might include salts, acids, bases, hydrocarbons, and oxides. Some chemistry courses might begin by discussing the types of bonds and have students classify compounds according to those, but at this stage the terms could serve to either confuse or bias the development of mental **models [SEP-2]** of what is actually happening at the molecular level.[6] When students **conduct an investigation [SEP-3]** to measure the conductivity of different solutions, they gather evidence that there must be some relationship between electricity and material properties. When they **investigate [SEP-3]** the boiling points of water with different concentrations of salt, they gather evidence that the salt must somehow be "attracting" the water and preventing it from escaping as a gas (making this leap requires that students have a mental model of the different states of matter at the molecular level from the middle grades, MS-PS1-4). Rather than memorizing trends in bulk properties, HS-PS1-3 requires students to **plan and conduct investigations [SEP-3]** that help them **develop a mental model [SEP-2]** of matter as moving particles attracted together by electrical forces. At this point, students' models of the causes of these phenomena are likely to be incomplete and disjoint. They will return to HS-PS1-3 in IS3.

6. The distinction between ionic and covalent bonds is oversimplified and chemical bonds exist on a continuum of different attractions. The goal is to get students to understand the nature of these attractions and how they govern behavior of atoms.

IS2 Chemistry Instructional Segment 2: Structure of Matter

Understanding chemistry allows us to understand many things about the world around us and to make decisions and discoveries to improve the quality of life. Often we do not see the direct influence of chemistry in our lives, but it is all around us. From the neodymium magnets that vibrate our cell phones to the plastics we use to protect and preserve our foods, chemistry is often overlooked and taken for granted. In this instructional segment, students will learn about the structure and properties of matter so that they may better understand how chemicals are used in both the natural and manufactured worlds around them.

Terminology can be added later to refer to different aspects of students' models.

CHEMISTRY INSTRUCTIONAL SEGMENT 2: STRUCTURE OF MATTER

Guiding Questions

- What is inside atoms and how does this affect how they interact?
- How does the structure of matter at the atomic scale explain patterns in the bulk properties of matter?

Performance Expectations

Students who demonstrate understanding can do the following:

HS-PS1-1. Use the periodic table as a model to predict the relative properties of elements based on the patterns of electrons in the outermost energy level of atoms. [Clarification Statement: Examples of properties that could be predicted from patterns could include reactivity of metals, types of bonds formed, numbers of bonds formed, and reactions with oxygen.] [*Assessment Boundary: Assessment is limited to main group elements. Assessment does not include quantitative understanding of ionization energy beyond relative trends.*]

HS-PS1-2. Construct and revise an explanation for the outcome of a simple chemical reaction based on the outermost electron states of atoms, trends in the periodic table, and knowledge of the patterns of chemical properties. [Clarification Statement: Examples of chemical reactions could include the reaction of sodium and chlorine, of carbon and oxygen, or of carbon and hydrogen.] [*Assessment Boundary: Assessment is limited to chemical reactions involving main group elements and combustion reactions.*]

CHEMISTRY INSTRUCTIONAL SEGMENT 2: STRUCTURE OF MATTER

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

Highlighted Science and Engineering Practices	Highlighted Disciplinary Core Ideas	Highlighted Crosscutting Concepts
[SEP-2] Developing and Using Models [SEP-6] Constructing Explanations (for science) and Designing Solutions (for engineering)	PS1.A: Structure and Properties of Matter PS1.B: Chemical Reactions	[CCC-1] Patterns [CCC-2] Cause and Effect: Mechanism and Explanation [CCC-6] Structure and Function

CA CCSS Math Connections: N-Q.1–3

CA CCSS for ELA/Literacy Connections: RST.9–10.7; WHST.11–12.2, 5

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

Through years of intense study, scientists have developed models that are very useful in explaining and predicting the properties and behavior of matter. Middle grade students are introduced to **models [SEP-2]** of atomic and molecular structure (MS-PS1-1), and are familiar with basic properties of matter such as density, melting point, boiling point, solubility, and flammability (MS-PS1-2). In high school, students develop a deeper understanding of these **models [SEP-2]** and learn how to apply them to **explain [SEP-6]** and predict chemical properties (HS-PS1-1), chemical reactions (HS-PS1-2), bulk properties (HS-PS1-3), and chemical energetics (HS-PS1-2).

In the middle grades, students learn that the structure and properties of matter observed on the macro-scale result from the structure and interaction of component particles too small to be seen. Performance expectation HS-PS1-1 requires that high school students build upon this understanding by applying the periodic table as a **model [SEP-2]** to *predict the relative properties of elements based on the patterns of electrons in the outermost (valence) energy level of atoms*. The *NRC Framework* states the following:

> By the end of grade 12, students should understand that each atom has a charged substructure consisting of a nucleus, which is made of protons and neutrons, surrounded by electrons. The periodic table orders elements horizontally by the number of protons in the atom's nucleus and places those with similar chemical properties in columns. The repeating patterns of this table reflect patterns of outer electron states. The structure and interactions of matter at the bulk scale are determined by electrical forces within and between atoms. The stability of matter is increased when the electric and magnetic field energy is minimized. A stable molecule has less energy, by an amount known as the binding energy, than the same set of atoms separated, and one must provide at least this energy in order to take the molecule apart. (National Research Council 2012)

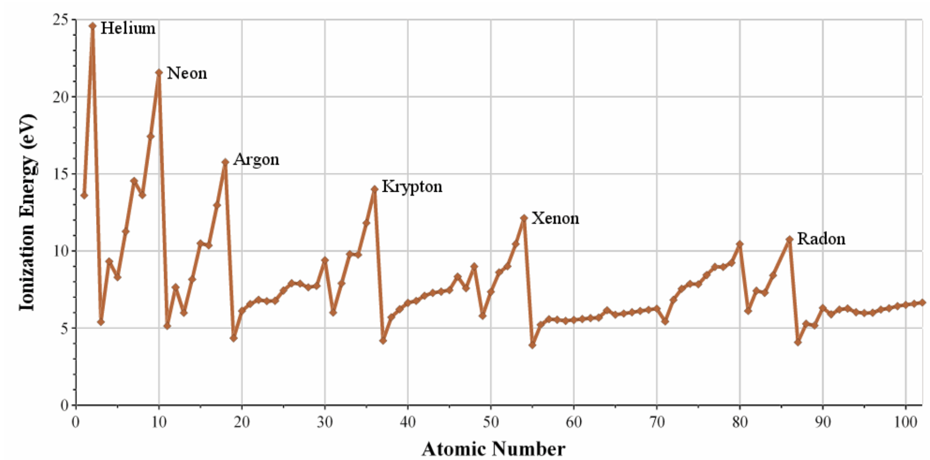
The performance expectations in the middle grades do not require students to develop a model of the atom's internal workings; this sequence differs from the 1998 California Science Content Standards in which the internal workings of the atom were introduced in eighth grade and it is conceivable that students highly proficient in the CA NGSS performance expectations for the middle grades have never heard the words *protons*, *neutrons*, and *electrons*. The CA NGSS learning progression has been designed so that this material is introduced at a time when it is developmentally appropriate and integrates with their learning in other disciplines (in this case, a formal description of electrical attraction with Coulomb's Law in high school physics). Students do, however, have significant experience recognizing **patterns [CCC-1]** and **asking questions [SEP-1]** about them. They have **analyzed data [SEP-4]** about the bulk properties of matter and are ready to begin relating them to the components that make up atoms.

Memorizing rules about the periodic table is not sufficient to meet HS-PS1-1. Instead, students must understand and apply underlying **models [SEP-2]** of atomic structure and interaction along with the principle of **cause and effect [CCC-2]**. They use these models to **explain [SEP-6]** why the properties of the elements **repeat in a periodic fashion [CCC-1]** and can use the periodicity to predict bulk properties of elements, their reactivity, and the types and numbers of bonds they will form with other elements.

Dmitri Mendeleev, who developed the predecessor of the modern periodic table, realized that the physical and chemical properties of elements were related to their atomic mass in a periodic way and arranged the 63 elements known when he was working so that groups with similar properties fell into vertical columns in his table. Students can build a mental model of how the periodic table is arranged by using a physical **model [SEP-2]** as an analog. By arranging color chips from a paint store into a matrix based on color and hue, students can understand the power of such models by predicting the existence of color/hue chips that were removed from the final matrix before the chips were distributed. This exercise mirrors the process Mendeleev used to predict the existence of elements not yet known.

Patterns [CCC-1] are a key crosscutting concept because they result from underlying causes. Observed patterns not only guide organization and classification but also prompt questions about relationships and the factors that influence them, and thereby lead to a discussion of **cause and effect [CCC-2]**. When chemists organized elements in order of increasing relative atomic mass, they noticed repeating, or periodic, patterns. For example, they noticed trends in chemical reactivity were punctuated by elements that were seemingly inert as shown in the high ionization energies of the noble gases in figure 8.11. These patterns led chemists to suppose that there were underlying causes that created these patterns. The recognition of these patterns thus contributed to our understanding of atomic theory, the key **model [SEP-2]** that students are expected to apply in IS2 and IS3. Using dynamic computer-based periodic tables, students can easily investigate a variety of properties (such as atomic radius, first ionization energy, and electron affinity) and observe periodic **patterns [CCC-1]** that provide evidence of patterns in underlying atomic structure.

Figure 8.11. Patterns in the First Ionization Energy of Different Elements



As students analyze plots of the properties of the elements as a function of atomic number, they should notice and discuss trends and patterns such as the comparatively low ionization energies of the alkali metals versus the high ionization energies of the noble gasses as seen in this plot of first ionization energies. *Source*: RJHall 2010
Long description of Figure 8.11.

The practice of **developing and using models [SEP-2]** in the CA NGSS often calls for students to develop their own models based on evidence they obtain directly. It took decades for the scientific community to develop models of the substructure of atoms that explain the patterns in the periodic table. One approach that helps students develop their own models is through a historical presentation of the evidence. A historical summary demonstrates how these models were repeatedly revised following revolutionary discoveries, starting with the billiard ball model and eventually culminating in Bohr's model and our modern quantum mechanical model. This sequence parallels the learning progression outlined in the CA NGSS during which students come into high school chemistry with the billiard ball model of atoms and leave with mastery of a more modern version (a quantum mechanical model of the atom is not assessed as part of the CA NGSS, so the working model adopted in individual classrooms depends on the local context. Bohr's model produces sufficient predictive power to meet the performance expectations in the CA NGSS). Students can make these models on their own by **obtaining information [SEP-8]** from the Internet about various analogies of atomic structure (Goh, Chia, and Tan 1994) and **evaluating [SEP-8]** the limitations of these models.

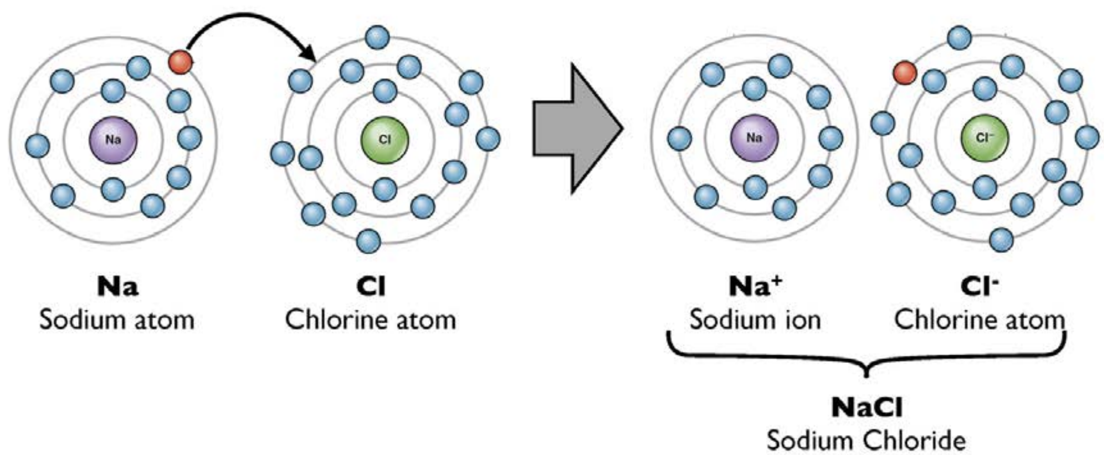
Opportunities for ELA/ELD Connections

Assign (or have students select) one of the various historical models of the atomic structure to research on the Internet. (A group of students can share the same model.) Each student can research and make their model, and then present the highlights of the model to a group or the class. If you have samples of excellent work completed in previous years or by students in a different period, show them to students who might benefit from this support. They can use the material to visualize or refer to an end product.

CA CCSS for ELA/Literacy Standards: SL.9–12.4, 5; RST.9–12.2; WHST.9–12.6
CA ELD Standards: ELD.PI. 9–12.6, 9

Students can then interpret the trends on the periodic table in light of their underlying model for atomic structure. They relate the overall order of the periodic table to the number of protons and electrons in the atom's outermost energy level. Students can then develop a simple model of interactions between atoms based on their electron configuration (figure 8.12). They should be able to use the periodic patterns of electron configuration in the periodic table to predict properties such as the overall reactivity of metals and the number of bonds an atom can form (HS-PS1-1), as well as being able to predict the outcome of simple chemical reactions (HS-PS1-2). For example, students should be able to predict that sodium is likely to lose electrons when interacting with other elements because it has only one loosely held electron in its valence shell, as indicated by its position in the first family. Similarly, they should be able to predict that sodium will react strongly with chlorine because chlorine tends to gain electrons due to its high electronegativity associated with its nearly filled valence shell as indicated by its position in the seventeenth family. Finally, they should be able to predict that the resulting sodium cation and chloride anion will be attracted to each other and form an ionic bond by applying the principles of electrostatic attraction.

Figure 8.12. Models of Atomic Structure Explain Periodic Trends

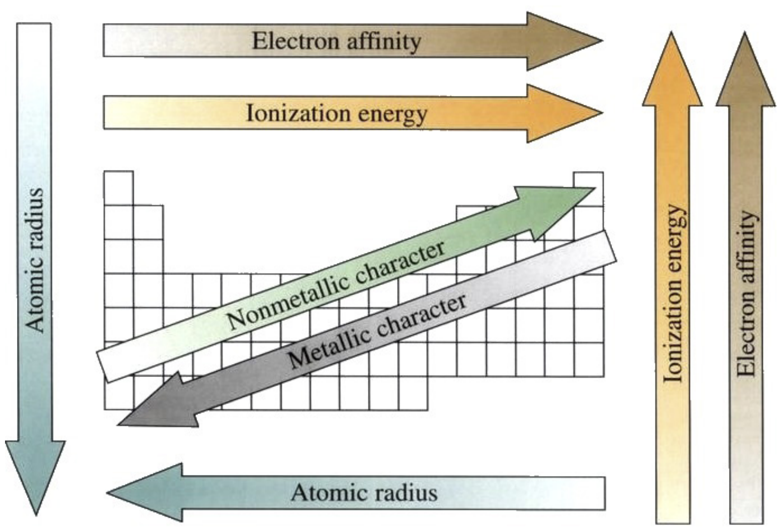


Students should predict trends within the periodic table based upon an application of models of atomic structure such as the Bohr model and octet rule illustrated here. *Source*: Adapted from OpenStax College 2013
Long description of Figure 8.12.

It is not sufficient for students to memorize and blindly apply rules for chemical bonding. Rather, they must develop **explanations [SEP-6]** for why atoms of main-group elements tend to combine in such a way that each atom has a filled outer (valence) shell, giving it the same electronic configuration as a noble gas (octet rule). To meet this performance expectation, students must describe thermodynamic principles that dictate that atoms will react with one another to transition to a more stable (lower energy) state. Filled orbitals, such as occur in a full octet state, are more symmetrical than other configurations, and such symmetry leads to greater stability. In addition, the electrons present in the different orbitals of the same sub-shell in a full octet can freely exchange their positions, leading to a decrease in exchange of energy and thus a lower net energy. The energy state is also affected by its electrical charge; an electrically neutral state has lower energy, and thus is more stable than an electrically charged state. For example, students should be able to explain that table salt (NaCl) is the result of Na+ ions and Cl- ions bonding. If sodium metal and chlorine gas mix under the right conditions, they will form salt as the sodium loses an electron, and the chlorine gains that electron. In the process, a great amount of light and heat is released, and the resulting salt thus has much lower energy and is relatively unreactive and stable, and won't undergo any explosive reactions like the sodium and chlorine that it is made of. Students will return to this idea again when they discuss bonding energy in IS3.

HS-PS1-2 requires students to **construct explanations [SEP-6]** and **argue from evidence [SEP-7]** rather than memorize facts and trends. Students should understand the basis for **trends and patterns [CCC-1]** shown in figure 8.13 and be able to explain the different types of chemical reactions. Once students understand the reasons for the trends observed in the periodic table, they can subsequently predict chemical reactions of significance in both the physical and biological realm. For example, by noting that carbon is in the fourteenth family, students should conclude that it therefore has four valence electrons that can be shared by such elements as hydrogen and oxygen and explain the existence of hydrocarbons based upon valence electron patterns.

Figure 8.13. Patterns and the Periodic Table



Students should understand the basis for trends and patterns in the periodic table, and be able to explain the types of chemical reactions and resulting bonds that occur between elements. *Source*: M. d'Alessio

[Long description of Figure 8.13.](#)

IS3

Chemistry Instructional Segment 3: Understanding Chemical Reactions

According to the NGSS storyline:

> [The performance expectations in the topic] "Chemical Reactions" help students formulate an answer to the questions: "How do substances combine or change (react) to make new substances? How does one characterize and explain these reactions and make predictions about them?" Chemical reactions, including rates of reactions and energy changes, can be understood by students at this level in terms of the collisions of molecules and the rearrangements of atoms. Using this expanded knowledge of chemical reactions, students are better able to understand a variety of important biological and geophysical phenomena, from cellular metabolism to reactions that form minerals and prepared to be critical consumers of information, so that they can engage in public discussion using evidence-based argumentation not only around science-related issues but across a broad range of topics. Students are also able to apply an understanding of the process of optimization in engineering design to chemical reaction systems. The crosscutting concepts of patterns, energy and matter, and stability and change are called out as organizing concepts for these disciplinary core ideas. In these performance expectations, students are expected to demonstrate proficiency in developing and using models, using mathematical thinking, constructing explanations, and designing solutions; and to use these practices to demonstrate understanding of the core ideas. (NGSS Lead States 2013f)

CHEMISTRY INSTRUCTIONAL SEGMENT 3: UNDERSTANDING CHEMICAL REACTIONS

Guiding Questions

- What holds atoms together to make molecules?
- Why do some combination of elements react and others do not?
- How do organisms harness energy from the chemical bonds in their food?

Performance Expectations

Students who demonstrate understanding can do the following:

HS-PS1-4. Develop a model to illustrate that the release or absorption of energy from a chemical reaction system depends upon the changes in total bond energy. [Clarification Statement: Emphasis is on the idea that a chemical reaction is a system that affects the energy change. Examples of models could include molecular-level drawings and diagrams of reactions, graphs showing the relative energies of reactants and products, and representations showing energy is conserved.] [*Assessment Boundary: Assessment does not include calculating the total bond energy changes during a chemical reaction from the bond energies of reactants and products.*]

HS-PS2-4. Use mathematical representations of Newton's Law of Gravitation and Coulomb's Law to describe and predict the gravitational and electrostatic forces between objects. [Clarification Statement: Emphasis is on both quantitative and conceptual descriptions of gravitational and electric fields.] [*Assessment Boundary: Assessment is limited to systems with two objects.*]

HS-PS3-5. Develop and use a model of two objects interacting through electric or magnetic fields to illustrate the forces between objects and the changes in energy of the objects due to the interaction. [Clarification Statement: Examples of models could include drawings, diagrams, and texts, such as drawings of what happens when two charges of opposite polarity are near each other.] [*Assessment Boundary: Assessment is limited to systems containing two objects.*]

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

Highlighted Science and Engineering Practices	Highlighted Disciplinary Core Ideas	Highlighted Crosscutting Concepts
[SEP-2] Developing and Using Models [SEP-5] Using Mathematical and Computational Thinking	PS1.A: Structure and Properties of Matter PS2.B: Types of Interactions PS3.C: Relationship Between Energy and Forces	[CCC-1] Patterns [CCC-2] Cause and Effect: Mechanism and Explanation [CCC-5] Energy and Matter: Flows, Cycles, and Conservation

CA CCSS Math Connections: A-SSE.1a–b, 3a–c; N-Q.1–3; MP.2, MP.4

CA CCSS for ELA/Literacy Connections: SL.11–12.5; RST.11–12.1; WHST.11–12.1.a–e

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

Students were introduced to chemical reactions in the middle grades. In particular, they learned that substances react chemically in characteristic ways; and in a chemical process, the atoms that make up the original substances are regrouped into different molecules, and these new substances have different properties from those of the reactants. In addition, they learned that the total number of each type of atom is conserved, and thus the mass does not change; and that some chemical reactions release energy, others store energy (PS1.B). Students in the middle grades demonstrated their understanding by **analyzing and interpreting data [SEP-4]** describing the properties of substances before and after the substances interact to determine if chemical reactions have occurred (MS-PS1-2), and by **developing and using models [SEP-2]** to describe how the total number of atoms does not change in a chemical reaction and thus mass is conserved (MS-PS1-5).

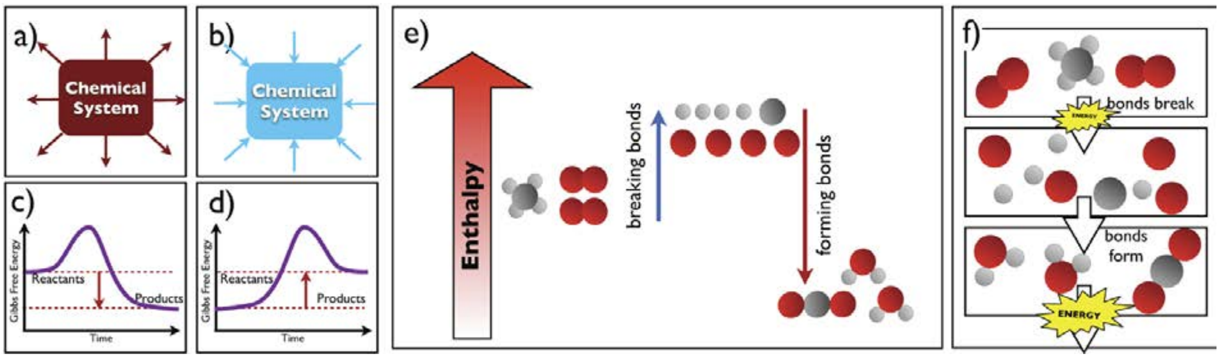
In this instructional segment, students build upon this understanding and their newly acquired understanding of the properties and structure of matter (IS1 and IS2) to learn how elements combine to form new compounds, the forces that hold them together, the forces between particles and molecules, and the energy needed to break or form bonds. Students will develop a conceptual **model [SEP-2]** of chemical bonding, which requires a shift towards the three-dimensional learning of the CA NGSS (table 8.5).

Table 8.5. Instructional Shifts for Chemical Bonding in the CA NGSS

LESS OF ...	MORE OF ...
Students are told, and memorize, that ionic bonds result from the transfer of electrons from one atom to another and covalent bonds from the sharing of electrons between two atoms. Students are then presented with differences in the two types of bonding. They conduct experiments to verify these differences.	Students observe how materials behave on their own and with other substances. They recognize **patterns [CCC-1]** that allow them to determine that there must be two different categories of materials. They use evidence about the properties to infer the strength and properties of the bonds that hold the materials together. Eventually, they label these categories with the appropriate scientific terms of ionic and covalent bonds.

An understanding of chemical structure is foundational to understanding properties of matter, particularly those involved in chemical reactions that are key to a myriad of physical and biological processes. **Energy [CCC-5]** is the capacity to perform processes and is necessary to cause the motion and interaction of atoms and molecules. Once students understand atomic structure and are able to predict simple chemical properties based upon the position of an element in the periodic table, they are ready to investigate chemical energetics. Performance expectation HS-PS1-4 requires students to **develop models [SEP-2]** that illustrate the **release or absorption of energy [CCC-5]** from chemical reactions. Students can use graphs, diagrams, and drawings to **model [SEP-2]** changes in total bond energy, such as those shown in figure 8.14 and use these tools to explain energy changes accompanying chemical reactions. Scientists drafted the models in figure 8.14, like many pictorial models that appear in textbooks. The models that those scientists produced when they were students were unlikely to be as simple and complete as these final products, but they refined their models over the years. Revising **models [SEP-2]** is an integral part of the nature of science.

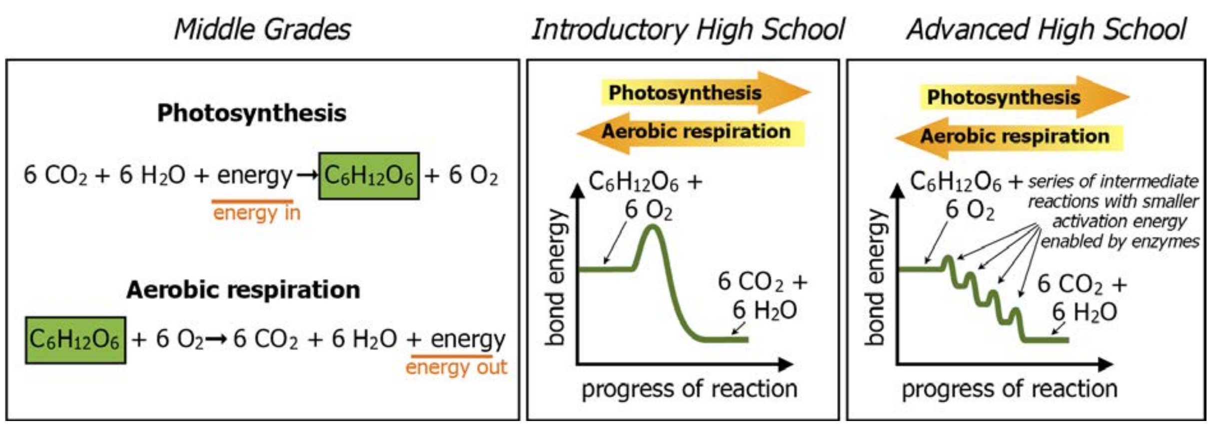
Figure 8.14. Models of Energy Changes in Chemical Reactions



Examples of a range of graphs, diagrams, and drawings developed by scientists as models of changes in total bond energy. Students develop their own mental models for energy changes in chemical reactions that they can express in pictorial models that may look like these. *Source*: M. d'Alessio. Long description of Figure 8.14.

In students' **models [SEP-2]** of chemical reactions, original chemical bonds are broken and new bonds form. Each of these changes affects the distribution of energy within the chemical system, so they must extend their **model [SEP-2]** to include these energy flows. **Energy conservation [CCC-5]** in chemical processes is, however, an abstract concept and must be discussed and developed with care. Students **conduct investigations [SEP-3]** to collect and **analyze data [SEP-4]** (both quantitative and descriptive observations) to discover that some reactions appear to release energy to their environment while others absorb it. In a more detailed **model [SEP-2]** of the energy flow, however, *all* chemical reactions *both* absorb and release energy, just in differing amounts. Chemical bonds are not tangible objects but actually the name given to a condition in which two atoms are attracted together by electric forces. Chemical reactions involve separating two atoms (requiring work to overcome their attraction, just like lifting a heavy load against the force of gravity) and bringing a different combination of the atoms closer together (which releases energy, much like a falling ball converts gravitational potential energy to kinetic energy as it is attracted to the Earth and moves closer to it). Whether or not a chemical reaction gives off energy overall depends on the relative magnitudes of these two energies. Chemists usually refer to the potential energy related to the relative position of two interacting atoms in a chemical bond as the *bond energy*. By comparing the bond energy of the products with the bond energy of the reactants, students can construct mathematical **models [SEP-2]** of the energy in the system and predict whether or not energy will be absorbed or released. A simple investigation to verify this model could include dissolving salt in water where the chemical bond between sodium and chlorine is broken (requiring lots of energy). New attractions between water and the sodium and chlorine are weak, so the particles remain relatively far apart (releasing relatively little potential energy). The temperature of water goes down when salt dissolves in it. Another example is the classic set of reactions that comprise photosynthesis and respiration. The complex biochemistry of photosynthetic reactions is not necessary at this stage, but the fact that the formation of biomass from carbon dioxide and water requires energy input is an important understanding that has been stressed in earlier grades. Energy input now can be understood in greater detail given comprehension of the energetics of chemical bonds. The equations in figure 8.15 are the net result of a number of other chemical reactions along the way (the various cycles involving ATP and other intermediate molecules). The reason these other reactions are required is because of the energy required to break bonds of the reactants apart (often called the *activation energy*, which some models in figure 8.14 depict as a temporary increase in energy during the chemical reaction). The intermediate stages involve certain proteins encoded by deoxyribonucleic acid (DNA) to re-orient the molecules and reduce the activation energy.

Figure 8.15. Developmental Progression of Models of Energy in Chemical Reactions



Students can revise their models and make them more detailed over time. In the middle grades, students use simplified equations for photosynthesis and aerobic respiration as a model of energy in chemical reactions (left: note that middle grades students are not assessed on balancing chemical equations). An introductory high school model of energy changes during these chemical reactions includes details about bonding energy (middle). A more advanced model that integrates core ideas from life science shows a series of intermediate chemical reactions inside cells each with a smaller activation energy (right). *Source*: M. d'Alessio

[Long description of Figure 8.15.](#)

High School Four-Course Model Chemistry Snapshot 8.5: Chemical Energetics

Both the CA NGSS and the California Common Core State Standards for Mathematics (CA CCSSM) include the practice of **developing and using models [SEP-2]**. CA CCSSM Math Practice Standard 4 (MP.4) states that high school students should be able "to identify important quantities in a practical situation and map their relationships using such tools as diagrams, two-way tables, graphs, flowcharts and formulas." Having taught for a number of years, Mr. S realized that his chemistry students often memorized diagrams and charts presented in the textbook without being able to apply these models to solving problems or **explaining [SEP-6]** the complex phenomena that they represent.

Anchoring phenomenon: Hot and cold packs look identical on the outside but use different ingredients to "spontaneously" change their temperature.

Mr. S developed a two-day lesson about modeling the energy in chemical bonds (HS-PS1-4) as part of a larger instructional segment on chemical reactions. At the beginning of class, Mr. S distributed reusable hot and cold packs used to treat sports injuries and instructed his students to flex the bags, feel the change in temperature, measure the temperature change using infrared thermometers obtained from the local building supply store, and record these changes in a collaborative online database. Despite variations in individual recordings among classmates, students noticed similar **patterns [CCC-1]** in the temperature gains or losses for the hot and cold packs.

California Common Core State Standards for English Language Arts/Literacy in History/Social Studies, Science, and Technical Subjects (CA CCSS for ELA/Literacy) standard L.11–12.4b requires students to "apply knowledge of Greek, Latin, and Anglo-Saxon roots and affixes to draw inferences concerning the meaning of scientific and mathematical terminology." Mr. H. wrote the words *endothermic* and *exothermic* on the board and asked students to enter as many words as they know or can find that use the roots: *end-*, *ex-* and *therm-* into an online form. Within a couple of minutes, the collaborative cloud-based list had grown to several dozen words, including *exit*, *extinct*, *exotic*, *exoskeleton*, *exocrine*, *extraterrestrial*, *endemic*, *endocrine*, *endosperm*, *thermometer*, *thermistor*, *thermophilic*, and *thermoregulation*. Mr. S then prompted his students to predict the meaning of these roots based upon the meanings shared by the words that contained them. Mr. S monitored their predictions as they entered them in an online input form and called upon students whose digital responses demonstrated understanding and who had not shared with the class recently. He asked these students to explain the meanings of these roots and predict the meanings of the words *endothermic* and *exothermic*. After clarifying that *endothermic* means absorbing heat, while *exothermic* means releasing heat, Mr. S

High School Four-Course Model Chemistry Snapshot 8.5: Chemical Energetics

asked students to identify the hot and cold pack reactions as being either endothermic or exothermic, and he once again assessed their responses from the online form.

Confident that his students had an intuitive understanding of exothermic and endothermic reactions as well as the vocabulary to describe these reactions, Mr. S projected a slide comparing several different annotated graphs (figure 8.14) and said, "Different people drew these diagrams to describe chemical reactions. What **patterns [CCC-1]** do you observe? Submit your thoughts to our online form." Scanning student responses, Mr. S formatively assessed the ability of his class to observe salient patterns, and noticed that the majority had noted that multiple drawings included one or more of the following features: two axes, time/progress axis, energy/enthalpy axis, changing molecular models, changing chemical formulas, changing energy values, and/or arrows indicating that energy is absorbed or released. Mr. S then selected Isabella, a student who had not had an opportunity to share in the last few days, to explain her observations. Isabella was confident that she had something significant to share because she knew that Mr. S pre-screened student responses in the cloud and only called on students who had demonstrated that they had something worthy of sharing. Isabella commented on the similarities and differences between the diagrams and explained that the model in the upper left might have represented the heat pack while one next to it might have represented the cold pack. Mr. S asked her to **provide evidence to support her argument [SEP-7]**, which she did. Mr. S then asked other students to share their observations and concluded by emphasizing that there are multiple ways to model or represent natural phenomena, and that each has its strengths and weaknesses. He then emphasized that some models are better at explaining or predicting phenomena than others, and that we should strive to improve our **models [SEP-2]** of the natural world to better explain the complex processes they represent.

Mr. S emphasized the idea that a chemical reaction affects the energy change of a system and can be **modeled [SEP-2]** with molecular-level drawings and diagrams of reactions, graphs showing the relative energies of reactants and products, and representations showing energy is conserved (also represented in figure 8.14). After explaining each model, Mr. S assigned as homework an online quiz that assessed student understanding of each type of model.

High School Four-Course Model Chemistry Snapshot 8.5: Chemical Energetics

Investigative phenomenon: Different chemical reactions produce different temperature changes.

On day 2, students planned and **conducted investigations [SEP-3]** using probes and computer probeware to continuously monitor the temperature change accompanying the following reactions:

1. $CaO(s) + H_2O(l) \rightarrow Ca(OH)_2(s)$
   (lime + water)
2. $NH_4NO_3(s) + H_2O\ (l) \rightarrow NH_4^+(aq) + NO_3^-(aq)$
   (ionization of ammonium nitrate, a fertilizer)
3. $HCl(dilute) + NaOH(dilute) \rightarrow H_2O + NaCl$ (neutralization)
4. $NaCl + H_2O \rightarrow Na^+(aq) + Cl^-(aq)$ (dissolving table salt)
5. $CaCl_2 + H_2O \rightarrow Ca^+(aq) + 2Cl^-(aq)$ (de-icing roads)
6. $NaHCO_3(s) + HCl(aq) \rightarrow H_2O(l) + CO_2(g) + NaCl(aq)$ (neutralization)
7. $CH_3COOH(aq) + NaHCO_3(s) \rightarrow CH_3COONa(aq) + H_2O(l) + CO_2(g)$
   (baking soda and vinegar)
8. $C_{12}H_{22}O_{11} + H_2O$ (in 0.5M HCl) $\rightarrow C_6H_{12}O_6$ (glucose) $+ C_6H_{12}O_6$
   (fructose) (decomposing table sugar)
9. $KCl + H_2O \rightarrow K^+(aq) + Cl^-(aq)$ (dissolving potassium chloride)
10. $NaCl + CH_3COOH(aq) \rightarrow Na^+(aq) + CH_3COO^- + HCl$
    (preparing HCl to clean tarnished metals)

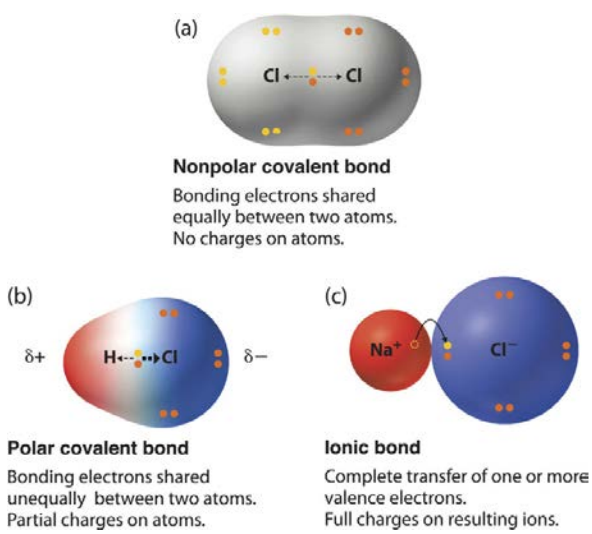
Students took screen captures of the temperature plots, classified each reaction as endothermic or exothermic, and represented each reaction using two or more of the model types shown in figure 8.14, or an additional model type that they developed on their own. When writing their lab reports, students applied scientific principles and evidence to **construct explanations [SEP-6]** for the thermal **changes [CCC-7]** that they had observed in each reaction.

Most of students' observations of bonding energy were at the macroscopic scale though their model of chemical bonds themselves includes an understanding of the role of charges and attractions at the atomic **scale [CCC-3]**. Students performed investigations into bulk properties in IS1 and IS2 (HS-PS1-3) so that they could **explain [SEP-6]** these differences in terms of chemical bonds. When considering ionic bonds, this model includes attractions between charged particles related to Coulomb's Law, which is assessed in the high school physics course (HS-PS2-4 and HS-PS3-5). Students will learn how the nucleus of one atom has enough attractive force to pull one, two, or three electrons away from nuclei that do not have the same attractive force on their own electrons. By applying the principles of electrostatic attraction, students should be able to predict that the resulting cations and anions will be attracted to each other and form ionic bonds. However, if either ion feels a stronger attraction to a different particle, then the existing bond is easily broken. Knowing that when salt dissolves in water, its bonds are broken, what can students infer about the charge of water molecules?

Materials with high boiling points are more likely to be bonded together more stably than materials with lower boiling points. As two non-metals come very close to one another, the respective orbitals of the atoms overlap, trapping two electrons in the energy field, creating the covalent bond (HS-PS3-5). Differences in how these ionic and covalent bonds are created (figure 8.16) are often overlooked, resulting in oversimplified definitions. To properly **explain [SEP-6]** the link between bulk effects and microscopic **causes [CCC-2]** (HS-PS1-3), students must develop robust models of how these bonds form.

Once students have a much more detailed microscopic model of chemical bonds, they can consider bonding energy again in terms of electromagnetic potentials and Coulomb's Law (HS-PS2-4). They can also **investigate [SEP-3]** other forms of attraction such as polar attractions and intermolecular forces. The clarification statement of HS-PS1-3 specifies that students do not need to refer to these attractions by name, but they should be able to investigate properties like surface tension and viscosity and provide a model-based explanation of how these properties relate to microscopic electromagnetic attractions.

Figure 8.16. Models of Covalent, Polar Covalent, and Ionic Bonding



Students should be able to develop and explain models of covalent, polar covalent, and ionic bonding.
Source: M. d'Alessio
Long description of Figure 8.16.

Opportunities for ELA/ELD Connections

Students write an informative/explanatory text about IS3, Understanding Chemical Reactions, based on models and discussions about chemical reactions, forces and changes in energy of objects due to interactions and models of covalent and ionic bonding. (Note: Some English learners hit a plateau in the development of English when they become functionally proficient or when their English is good enough to get by. Encourage these students to continue to develop their proficiency by asking them to expand and enrich their ideas verbally and in their writing.)

CA CCSS for ELA/Literacy Standards: WHST.9–12.2

CA ELD Standards: ELD.PI. 9–12.10

IS4 Chemistry Instructional Segment 4: Modifying Chemical Reactions

In the middle grades, students developed models to predict and describe changes in particle motion, temperature, and state of a pure substance when thermal energy was added or removed (MS-PS1-4). Building upon this understanding and what they have just learned about chemical reactions in IS3, students are prepared to investigate factors that influence and modify chemical reactions.

CHEMISTRY INSTRUCTIONAL SEGMENT 4: MODIFYING CHEMICAL REACTIONS

Guiding Questions

- How can we alter chemical equilibrium and reaction rates?
- How can we predict the relative quantities of products in a chemical reaction?

Performance Expectations

Students who demonstrate understanding can do the following:

HS-PS1-5. Apply scientific principles and evidence to provide an explanation about the effects of changing the temperature or concentration of the reacting particles on the rate at which a reaction occurs. [Clarification Statement: Emphasis is on student reasoning that focuses on the number and energy of collisions between molecules.] [*Assessment Boundary: Assessment is limited to simple reactions in which there are only two reactants; evidence from temperature, concentration, and rate data; and qualitative relationships between rate and temperature.*]

HS-PS1-6. Refine the design of a chemical system by specifying a change in conditions that would produce increased amounts of products at equilibrium.* [Clarification Statement: Emphasis is on the application of Le Châtelier's Principle and on refining designs of chemical reaction systems, including descriptions of the connection between changes made at the macroscopic

CHEMISTRY INSTRUCTIONAL SEGMENT 4: MODIFYING CHEMICAL REACTIONS

level and what happens at the molecular level. Examples of designs could include different ways to increase product formation including adding reactants or removing products.] [*Assessment Boundary: Assessment is limited to specifying the change in only one variable at a time. Assessment does not include calculating equilibrium constants and concentrations.*]

HS-PS1-7. Use mathematical representations to support the claim that atoms, and therefore mass, are conserved during a chemical reaction. [Clarification Statement: Emphasis is on using mathematical ideas to communicate the proportional relationships between masses of atoms in the reactants and the products, and the translation of these relationships to the macroscopic scale using the mole as the conversion from the atomic to the macroscopic scale. Emphasis is on assessing students' use of mathematical thinking and not on memorization and rote application of problem- solving techniques.] [*Assessment Boundary: Assessment does not include complex chemical reactions.*]

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

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

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

Highlighted Science and Engineering Practices	Highlighted Disciplinary Core Ideas	Highlighted Crosscutting Concepts
[SEP-2] Developing and Using Models [SEP-5] Using Mathematical and Computational Thinking [SEP-6] Constructing Explanations (for science) and Designing Solutions (for engineering) [SEP-7] Engaging in Argument from Evidence	PS1.B: Chemical Reactions ETS1.C: Optimizing the Design Solution	[CCC-1] Patterns [CCC-2] Cause and Effect: Mechanism and Explanation [CCC-5] Energy and Matter: Flows, Cycles, and Conservation [CCC-7] Stability and Change

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

CA CCSS for ELA/Literacy Connections: RST.11–12.1, 2; WHST.11–12.7

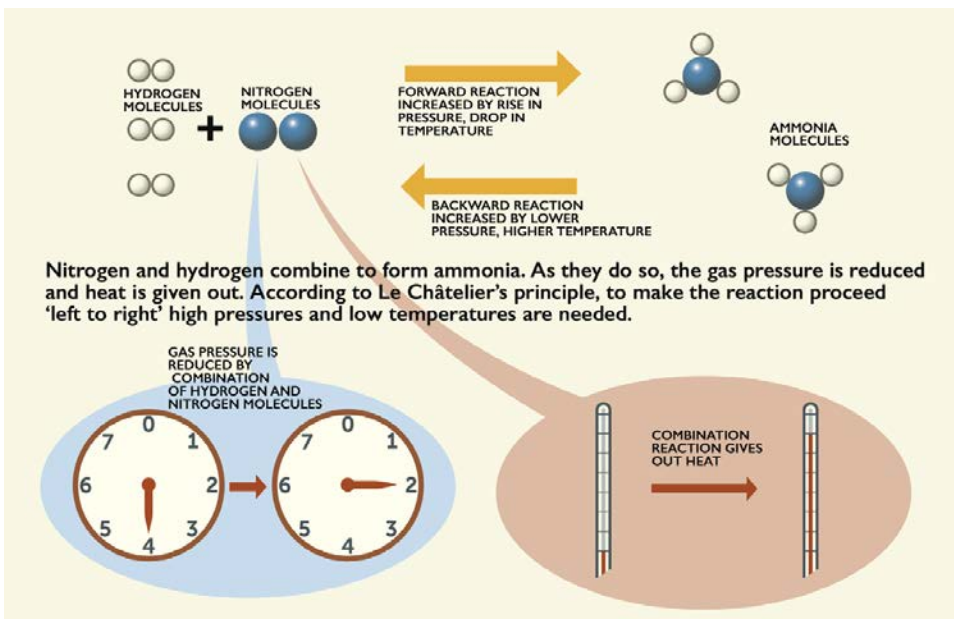
CA ELD Connections: ELD. PI.11–12.1, 5, 6a–b, 9, 10, 11a

In this instructional segment students expand their **model [SEP-2]** of chemical reactions as processes where these bonds are broken apart, typically because two or more molecules collide and the atoms are rearranged, resulting in molecules with new properties. Students will find different ways to express **cycles of matter [CCC-5]** within chemical **systems [CCC-4]**. Matter is conserved because the same set of atoms is present in the final state (product) as was there in the initial state (reactant). By the completion of this instructional segment, students are able to use stoichiometric principles as evidence of, and examples of, the conservation of matter. Students must be able to explain the relationship between the mathematics of chemical equations and the conservation of matter.

This instructional segment on chemical reactions emphasizes the crosscutting concepts of **stability and change [CCC-7]**. **Stability [CCC-7]** refers to the condition in which certain parameters in a system remain relatively constant, even as other parameters change. Dynamic equilibrium is an example of stability in which reactions in one direction are equal and opposite to those in the reverse direction, so although changes are occurring, the overall system remains stable. Dynamic equilibrium illustrates the principle of stability in an environment undergoing constant change. If, however, the inputs are sufficiently altered, a state of disequilibrium may result, causing significant changes in the outputs. Performance expectation HS-PS1-5 requires students to **create a scientific explanation [SEP-6]** about what **cause and effect [CCC-2]** by applying "scientific principles and evidence to provide an explanation about the effects of changing the temperature or concentration of the reacting particles on the rate at which a reaction occurs." After studying basic principles of chemical kinetics, students are prepared to investigate the response of reaction rates to varying temperatures and concentrations of reactants. For example, students can mix baking soda (sodium hydrogen carbonate, $NaHCO_3$) and vinegar (acetic acid, CH_3COOH) in sealed sandwich bags and gauge the speed and degree of reaction by the rate and amount of CO_2 gas produced as indicated by the swelling of the bag: $NaHCO_3$ (aq) + CH_3COOH (aq) $\rightarrow$ CO_2 (g) + H_2O (l) + CH_3COONa (aq). Students can **investigate [SEP-3]** the role of the quantity of molecular collisions by repeating the activity with differing concentrations of vinegar. They can then **investigate [SEP-3]** the role of temperature by warming or cooling the reactants while keeping their concentrations constant. By observing the swelling of the bags in response to varying temperatures and concentrations, students should discover that those factors that increase the number and energy of molecular collisions (increased concentration and temperature of reactants) result in increased reaction rates. Combining a conceptual model with experimental evidence, students can thus provide reasoned **explanations [SEP-6]** for factors influencing chemical reaction rates.

Once students understand the effect of changing the concentration of reactants and products on reaction rates, they are ready to apply their understanding to novel situations. Performance expectation HS-PS1-6 requires students to "refine the design of a chemical system by specifying a change in conditions that would produce increased amounts of products at equilibrium." By applying Le Châtelier's Principle, students can predict ways to increase the amount of product in a chemical reaction. To "refine the design of a chemical system," students must first be able to measure output and then test the effectiveness of changing the temperature and relative concentrations of reactants and products. For example, gas pressure is reduced and heat is produced when hydrogen and nitrogen combine to form ammonia (figure 8.17). According to Le Châtelier's Principle, the reaction can proceed to produce more ammonia by increasing the pressure and/or by dropping the temperature. Conversely, more ammonia will decompose into hydrogen and nitrogen by lowering the pressure and/or raising the temperature.

Figure 8.17. Le Châtelier's Principle



Students should be able to apply Le Châtelier's Principle to predict ways to increase the product of a chemical reaction. *Source*: The Worlds of David Darling 2015
Long description of Figure 8.17.

As students tackle HS-PS1-6, they must invoke the engineering strategies specified in HS-ETS1-2 in which they are required to "design a solution to a complex real-world problem by breaking it down into smaller, more manageable problems." For example, students might be challenged to increase the amount of precipitated table salt in solution [$NaCl(s) \longleftrightarrow Na^+(aq) + Cl^-(aq)$] without adding more salt. By experimenting with the addition of other sodium salts, students may discover that an increase in free sodium ions shifts the reaction in favor of the precipitate. To optimize the production of sodium, students may also experiment with changes in temperature, discovering that decreases in temperature favor the production of precipitate. In doing such investigations, students are applying the engineering skill of optimization as they refine their design to increase productivity.

The first two performance expectations in this instructional segment deal with *chemical kinetics*, the study of the rates of chemical processes. Chemical kinetics investigates how the speed and yield of chemical reactions can be influenced by different conditions. The final performance expectation in this instructional segment requires students to "use mathematical representations to support the claim that atoms, and therefore mass, are conserved during a chemical reaction" (HS-PS1-7). The most obvious way to accomplish this performance objective is by understanding and applying the basic principles of stoichiometry through laboratory investigations, problem solving, and reinforcement with apps and programs. The word *stoichiometry* derives from two Greek words: *stoicheion* (meaning element) and *metron* (meaning measure). Stoichiometry is based upon the law of the conservation of mass and deals with calculations about the masses of reactants and products involved in a chemical reaction.

The law of definite proportions, sometimes called Proust's Law, states that a chemical compound always contains exactly the same proportion of elements by mass. An equivalent statement is the law of constant composition, which states that all samples of a given chemical compound have the same elemental composition by mass. Students must learn that compounds appear in whole-number ratios of elements and that chemical reactions result in the rearrangement of these elements into other whole-number ratios. Students can develop a deeper understanding of the principles involved in HS-PS1-7 by massing and comparing the reactants and products of simple chemical reactions. For example, if students dehydrate copper sulfate pentahydrate ($CuSO_4 \cdot 5H_2O$) into the anhydrous salt ($CuSO_4$) by heating, they will find that the ratio of the mass of the resulting copper sulfate (dry mass) to water (the mass lost in dehydration) is always the same, regardless of how much copper sulfate pentahydrate is used. Students can infer that because the ratio of the component molecules in such a dehydration reaction remains constant, then the ratio of component elements must also remain constant. By applying **mathematical thinking [SEP-5]**, students learn to balance chemical reactions and predict relative quantities of products.

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Performance Expectations

Students who demonstrate understanding can do the following:

HS-PS1-6. Refine the design of a chemical system by specifying a change in conditions that would produce increased amounts of products at equilibrium.* [Clarification Statement: Emphasis is on the application of Le Châtelier's Principle and on refining designs of chemical reaction systems, including descriptions of the connection between changes made at the macroscopic level and what happens at the molecular level. Examples of designs could include different ways to increase product formation including adding reactants or removing products.] [Assessment Boundary: Assessment is limited to specifying the change in only one variable at a time. Assessment does not include calculating equilibrium constants and concentrations.]

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

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

HS-ETS1-3. Evaluate a solution to a complex real-world problem based on prioritized criteria and trade-offs that account for a range of constraints, including cost, safety, reliability, and aesthetics, as well as possible social, cultural, and environmental impacts.

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

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

Highlighted Science and Engineering Practices	Highlighted Disciplinary Core Ideas	Highlighted Crosscutting Concepts
[SEP-1] Asking Questions and Defining Problems [SEP-2] Developing and Using Models [SEP-6] Constructing Explanations (for science) and Designing Solutions (for engineering)	PS1.B: Chemical Reactions ETS1.A: Defining and Delimiting Engineering Problems ETS1.B: Developing Possible Solutions ETS1.C: Optimizing the Design Solution	[CCC-4] System and System Models [CCC-7] Stability and Change

Highlighted California Environmental Principles and Concepts:

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

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

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CA CCSS Math Connections: A-SSE.1; F-BF.1; F-IF.4–7; F-LE.1–4; MP.2, MP.4

CA CCSS for ELA/Literacy Connections: SL.9–12.1, 2; RST.11–12.1, 2, 7–10; WHST.9–12.1a–b, 2a, 6–10

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

Introduction

Understanding chemical reactions prepares students to do more than just predict what will form in the bottom of a test tube. This vignette introduces a story about the role of chemistry in modern agriculture and the goal to eradicate global hunger. Students examine chemical reactions in synthetic fertilizers and ask questions about how they could be produced more efficiently. They play the part of chemical engineers, refining the chemical system so that it produces the most reaction products for the least reactants

Length and position in course: This vignette illustrates a sample seven-day learning progression within a larger curricular instructional segment on chemical reactions. Prior to this learning event, students addressed questions such as "How can you alter reaction rates?" and "How can you predict the relative quantities of products in a chemical reaction?"

5E Lesson Design : This sequence is based on an iterative 5E model. See chapter 11 on instructional strategies for tips on implementing 5E lessons.

Day 1: Questioning a Discrepant Event

Students observe a flask of clear liquid turn blue when it is shaken and ask questions about what happened.

Day 2: Exploring a System in Equilibrium

Students create a physical model of a chemical system in dynamic equilibrium by pouring water back and forth between two containers.

Days 3–4: Equilibrium at the Atomic Level

Students explain equilibrium in chemical reactions by combining evidence from their physical model and a computer simulation that makes the atomic scale visible. They assess their mental model through an online video tutorial.

Day 5: Chemical Engineering and Modern Agriculture

Students obtain and evaluate information about world hunger, how synthetic fertilizers have helped increase agricultural productivity, the essential chemical reactions that enable fertilizers to work, and the possible environmental impacts of fertilizer use.

Days 6–7: Altering Equilibrium

Students complete a chemical engineering design challenge during which they have to find a way to disrupt different chemical systems that are in equilibrium and alter them so that they increase the concentration of products.

Day 8: Explaining Results

Students explain how they achieve their design goals and then communicate their findings to their peers. Upon reviewing one another's findings, students refine their chemical systems to see if they could improve the yield of products further.

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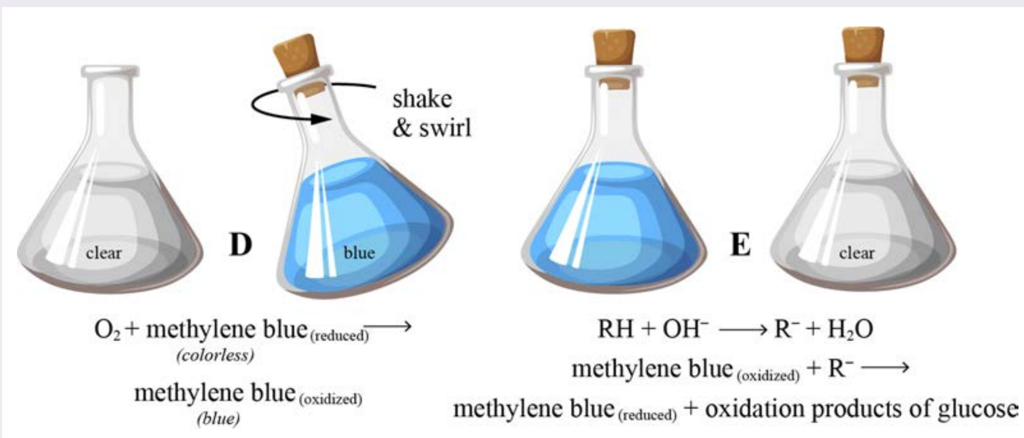
Day 1: Questioning a Discrepant Event (Engage)

Anchoring phenomenon: A flask of clear liquid spontaneously turns blue when swirled, but the color quickly fades.

Mr. S designed a series of quick, introductory activities that would pique students' curiosity and help them connect prior knowledge to new learning. Knowing that his students were fascinated with illusions and tricks, Mr. S prepared a "magic" trick that would leave his students asking, "How did he do that?" Mr. S selected an activity that he referred to as "Feeling Blue," a discrepant event that generated unexpected results and engendered a "need to know" among his students. Mr. S presented a flask with a clear liquid and asked his students to write down everything that they observed. He then swirled the flask for fifteen seconds, and the liquid in the flask "magically" turned blue. The students were already starting to ask questions when they noticed that the color quickly disappeared. He then asked a student to come up and see if they could repeat the "magic." Once again, the liquid turned a vivid blue with swirling and clear upon standing. Additional students volunteered to come forward and swirl the flask, but each time the color change was less dramatic than before (figure 8.18).

Figure 8.18. Demonstration of Le Châtelier's Principle (Equilibrium Law)



Source: Herr and Cunningham 1999, 416
Long description of Figure 8.18.

The students are now begging Mr. S to explain the trick, and he simply asked, "What did you observe? What might this indicate? What did we learn in the previous instructional segment?" Emma raised her hand and said, "Doesn't color change generally indicate that a chemical reaction has taken place? But no one added any chemicals to the flask!" to which Jackson replied, "But there are chemicals in the air, and maybe one of them is reacting with something in the liquid." Lamarr then said, "Yeah, but what causes the color to disappear after

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the swirling stops and the flask is left to sit still?" Rather than answering their questions directly, Mr. S employed Socratic questioning to stimulate critical thinking and illuminate ideas. Mr. S asked his students to pull out their mobile devices and respond to these questions, interspersed with further discussion and prompts: "What are five indications of a chemical reaction? What is a chemical indicator? When have we used chemical indicators in the past? What chemicals are in the air? Which one is the most reactive? Is there any evidence that this might be a redox reaction? Are all reactions reversible? What might cause this reaction to reverse upon standing?"

Students entered their responses into a collaborative online spreadsheet that Mr. S monitored. Mr. S scanned the answers to look for ideas that demonstrated understanding of the chemical processes involved. He called on specific students to explain their ideas and engaged as many students as possible, including students generally reluctant to raise their hands. This process affirmed the reasoning and ideas of his students and ensured full engagement in the lesson.

Mr. S introduced Le Châtelier's Principle, or the Equilibrium Law: *When a system at equilibrium is subjected to a change in concentration, pressure, volume, or temperature, then the system readjusts itself to counteract the effect of the applied change until a new equilibrium is established*. He confirmed student hypotheses that the addition of oxygen upon swirling disrupted equilibrium in the liquid, causing the reaction to proceed to the blue state, and then once again asked students to enter a response with their mobile devices to his question "What might cause the color to disappear?" As he assessed student responses on his computer, Mr. S noted that 80 percent of his students had figured out that the lack of free oxygen in the liquid upon standing must create another stress which favors the reverse reaction, causing the chemical reaction to shift in the direction of the clear reactants.

Recognizing that his students were progressing well in the construction of their **models [SEP-2]** of this chemical system, Mr. S discussed the phenomenon and its implications. He explained that the solution was prepared by adding 8 gram (g) of potassium hydroxide (KOH) to 300 milliliter (mL) of water in a flask, and then cooled prior to the addition of 10 g of glucose and 2 drops of methylene blue indicator. To connect to their prior understanding of acids and bases, Mr. S asked them to indicate if the solution he has described would be basic or acidic? Once again he scanned student inputs and noticed that more than 90 percent remembered that hydroxides create basic environments. He then explained that in a basic environment, glucose (represented here as RH), is ionized to the R- anion, which then reacts to reduce methylene blue to the colorless state,

$$RH + OH^- \rightarrow R^- + H_2O$$

$$\text{methylene blue}_{\text{(oxidized)}}[\textit{blue}] + R^- \rightarrow \text{methylene blue}_{\text{(reduced)}}[\textit{clear}]$$

When the flask is shaken, oxygen in the air oxidizes methylene blue, turning it blue.

$$O_2 + \text{methylene blue}_{\text{(reduced)}}[\textit{clear}] \rightarrow \text{methylene blue}_{\text{(oxidized)}}[\textit{blue}]$$

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If the flask were allowed to rest on a table, equilibrium would be reached and the flask would remain colorless. When the flask was shaken, oxygen from the atmosphere dissolved into the solution, disrupting equilibrium. Le Châtelier's Principle states that if any of the factors determining equilibrium is changed, the system will adjust so that the change is minimized. Thus, as oxygen levels rose as a result of shaking, methylene blue was again oxidized and the blue color returned, but as oxygen levels fell with time upon standing, the reduction reaction prevailed and the solution returned to its colorless equilibrium state. Students were reminded of safety precautions and provided materials to test the reaction on their own.

Day 2: Exploring a System in Equilibrium (Explore)

Investigative phenomenon: (Students develop a physical model of equilibrium.)

During the explore phase of the 5E lesson sequence, students developed concepts, processes, and skills through exploration and manipulation. To help students conceptualize the invisible molecular processes required to reach chemical equilibrium, Mr. S provided an analogous tangible activity in which students manipulated variables to observe how they affected a physical equilibrium. Students were provided with two 1000 mL containers as well as one 50 mL and one 100 mL beaker. Seven hundred mL of water with food coloring (to increase visibility) was placed in container A but none in container B. Students record the volumes in both beakers at "exchange zero." They then used the 100 mL beaker to transfer water from container A to container B while simultaneously using the 50 mL beaker to transfer water from container B to container A, while keeping both containers flat on the table. An "exchange" was defined as one transfer from A to B accompanied by a simultaneous transfer from B to A. Students repeat the process, recording the volumes following each exchange (figure 8.19).

Figure 8.19. A Physical Model of Equilibrium

Students explore dynamic equilibrium using a kinesthetic, physical model in which the opposing transfers of liquid between beakers represent forward and reverse chemical reactions. *Source*: mrsbuskey 2009.
Long description of Figure 8.19.

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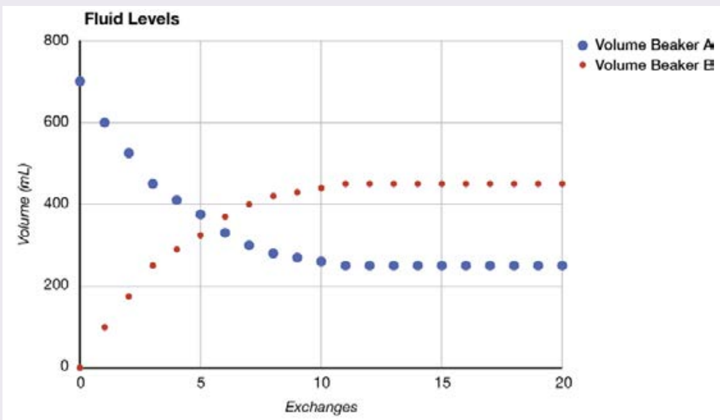
The exchange process was halted once the levels in the containers did not change noticeably for five or more exchanges, and students subsequently plotted their data using online spreadsheets (figure 8.20). Mr. S explained that a dynamic physical equilibrium has been reached when the levels no longer changed, and that this activity was analogous to chemical equilibrium. Students were then asked to explain the analogy in an online form. Mr. S assessed their understanding and confirmed that the water level in container A indeed represented the concentration of reactants, while the water level in container B represented the concentration of products, and that the water level in the 100 mL beaker represented the rate of the forward reaction while the water level in the 50 mL beaker represented the rate of the reverse reaction, and that the final water levels in containers A and B represented the concentrations of reactants and products once dynamic equilibrium has been reached. This activity encouraged students to **develop and use models [SEP-2]** as well as to apply the crosscutting concept of **systems and system models [CCC-4]**.

Figure 8.20. Fluid Levels Recorded from the Physical Model



Students share their data using an online form that inputs data into a collaborative spreadsheet. The data is instantly averaged and plotted and is accessible to all students for analysis and discussion. Prepared by M. d'Alessio using Google Sheets.
Long description of Figure 8.20.

Mr. S asked his students to predict what the final water levels in the containers would be given specific ratios of water in the containers at "exchange zero." Each lab group was assigned a different ratio of water in the "reactants" container to water in the "products" container and asked to measure the water levels once dynamic equilibrium was reached. Students reported their values in a collaborative online database, which they referenced when writing a lab report explaining class results for all starting ratios. Many students were surprised to find that equilibrium levels were the same, regardless of the starting water levels in the reactants and products containers. By the end of this activity, students had *developed a tangible* **system model [SEP-2]** to explain chemical equilibrium. In their **model [SEP-2]**, dynamic equilibrium

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was dependent upon the size of the transfer beakers, not on the initial water levels in the containers. Student models explained that water levels in the transfer beakers were analogous to forward and reverse chemical reaction rates, and that equilibrium levels of water in the containers were analogous to equilibrium concentrations of reactants and products.

Mr. S found that this activity was helpful in dispelling a number of misconceptions concerning equilibrium. Students often hold the misconception that “equilibrium” means “equal concentrations of reactants and products.” As students examined the equilibrium conditions, they noted that although the water levels in container A and container B were not changing, the amount of water in both containers at equilibrium was different, and by analogy, the concentrations of reactants and products in a chemical reaction might be quite different from each other once chemical equilibrium has been reached. This activity was also helpful in dispelling misconceptions regarding the directionality of reactions. Chemical equations in textbooks and handouts are often written with one right-pointing single-tipped arrow, creating the impression that reactions proceed only in that direction. This activity illuminated this misconception, as students realized that the equilibrium state could be approached from either direction. In addition, many students held the misconception that chemical reactions ceased once equilibrium had been reached. In this activity, they noted that although equilibrium had been reached, liquid continued to flow from container A to container B, and from container B to container A, and by inference realized that invisible molecular reactions continued even though equilibrium had been reached. At this point, Mr. S explained that “dynamic” equilibrium implied that there was no net change in reactants and products, not that reactions had ceased.

Mr. S then asked his students, “What will happen if we add 200 mL of water to container B once dynamic equilibrium has been reached and the exchanges continue?” Students engaged in a think-pair-share activity (a collaborative learning strategy in which students individually think about the question before sharing their ideas with their classmates). Once students had explained the rationale for their predictions, Mr. S asked them to resume the activity, adding 200 mL of water to container B while continuing to make exchanges and record water levels. In the process, students noticed that the addition of 200 mL to container B resulted in a subsequent rise in the water level in container A, providing a nice segue to Le Châtelier’s Principle: *When a system at equilibrium is subjected to a change in concentration, pressure, volume, or temperature, then the system readjusts itself to counteract the effect of the applied change until a new equilibrium is established.* Thus, a change in the water level in container-B, (representing the concentration of the products), caused a readjustment in the system such that there was a net movement of water from container B to container A (representing the dominance of the reverse reaction relative to the forward reaction) until dynamic equilibrium is reestablished.

Days 3–4: Equilibrium at the Atomic Level (Explain)

Over the next two days, students developed mental models and used them to explain the phenomena they had just explored. The explain stage in 5E lesson design mirrors **constructing explanations [SEP-6]** because the learners themselves should be constructing the explanation,

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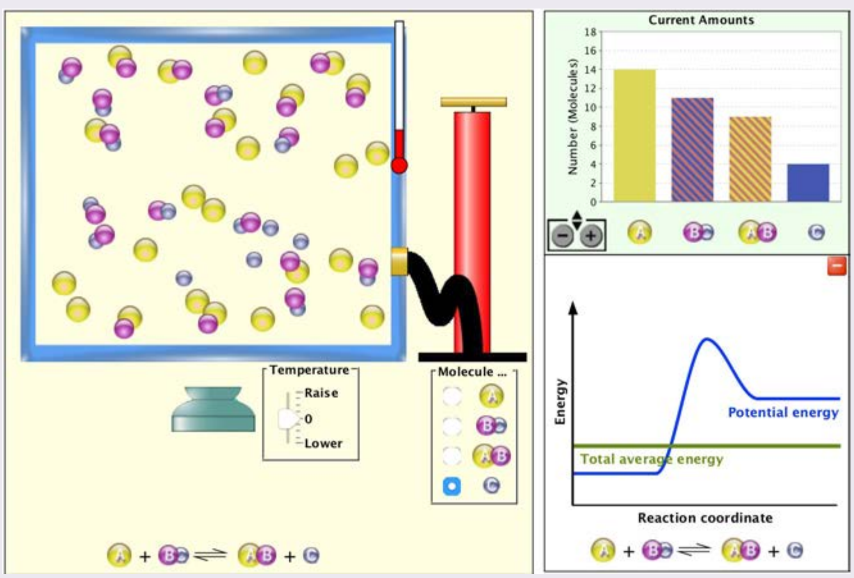
not having the teacher explain things to them.

Students would, however, need some common vocabulary to discuss the phenomena they had just explored. To assist language learners, Mr. S introduced the prefixes, roots, and suffixes embedded in key terms such as dynamic, equilibrium, transfer, exchange, reaction, molecule, reactant, and product. To help relate these terms to students' prior knowledge, Mr. S instructed his students to provide terms from everyday English that contained similar prefixes, roots, and suffixes. Mr. S had found that this activity not only assisted English language learners in acquiring academic language, but it also benefited native speakers as they learned to analyze structure and see patterns in both scientific and everyday vocabulary.

Students gained further understanding of equilibrium and Le Châtelier's Principle through online simulations of chemical systems. Students changed variables (concentration of reactants, concentration of products, temperature, pressure) one at a time and recorded changes in the equilibrium conditions. They could directly test and refine their mental **model [SEP-2]** of Le Châtelier's Principle. Students entered their observations into an online collaborative database and wrote a lab report in which they explained their findings using data collected in the simulator by the entire class. Mr. S assessed student understanding by posing a variety of "what-if" scenarios and asked students to predict the outcomes using their mental models instead of the simulator. As they discussed each scenario with partners, they articulated features of their models and learned from one another.

Figure 8.21. Online Simulation of Factors Affecting Equilibrium



To understand how stresses affect equilibrium, students changed one variable at a time in online simulations and recorded and analyzed results. *Source*: PhET Interactive Simulations, University of Colorado Boulder (PhET) 2015.

Long description of Figure 8.21.

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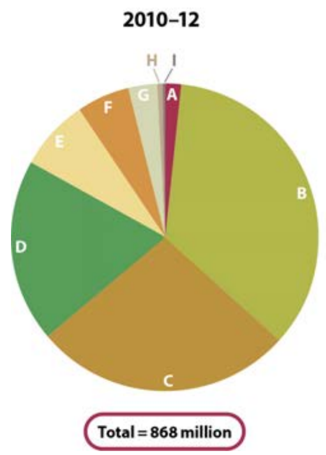
To help students convert their mental model to a conceptual model based on chemical equations, Mr. S developed a video quiz, adding images, text, and quizzes to an exemplary online video concerning Le Châtelier's Principle. During playback, the video paused, requiring student responses to teacher prompts. Student inputs to each prompt were recorded by the video quiz before the quiz advanced, providing accountability and ensuring that the video was truly an interactive learning experience. Mr. S reviewed overall class performance on the embedded questions to isolate common areas that needed further discussion.

Day 5: Chemical Engineering and Modern Agriculture (Extend, Elaborate)

Before introducing a chemical engineering design challenge, Mr. S introduced the complex real-world problem of feeding the world's growing population, and then showed how chemistry could help through nitrogen fixation. Using multimedia, lecture, and discussion, Mr. S presented the following information. According to the Food and Agriculture Organization of the United Nations (2012), more than 800 million people suffer from chronic undernourishment, mostly in developing countries (figure 8.22).

Figure 8.22. Global Distribution of People Who Suffer from Chronic Undernourishment



Number of undernourished *(millions)*	1990–92	2010–12
A Developed regions	20	16
B Southern Asia	327	304
C Sub-Saharan Africa	170	234
D Eastern Asia	261	167
E South-Eastern Asia	134	65
F Latin America and the Caribbean	65	49
G Western Asia and Northern Africa	13	25
H Caucasus and Central Asia	9	6
I Oceania	1	1

Source: Food and Agriculture Organization of the United Nations 2012

Long description of Figure 8.22.

Investigative phenomenon: Chemical fertilizers use ammonia. Ammonia synthesis occurs slowly at room temperature but speeds up at low temperatures.

Although the reasons for world hunger and undernourishment are complex, one thing is clear, if it were not for agricultural chemistry, the situation would be much worse. Chemistry

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has revolutionized agriculture and enabled yields far greater than anyone could have imagined a century ago. Of all of the advances in agricultural chemistry, none is as significant as the Haber process for making ammonia. Plants require nitrogen to synthesize proteins, grow, and produce fruit, and although 78 percent of the Earth's atmosphere is made of nitrogen, it is not in a form that plants can use. Nitrogen is a fundamental part of chlorophyll, and when leaves contain sufficient nitrogen, photosynthesis can proceed at high rates. Plant growth and crop productivity are greatly enhanced when additional nitrogen is provided in the form of ammonium nitrate, ammonium sulfate, or other nitrogen-rich compounds. The question is "How does one fix atmospheric nitrogen into a form that can be used by plants?" Prior to Haber, chemists had established the following equation for the synthesis of ammonia from atmospheric nitrogen:

$$N_2(g) + 3\ H_2(g) \rightarrow 2\ NH_3\ (g) \quad \Delta H = -92\ kJ/mol$$

Although this reaction was well known, yields of ammonia were very small. Determined to increase yields, Fritz Haber began to study this reaction in great detail, employing Le Châtelier's Principle to shift the reaction towards the right. Looking at the equation, one will note that there are twice as many molecules of gas on the left side as on the right side. Thus, pressure decreases when proceeding from left to right. Le Châtelier's Principle suggests that high pressure will force the reaction to the right so as to relieve the applied "stress." Haber noted that this is an exothermic reaction, as indicated by the 92 kilojoules per mole that are given off ($\Delta H = -92$ kJ/mol), and by applying Le Châtelier's Principle, he determined that yield could be increased if carried out at low temperatures. Applying Le Châtelier's Principle once more, Haber reasoned that a removal of the product (NH_3, ammonia) would shift the reaction towards greater yield. Since the condensation temperature of ammonia is higher than that of nitrogen or hydrogen, Haber was able to increase yields by cooling the reaction mixture until ammonia liquefied and could be removed from the reaction apparatus. Haber also developed an iron-based catalyst to speed the reaction. Eventually, Haber achieved very high yields of ammonia by creating conditions of high pressure and low temperature, accompanied by a catalyst and continuous removal of ammonia. The Haber process of nitrogen fixation revolutionized the production of nitrogen-based fertilizers, providing increased crop yields worldwide (figure 8.23). It has been estimated that a third of the Earth's more than 7 billion people are fed thanks to the Haber process (Smil 1997).

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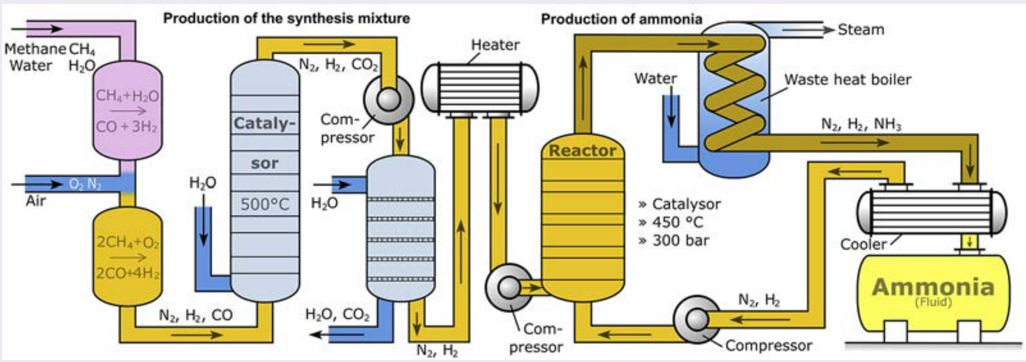
Figure 8.23. Haber Process of Nitrogen Fixation



An analysis of the Haber process of nitrogen fixation provides students the opportunity to make connections between chemistry, chemical engineering, societal needs and history. *Source*: Williams 2010

Long description of Figure 8.23.

Investigative phenomenon: High concentrations of ammonia and other chemical fertilizers are observed in local streams.

While fertilizers are extremely useful, students **obtained and evaluated information [SEP-8]** about some of the negative **effects [CCC-2]** fertilizer use could have on ecosystems in California (EP&C II, IV). Could they design a system that minimized the amount of fertilizer that washed away into nearby streams? Are certain fertilizers less soluble in water than others?

Days 6–7: Chemical Engineering and Modern Agriculture (Extend, Elaborate)

Students applied their model of chemical equilibrium and Le Châtelier's Principle to a chemical engineering design problem during which they were required to manipulate a chemical system so that it produced more products at equilibrium (HS-PS1-6).

Students began with an online tutorial during which they must explain how they can change pressure, temperature, reactant concentrations, and product concentrations to increase the yield of the products in equations below (figure 8.24):

	Reaction	ΔH (kJ)
1	$CH_4(g) + 2O_2(g) \rightarrow CO_2(g) + 2H_2O(l)$	-890.4
2	$C_3H_8(g) + 5O_2(g) \rightarrow 3CO_2(g) + 4H_2O(l)$	-2219.2
3	$2C_8H_{18}(l) + 25O_2(g) \rightarrow 16CO_2(g) + 18H_2O(l)$	-10943
4	$2CH_3OH(l) + 3O_2(g) \rightarrow 2CO_2(g) + 4H_2O(l)$	-1452
5	$C_2H_5OH(l) + 3O_2(g) \rightarrow 2CO_2(g) + 3H_2O(l)$	-1367
6	$C_6H_{12}O_6(s) + 6O_2(g) \rightarrow 6CO_2(g) + 6H_2O(l)$	-2804

HIGH SCHOOL FOUR-COURSE MODEL CHEMISTRY VIGNETTE 8.2: CHEMICAL EQUILIBRIUM

	Reaction	ΔH (kJ)
7	$2CO(g) + O_2(g) \rightarrow 2CO_2(g)$	-566.0
8	$C(s) + O_2(g) \rightarrow CO_2(g)$	-393.5
9	$4Al(s) + 3O_2(g) \rightarrow 2Al_2O_3(s)$	-3351
10	$N_2(g) + O_2(g) \rightarrow 2NO(g)$	+182.6
11	$N_2(g) + 2O_2(g) \rightarrow 2NO_2(g)$	+66.4
12	$2H_2(g) + O_2(g) \rightarrow 2H_2O(g)$	-483.6
13	$2H_2(g) + O_2(g) \rightarrow 2H_2O(l)$	-571.6
14	$N_2(g) + 3H_2(g) \rightarrow 2NH_3(g)$	-91.8
15	$2C(s) + 3H_2(g) \rightarrow C_2H_6(g)$	-84.0
16	$2C(s) + 2H_2(g) \rightarrow C_2H_4(g)$	+52.4
17	$2C(s) + H_2(g) \rightarrow C_2H_2(g)$	+227.4
18	$H_2(g) + I_2(g) \rightarrow 2HI(g)$	+53.0
19	$KNO_3(s) \xrightarrow{H_2O} K^+(aq) + NO_3^-(aq)$	+34.89
20	$NaOH(s) \xrightarrow{H_2O} Na^+(aq) + OH^-(aq)$	-44.51
21	$NH_4Cl(s) \xrightarrow{H_2O} NH_4^+(aq) + Cl^-(aq)$	+14.78
22	$NH_4NO_3(s) \xrightarrow{H_2O} NH_4^+(aq) + NO_3^-(aq)$	+25.69
23	$NaCl(s) \xrightarrow{H_2O} Na^+(aq) + Cl^-(aq)$	+3.88
24	$LiBr(s) \xrightarrow{H_2O} Li^+(aq) + Br^-(aq)$	-48.83
25	$H^+(aq) + OH^-(aq) \rightarrow H_2O(l)$	+55.8

Students applied what they had learned to predict how yields of various reactions might be increased by adjusting pressure, temperature, reactant concentration, and product concentration. *Source*: Calculated from Wikipedia 2017.

Investigative phenomenon: How can we shift a chemical reaction to yield more products by adjusting the temperature, pressure, or by adding acids, bases, or other salts or ions?

Satisfied with the results of the online work, Mr. S introduced students to a series of chemical reactions and challenged them to predict how to use temperature, pressure, acids, bases, or other salts or ions to disturb the equilibrium to increase product yield. After

HIGH SCHOOL FOUR-COURSE MODEL CHEMISTRY VIGNETTE 8.2: CHEMICAL EQUILIBRIUM

completing a safety quiz and acquiring safety goggles, lab coats, and gloves, students were provided with a series of six test tubes containing solutions at equilibrium. In each case, students had to examine the chemical reaction and determine how the reaction might be shifted towards the products. Students were provided with indicators (phenolphthalein, methyl orange) to determine pH, syringes for increasing or decreasing pressure, acids and bases for adjusting pH, hot plates and ice for changing temperatures, and supplemental chemicals to adjust ion concentrations. Students were encouraged to label all test tubes and containers and to take photographs of each reaction so that they could review and analyze reactions in greater details. Students were asked to write their predictions in their online lab reports and upload movies (or before and after photographs) of color changes as evidence.

$$\underbrace{Na+(aq)+HCO_3^-(aq)}_{[clear]} \longleftrightarrow \underbrace{Na^+(aq) + OH^-(aq)+CO_2(g)}_{[pink]} \quad \text{(indicator: phenolphthalein)}$$

$$\underbrace{NH_3(aq)+H_2O(l)}_{[clear]} \longleftrightarrow \underbrace{NH_4(aq)+OH^-(aq)}_{[pink]} \quad \text{(indicator: phenolphthalein)}$$

$$\underbrace{CH_3COOH(aq)+ H_2O(l)}_{[yellow]} \longleftrightarrow \underbrace{H_3O^+(aq) + CH_3COO^-\ (aq)}_{[red]} \quad \text{(indicator: methyl orange)}$$

$$\underbrace{Co^{2+}(aq) + 4Cl^- + heat\ (aq)}_{[pink]} \longleftrightarrow \underbrace{CoCl_4^{2-}\ (aq)}_{[blue]}$$

$$\underbrace{Cu^{2+}(aq) + 4Br^-(aq)}_{[blue]} \longleftrightarrow \underbrace{CuBr_4^{2-}(aq)}_{[yellow]}$$

$$\underbrace{Fe^{3+}(aq) + SCN^-(aq)}_{[yellow]} \longleftrightarrow \underbrace{FeSCN^{2+}\ (aq)}_{[red]}$$

Day 8: Explaining Results (Evaluate)

During the evaluation phase, learners assessed their results and communicated their findings. Mr. S asked students to construct an **argument from evidence [SEP-7]** that they had successfully shifted their chemical reaction to produce more products. Each group presented one chemical system that they were particularly excited about. The first group described their modification to the first chemical system. They cited the appearance of pink or an increased intensity in pink color as evidence that they had achieved success, since the hydroxide ion in the product (OH^-) turns phenolphthalein pink. The group presenting the fourth equation cited a shift from pink or purple to blue to indicate success in producing more $CoCl_4^{2-}$. After reviewing their findings, students had to explain how they could improve their yields or produce the same yield with a smaller disturbance. For example, groups that added acid to their compound might have been worried about the environmental impact of adding acid to the system (EP&C IV) and tried to see if they could produce the same result with a temperature change. Comparing these possible interventions and thinking about which would be easier to implement in different conditions is one way to meet HS-ETS1-3. Students then proceeded to test their different hypotheses, recording results with their cameras as before. Working within the constraints of

HIGH SCHOOL FOUR-COURSE MODEL CHEMISTRY VIGNETTE 8.2: CHEMICAL EQUILIBRIUM

resource availability and time, students presented their final results in an online lab report that was shared with their class. This process of refining their chemical system was also a chance for students to reflect on their own learning while summarizing their thoughts about the experience in digital blog posts.

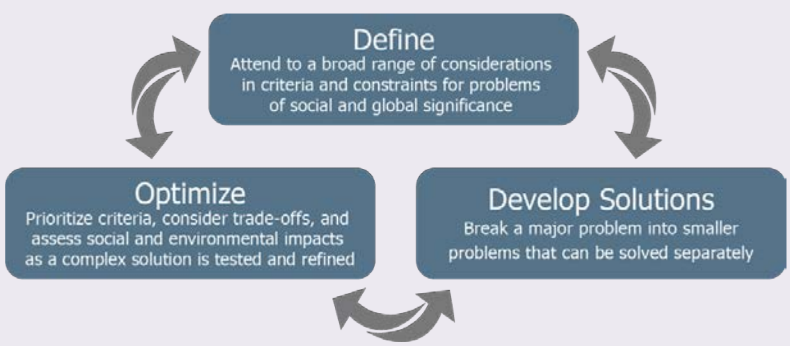
Vignette Debrief

This activity illustrated 3-D learning as students addressed HS-PS1-6.

SEPs. As students proceeded through the engineering cycle in this activity, they employed most of the CA NGSS science and engineering practices. First they **defined the problem [SEP-1]**: to design a chemical system that would result in the greatest yields at equilibrium given the constraints of the resources provided and the time allotted. Next, they **developed and employed models [SEP-2]** as they applied Le Châtelier's Principle first to the physical model on day 2 and then to chemical equations. They then **planned and carried out investigations [SEP-3]** to determine success as measured by predicted color changes. They then **analyzed and interpreted data [SEP-4]** to determine factors related to increased yield. Using these data, they **constructed explanations and designed improved solutions [SEP-6]** and **engaged in arguments from evidence [SEP-7]** to defend their new chemical systems. Throughout the activity, students **obtained and evaluated [SEP-8]** data and **communicated [SEP-8]** their findings by posting in their online lab reports.

DCIs. This vignette provided the framework for instruction of chemical equilibrium at the high school level (PS1.B). In addition, students addressed all three engineering, technology, and applications of science (ETS) DCIs. They *defined and delimited the engineering problem* (ETS1.A) while they worked toward criteria and within constraints. They *developed possible solutions* (ETS1.B) and shared their findings with the class through online lab reports. Finally, *students optimized their design solutions* (ETS1.C) using evidence obtained from their experiments (figure 8.25).

Figure 8.25. CA NGSS Engineering Design Cycle



As students proceed through this learning event, they engage in all aspects of the CA NGSS engineering cycle. *Source*: NGSS Lead States 2013
Long description of Figure 8.25.

HIGH SCHOOL FOUR-COURSE MODEL CHEMISTRY VIGNETTE 8.2: CHEMICAL EQUILIBRIUM

CCCs. Students paid particular attention to the interaction between different chemical species in a chemical **system [CCC-4]**. They evaluated the system's stability and response to **change [CCC-7]** as they designed environments that disturbed equilibrium to increase product yield. After evaluating such data, students defended their redesigns by providing arguments of presumed **cause and effect [CCC-2]**.

EP&Cs. By focusing on chemical fertilizers on day 5, this lesson provided opportunities for students to explore the exchange of matter between natural and human systems (EP&C II, IV). As written, the vignette only mentioned these topics, but adding a few additional days could allow students to dive more deeply into the environmental issues surrounding chemical fertilizers and the modern advances in organic agriculture that do not rely on chemical fertilizers. The additional time would allow students to relate agricultural runoff to broader issues in the water cycle (ESS2.C). Chemical interactions between water and different fertilizers allow teachers to tie ESS2.C to chemistry and take ESS2.C to the high school level.

CA CCSS Connections to English Language Arts and Mathematics. Throughout the vignette, the students engaged in small group and partner discussions with their classmates to explore chemical reactions (SL.9–12.1, 2). They made observations and recorded and analyzed data. They also engaged in writing lab reports and constructed arguments from evidence. (WHST.9–12.1a–b, 2a, 6–10). Both the conceptual and quantitative aspects of chemical equilibrium required extensive **mathematical thinking [SEP-5]**. Teachers could take advantage of specific connections to CCSS Math connections by emphasizing different representations of equilibrium. Teachers would need to tailor the complexity of these connections to the math level of their students. On day 2 as students created a physical model, teachers could have asked students to construct an equation that fit the observed fluid levels as a function of time. They would have found that linear and quadratic functions did not model the data well, but an exponential function did (MP.4, F-BF.1, F-LE.1–4). Students could have noticed that the rate of change was very fast at the beginning but slowed later; then they could have asked questions about how this related to the structure of the equation they wrote (F-IF.6). On day 5, students could have constructed the equation of the equilibrium constant for the ammonia synthesis reaction. Students could have recognized the structure of the equation as a multivariable equation with terms and coefficients (A-SSE.1). Teachers could have prompted students to graph and interpret these functions from different representations (F-IF.7), identified the key features of the functions (F-IF.4) and explicitly discussed the domain over which they were valid (F-IF.5). Students discussed how each of Haber's changes (low temperature, high pressure, iron catalyst) would be expressed in the equilibrium equations. Did the equilibrium constant change under these conditions, or was it just a change in the terms? Through scaffolded discussions, students gained a more detailed understanding of both the chemistry and the structure of the mathematical model.

HIGH SCHOOL FOUR-COURSE MODEL CHEMISTRY VIGNETTE 8.2: CHEMICAL EQUILIBRIUM

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IS5

Chemistry Instructional Segment 5: Conservation of Energy and Energy Transfer

According to the NGSS storyline:

The Performance Expectations associated with the topic Energy help students formulate an answer to the question "How is energy transferred and conserved?" The disciplinary core idea expressed in the Framework for PS3 is broken down into four sub-core ideas: Definitions of Energy, Conservation of Energy and Energy Transfer, the Relationship between Energy and Forces, and Energy in Chemical Process and Everyday Life. Energy is understood as quantitative property of a system that depends on the motion and interactions of matter and radiation within that system, and the total change of energy in any system is always equal to the total energy transferred into or out of the system. Students develop an understanding that energy at both the macroscopic and the atomic scale can be accounted for as either motions of particles or energy associated with the configuration (relative positions) of particles. In some cases, the energy associated with the configuration of particles can be thought of as stored in fields. Students also demonstrate their understanding of engineering principles when they design, build, and refine devices associated with the conversion of energy. The crosscutting concepts of cause and effect; systems and system models; energy and matter; and the influence of science, engineering, and technology on society and the natural world are further developed in the performance expectations associated with PS3. In these performance expectations, students are expected to demonstrate proficiency in developing and using models, planning and carrying out investigations, using computational thinking, and designing solutions; and to use these practices to demonstrate understanding of the core ideas. (NGSS Lead States 2013f)

CHEMISTRY INSTRUCTIONAL SEGMENT 5: ENERGY CONSERVATION, TRANSFER, AND APPLICATIONS

Guiding Questions

- How is energy transferred and conserved?
- Why do some reactions release energy and others absorb it?
- How can energy from chemical reactions be harnessed to perform useful tasks?

Performance Expectations

Students who demonstrate understanding can do the following:

HS-PS3-1. Create a computational model to calculate the change in the energy of one component in a system when the change in energy of the other component(s) and energy flows in and out of the system are known. [Clarification Statement: Emphasis is on explaining the meaning of mathematical expressions used in the model.] [*Assessment Boundary: Assessment is limited to basic algebraic expressions or computations; to systems of two or three components; and to thermal energy, kinetic energy, and/or the energies in gravitational, magnetic, or electric fields.*]

HS-PS3-3. Design, build, and refine a device that works within given constraints to convert one form of energy into another form of energy.* [Clarification Statement: Emphasis is on both qualitative and quantitative evaluations of devices. Examples of devices could include Rube Goldberg devices, wind turbines, solar cells, solar ovens, and generators. Examples of constraints could include use of renewable energy forms and efficiency.] [*Assessment Boundary: Assessment for quantitative evaluations is limited to total output for a given input. Assessment is limited to devices constructed with materials provided to students.*]

HS-PS3-4. Plan and conduct an investigation to provide evidence that the transfer of thermal energy when two components of different temperature are combined within a closed system results in a more uniform energy distribution among the components in the system (second law of thermodynamics). [Clarification Statement: Emphasis is on analyzing data from student investigations and using mathematical thinking to describe the energy changes both quantitatively and conceptually. Examples of investigations could include mixing liquids at different initial temperatures or adding objects at different temperatures to water.] [*Assessment Boundary: Assessment is limited to investigations based on materials and tools provided to students.*]

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

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

HS-ETS1-3. Evaluate a solution to a complex real-world problem based on prioritized criteria and trade-offs that account for a range of constraints, including cost, safety, reliability, and aesthetics as well as possible social, cultural, and environmental impacts.

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

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

CHEMISTRY INSTRUCTIONAL SEGMENT 5: ENERGY CONSERVATION, TRANSFER, AND APPLICATIONS

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

Highlighted Science and Engineering Practices	Highlighted Disciplinary Core Ideas	Highlighted Crosscutting Concepts
[SEP-2] Developing and Using Models [SEP-3] Planning and Carrying Out Investigations [SEP-4] Analyzing and Interpreting Data [SEP-5] Using Mathematics and Computational Thinking [SEP-6] Constructing Explanations (for science) and Designing Solutions (for engineering)	PS3.A: Definitions of Energy PS3.D: Energy in Chemical Processes and Everyday Life ETS1.A: Defining and Delimiting Engineering Problems ETS1.B: Developing Possible Solutions	[CCC-3] Scale, Proportion, and Quantity [CCC-4] System and System Models [CCC-5] Energy and Matter: Flows, Cycles, and Conservation

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

CA CCSS Math Connections: N-Q.1–3; MP.2, MP.4

CA CCSS for ELA/Literacy Connections: RST.11–12.1, 7, 8, 9; WHST.9–12.7, 8, 9; SL.11–12.5

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

By the end of grade eight, students have developed a basic understanding of potential and kinetic energy, and that temperature is a measure of the average kinetic energy of matter (PS3.A). In addition, they have learned that energy is conserved and spontaneously transfers out of hotter regions or objects into colder ones (PS3.B). Students will build upon this knowledge, and their recently acquired understanding of the properties and structure of matter (IS1 and IS2) and chemical reactions (IS3 and IS4), to gain a deeper understanding of energy conservation, transfer, and applications.

Energy [CCC-5] is perhaps the most unifying crosscutting concept in all of science. Energy is a property of both matter and radiation and is manifested as the capacity to perform work, such as causing the motion or interaction of molecules on a microscale, or the movement of machines or planets on a macroscale. Energy can change form, but it cannot be created or destroyed. On the microscopic scale, energy can be **modeled [SEP-2]** as the motion of particles, or as force fields (electric, magnetic, gravitational) that mediate interactions between such particles. At the macroscopic scale, energy is manifested in a variety of phenomena such as motion, light, sound, electromagnetic fields, and heat.

Chemistry is often described as the “study of matter,” including the identification of the substances of which matter is composed, the investigation of properties of matter, energy flows in matter, and the ways in which matter interacts, combines, and changes. Heat is the form of energy that flows between samples of matter because of differences in temperature. The laws of thermodynamics define the fundamental physical quantities (temperature, energy, and entropy) that characterize matter, and are therefore essential for understanding matter and chemical interactions. The Zeroth Law of Thermodynamics states that two systems in thermodynamic equilibrium have the same temperature and will not exchange heat. If, however, two closed systems with different temperatures are brought into thermal contact, heat will flow from the system of higher temperature to the system of lower temperature until the two systems reach the same intermediate temperature in accordance with the Second Law of Thermodynamics.

The First Law of Thermodynamics states that the total energy of an isolated system is constant, and that although energy can be transformed from one form to another, it can neither be created nor destroyed. The **conservation of energy [CCC-5]** is thus a unifying theme in science because energy must always be accounted for in all exchanges, inviting scientists to study its flow throughout the complex biological, chemical, physical, geological, and astronomical systems they study. Energy transfers between organisms in food webs, by wind and ocean currents on Earth, by light from one astronomical body to another, and between molecules in chemical reactions, to name just a few processes.

Science students are expected to use mathematics to represent physical variables and their relationships, and to make quantitative predictions. Performance expectation HS-PS3-1 requires students to **use mathematics and computational thinking [SEP-5]** to “create computational models to calculate the change in the energy of one component in a system when the change in energy of the other component(s) and energy flows in and out of the system are known.” This performance expectation requires students to apply thermodynamic principles in studying the energy changes accompanying chemical reactions. In a chemical reaction, the energy stored in chemical bonds may be converted into other forms of energy such as light and heat. In chemical reactions, bonds in reactant molecules are broken and new bonds are formed. Energy is required to break bonds and energy is released when bonds are formed. HS-PS3-1 requires students to **model [SEP-2]** such energy changes with algebraic expressions.

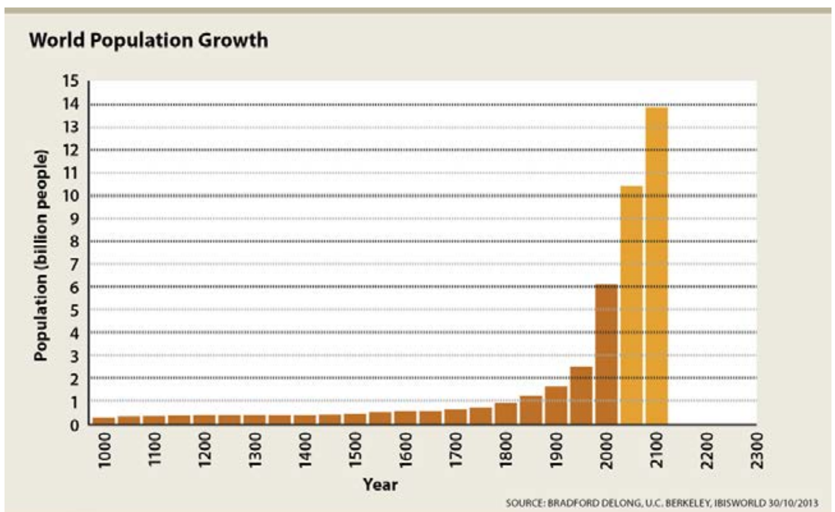
Scientists can **model [SEP-2]** chemical reactions by programming computers with mathematical expressions that describe the exchanges of **matter and energy [CCC-5]** accompanying such reactions. Performance expectation HS-ETS1-4 requires students to "use a computer simulation to model the impact of proposed solutions to a complex real-world problem with numerous criteria and constraints on interactions within and between systems relevant to the problem." The real world is much more complex than textbook solutions suggest. To give students a better understanding of such complexity, this performance expectation requires that they evaluate the complexity involved in solving real-world problems given the constraints within which scientists and engineers must work (HS-ETS1-1). These two performance expectations (HS-PS3-1 and HS-ETS1-4) can be met using a variety of computer applications that model chemical interactions for real-world problems, such as optimizing the design of a battery for an electrical vehicle or designing a fuel cell to minimize energy transformed to heat. As students master these performance expectations, they learn how scientists use **mathematical reasoning [SEP-5]** to make predictive **models [SEP-2]**. Through such experiences, students learn how to generate alternative solutions to a problem, leading them to engage in performance expectation HS-ETS1-3 in which they "evaluate a solution to a complex real-world problem based on prioritized criteria and trade-offs that account for a range of constraints, including cost, safety, reliability, and aesthetics, as well as possible social, cultural, and environmental impacts."

After working with the First Law of Thermodynamics (Conservation of Energy), students are ready to deal with the Second Law, which states that isolated systems always progress toward thermodynamic equilibrium with maximum entropy. Equipped with the algebraic skills necessary to model energy changes in chemical reactions, students will "plan and conduct an investigation to provide evidence that the transfer of thermal energy when two components of different temperature are combined within a closed system results in a more uniform energy distribution among the components in the system" (HS-PS3-4). To accomplish this, students could **plan and carry out an investigation [SEP-3]** of the Second Law of Thermodynamics by measuring the temperatures and masses of two bodies of water before and after mixing or the temperatures of metal blocks and water prior to and following immersion. By repeating these investigations with differing quantities of materials, students can apply the concept of **scale, proportion, and quantity [CCC-3]** to predict temperature changes, equilibrium conditions, and magnitudes of energy transferred (HS-PS3-1).

Engineering Connection: The Chemistry of Global Energy Supplies

A key aspect of three-dimensional learning is that students use SEPs to apply CCCs to DCIs in other fields of study. The **flows, cycles, and conservation of energy and matter [CCC-5]** is one of the most unifying crosscutting concepts, providing links between all of the sciences and many other fields of study as well, including the social and behavioral sciences. Figure 8.26 illustrates the growth of the world population during the last millennium, including a forecast for the twenty-first century. Students should be able to read such a graph and recognize that there will be twice as many people by 2100 as there were in 2000. Consequently, there will be an increased demand for all resources (EP&C I), but particularly energy resources.

Figure 8.26. World Population Growth



World population growth poses chemical resource challenges that students can analyze.
Source: IBISWorld 2013
[Long description of Figure 8.26.](#)

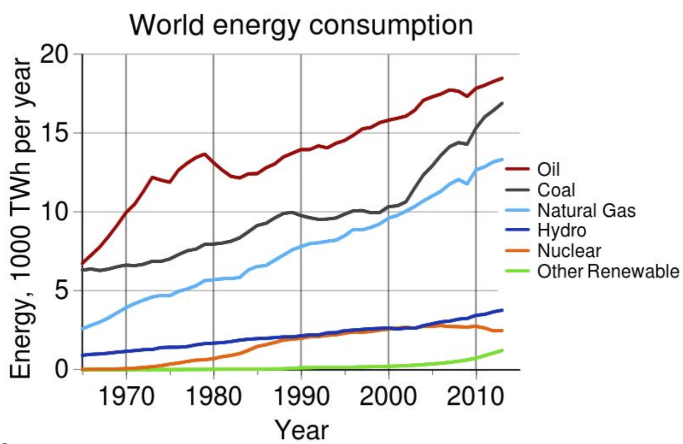
Figure 8.27 shows trends in world energy consumption and illustrates that the three major sources of energy worldwide are fossil fuels (oil, coal, and natural gas). Students can obtain information about the impacts of fossil fuels on natural systems that arise because harnessing the energy from fossil fuels also disrupts global cycles of matter in the Earth system (ESS2.A; EP&C III, IV). Climate change results from rising levels of greenhouse gases (e.g., carbon dioxide, methane, and nitrous oxide). Carbon dioxide is released when fossil fuels react with oxygen during combustion, and students can **obtain information [SEP-8]** about chemical methods of carbon sequestration currently being researched. Natural gas, primarily methane, often leaks at many locations between where it is pumped from the ground and where people eventually use it. Students can **obtain information [SEP-8]** about cutting-edge technologies to monitor leaks in real time.

Engineering Connection: The Chemistry of Global Energy Supplies

Acid rain results from nitrogen and sulfur oxides commonly released during combustion of sulfur-rich fuels such as coal. Students could **obtain information [SEP-8]** about the chemical technology used to minimize the release of sulfur dioxide. Since these systems were mandated, acid rain has substantially declined in the United States.

Smog involves reactions between tailpipe emissions of cars and the air (with sunlight adding some of the energy to break chemical bonds). Students could also **obtain information [SEP-8]** about how improvements to the combustion efficiency of cars have reduced smog. Students should do more than just explain the chemical reactions in each of these processes. They should consider the criteria and constraints about society's need for clean air and clean water along with the need for more energy (HS-ETS1-1; EP&C V). Students should be encouraged to break down the problem into smaller, more manageable problems that can be solved through [chemical] engineering (HS-ETS1-2).

Figure 8.27. What Fuels Provide the World's Energy?



Source: BP 2016

Long description of Figure 8.27.

Throughout history, chemical compounds have served as the primary energy source for civilizations. Primitive societies gathered and burned wood, releasing energy by the oxidation of cellulose to cook food and warm homes. Thousands of years ago, people started mining coal, which became prized because it yields more energy per unit mass and can often be obtained in areas where wood is not readily available. Although petroleum has been known for more than four thousand years, it was not tapped widely as a fuel source until the middle of the nineteenth century. Today, fossil fuels are used to power internal combustion engines to convert the chemical potential energy of fuels to kinetic energy in moving vehicles. Similarly, combustion turbines convert the chemical potential energy within fossil fuels to electromagnetic energy to provide electricity for industry and consumers.

Engineering Connection: Designing an Energy Conversion Device

Engineers have designed a range of devices to convert chemical potential energy in organic matter to other forms of energy. Cars, gas furnaces, and wood stoves are all examples. Students can build their own device to convert energy from one form to another by **designing [SEP-6]** calorimeters that combust food to transform chemical potential energy into light energy and thermal **energy [CCC-5]** (HS-PS3-3, HS-ETS1-2). By using a calorimeter to measure the caloric density of various foods, students can **calculate [SEP-5]** the approximate **amount [CCC-3]** of chemical potential energy in such things as jellybeans, cashews, oily snack foods, and more. They can then refine their design to convert the greatest percentage of chemical potential energy from these foods into heat energy during combustion of the food so that it provides the most reliable estimates of food energy (HS-ETS1-3). The efficiency of such calorimeters may be estimated by dividing the thermal energy captured in the water of calorimeters by the calculated caloric value present in the food prior to burning. Regardless of the selected activities, students should apply scientific and engineering reasoning to **define problems [SEP-1]** and **design and optimize solutions [SEP-6]** to real-world devices that convert chemical potential energy into other energy forms.

Concept Map of Chemistry Disciplinary Core Ideas

In meeting the performance expectations selected for this course, instructors must introduce some DCIs as well as build on the DCIs introduced in the middle grades. Figure 8.28 shows a concept map with the relationships between DCIs introduced during the middle grades and high school level. This concept map is *not* a conceptual flow with a specific order or sequence nor is it a comprehensive illustration of all ideas that should be taught in the courses. Nor does it illustrate interdisciplinary connections that should be drawn. It may, however, be helpful in identifying how DCIs build from middle grades to high school and relate to one another. This map is explicitly placed at the end of the instructional segments so that readers view them with a full appreciation of how these DCIs must be explored using the other two dimensions of CA NGSS as outlined in the course above. The concept map is limited only to DCIs, so even if students had a full appreciation of what is in these maps, they also need practice in doing science and engineering (SEPs) and identifying big-picture relationships to other disciplines (CCCs).

Figure 8.28. Relationship of DCIs in Chemistry, including High School and Middle Grades Content

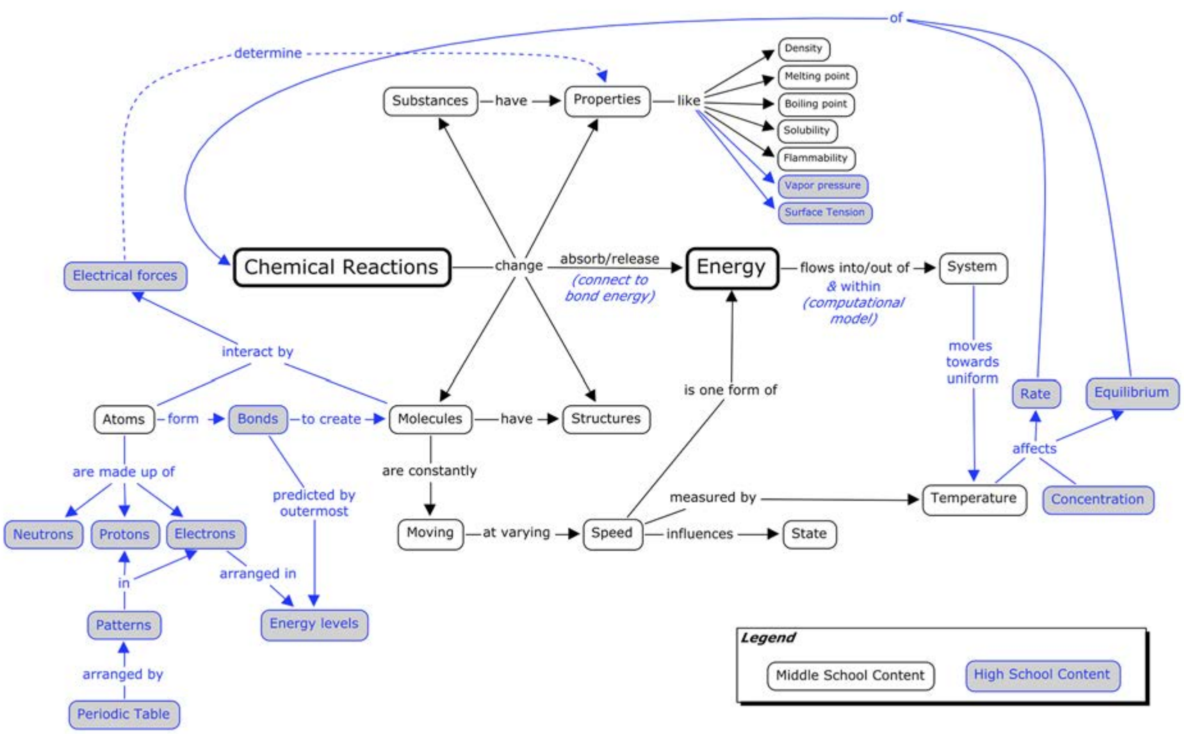


Diagram by M. d'Alessio

Long description of Figure 8.28.

High School Four-Course Model: Physics

Introduction to the Physics Course

According to the Next Generation Science Standards:

> Students in high school continue to develop their understanding of the four core ideas in the physical sciences. These ideas include the most fundamental concepts from chemistry and physics but are intended to leave room for expanded study in upper-level high school courses. The high school performance expectations in Physical Science build on the middle school ideas and skills and allow high school students to explain more in-depth phenomena central not only to the physical sciences, but to life and [E]arth and space sciences as well. These performance expectations blend the core ideas with **scientific and engineering practices (SEPs)** and **crosscutting concepts (CCCs)** to support students in developing useable knowledge to explain ideas across the science disciplines. In the physical science performance expectations at the high school level, there is a focus on several scientific practices. These include developing and using models, planning and conducting investigations, analyzing and interpreting data, using mathematical and computational thinking, and constructing explanations; and to use these practices to demonstrate understanding of the core ideas. Students are also expected to demonstrate understanding of several engineering practices, including design and evaluation. (NGSS Lead States 2013f)

Physical processes govern everything in the universe. All students in California should have the opportunity to **investigate [SEP-3]** the relationships between physical events that they observe and the fundamental underlying forces that **cause [CCC-2]** them.

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. Many of the phenomena selected illustrate California's EP&Cs, which are an essential part of the CA NGSS (see chapter 1 of this framework). However, the phenomena chosen for this statewide document will not be ideal for every classroom in a state as large and diverse as California. Teachers are therefore encouraged to select phenomena that will engage their students and use this chapter's examples as inspiration for designing their own instructional sequence. For example, the course could be restructured around contemporary issues of health or ecosystem change faced by a local community.

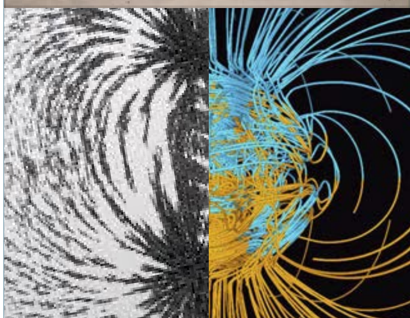
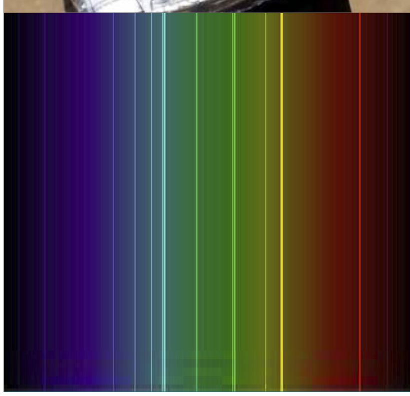
This example course is divided into instructional segments centered on questions about observations of a specific phenomenon. Different phenomena require different amounts of investigation to explore and understand, so each instructional segment should take a different fraction of the school year. As students achieve the performance expectations within the instructional segment, they uncover **Disciplinary Core Ideas (DCIs)** from physical science and engineering. Students engage in multiple practices in each instructional segment, not only those explicitly indicated in the performance expectations. Students also focus on one or two CCCs as tools to make sense of their observations and investigations; the CCCs are recurring themes in all disciplines of science and engineering and help tie these seemingly disparate fields together.

This section clarifies the general level of understanding required to meet each performance expectation, but the exact depth of understanding expected of students depends on this course's place in the overall high school sequence. Teachers could modify the content and complexity so that the course serves as a basic freshman introduction to science, serves as a senior capstone that integrates and applies science learning from all previous science courses, or aligns with the expectations of advanced placement (AP) or international baccalaureate (IB) curriculum.

Example Course Mapping for a Physics Course

This example course is divided into four instructional segments that group together related component ideas within the DCIs (table 8.6). Care was taken in designing this chapter so that it can be helpful for districts regardless of the sequence in which students complete the four high school courses. As such, it lacks some of the rich interdisciplinary connections that are possible. As schools and districts adopt a specific sequence, they can take advantage of links to previous courses by making connections to this prior knowledge. The level of mathematics used in this course will also vary based upon its sequence. High school seniors should be capable of more advanced problem solving than this example course requires, but meeting the performance expectations of the CA NGSS requires more than just **mathematical and computational thinking [SEP-5]**. As assessments such as the Force Concept Inventory illustrate (Hestenes 1998), many students can perform calculations without developing rich mental **models [SEP-2]** that allow them to formulate evidence-based explanations or **design solutions [SEP-6]** to real-world challenges. The approach outlined in this course should therefore even aid teachers that plan to go "beyond the standards" with a more mathematically rigorous course by showing them ways that all of the SEPs from the CA NGSS fit into a physics course and how the CCCs relate that course to bigger issues that span across scientific disciplines.

Table 8.6. Overview of Instructional Segments for High School Physics

	**1 Forces and Motion** Students make predictions using Newton's Laws. Students mathematically describe how changes in motion relate to forces and momentum. They engage in a design challenge to reduce the effects of a collision.
	**2 Types of Interactions** Students investigate gravitational and electromagnetic forces and describe them mathematically. They investigate the unity of electricity and magnetism. They develop a model of the internal structure of atoms and use it to link the macroscopic properties of materials to microscopic electromagnetic attractions.
	**3 Energy** Students design and test their own energy conversion devices. They develop models of nuclear processes, thermal energy, and electric and magnetic fields, and then use these models to further their understanding of energy flow in systems.
	**4 Waves and Electromagnetic Radiation** Students make mathematical models of waves and then obtain, evaluate, and communicate information about interactions between waves and matter with a particular focus on electromagnetic waves. They obtain, evaluate, and communicate information about health hazards associated with electromagnetic waves. They use models of wave behavior to explain information transfer using waves and the wave-particle duality.

Sources: National Highway Traffic Safety Administration 2016; adapted from Black and Davis 1913, 242, figure 200; adapted from NASA 2003a; Ousley 2013; NASA 2015

IS1

Physics Instructional Segment 1: Forces and Motion

According to the NGSS storyline:

> The Performance Expectations associated with the topic Forces and Interactions support students' understanding of ideas related to why some objects will keep moving, why objects fall to the ground, and why some materials are attracted to each other while others are not. Students should be able to answer the question "How can one explain and predict interactions between objects and within systems of objects?" The disciplinary core idea expressed in the *Framework for PS2* is broken down into the sub ideas of Forces and Motion and Types of Interactions. The performance expectations in PS2 focus on students building understanding of forces and interactions and Newton's Second Law. Students also develop understanding that the total momentum of a system of objects is conserved when there is no net force on the system. Students are able to use Newton's Law of Gravitation and Coulomb's Law to describe and predict the gravitational and electrostatic forces between objects. Students are able to apply scientific and engineering ideas to design, evaluate, and refine a device that minimizes the force on a macroscopic object during a collision. The crosscutting concepts of patterns, cause and effect, and systems and system models are called out as organizing concepts for these disciplinary core ideas. In the PS2 performance expectations, students are expected to demonstrate proficiency in planning and conducting investigations, analyzing data and using math to support claims, and applying scientific ideas to solve design problems; and to use these practices to demonstrate understanding of the core ideas. (NGSS Lead States 2013f)

PHYSICS INSTRUCTIONAL SEGMENT 1: FORCES AND MOTION

Guiding Questions

- How can Newton's laws be used to explain how and why things move?
- How can Newton's Laws be used to solve engineering problems?

Performance Expectations

Students who demonstrate understanding can do the following:

HS-PS2-1. Analyze data to support the claim that Newton's second law of motion describes the mathematical relationship among the net force on a macroscopic object, its mass, and its acceleration. [Clarification Statement: Examples of data could include tables or graphs of position or velocity as a function of time for objects subject to a net unbalanced force, such as a falling object, an object rolling down a ramp, or a moving object being pulled by a constant force.] [*Assessment Boundary: Assessment is limited to one-dimensional motion and to macroscopic objects moving at non-relativistic speeds.*]

HS-PS2-2. Use mathematical representations to support the claim that the total momentum of a system of objects is conserved when there is no net force on the system. [Clarification Statement: Emphasis is on the quantitative conservation of momentum in interactions and the qualitative meaning of this principle.] [*Assessment Boundary: Assessment is limited to systems of two macroscopic bodies moving in one dimension.*]

HS-PS2-3. Apply scientific and engineering ideas to design, evaluate, and refine a device that minimizes the force on a macroscopic object during a collision. [Clarification Statement: Examples of evaluation and refinement could include determining the success of the device at protecting an object from damage and modifying the design to improve it. Examples of a device could include a football helmet or a parachute.] [*Assessment Boundary: Assessment is limited to qualitative evaluations and/or algebraic manipulations.*]

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

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

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

**PHYSICS INSTRUCTIONAL SEGMENT 1:
FORCES AND MOTION**

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

Highlighted Science and Engineering Practices	Highlighted Disciplinary Core Ideas	Highlighted Crosscutting Concepts
[SEP-1] Asking Questions and Defining Problems [SEP-4] Analyzing and Interpreting Data [SEP-5] Using Mathematics and Computational Thinking [SEP-6] Constructing Explanations (for science) and Designing Solutions (for engineering)	PS2.A : Forces and Motion ETS1.A: Defining and Delimiting Engineering Problems ETS1.B: Developing Possible Solutions ETS1.C: Optimizing the Design Solution	[CCC-2] Cause and Effect: Mechanism and Explanation [CCC-4] Systems and System Models Influence of Science, Engineering, and Technology on Society and the Natural World

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

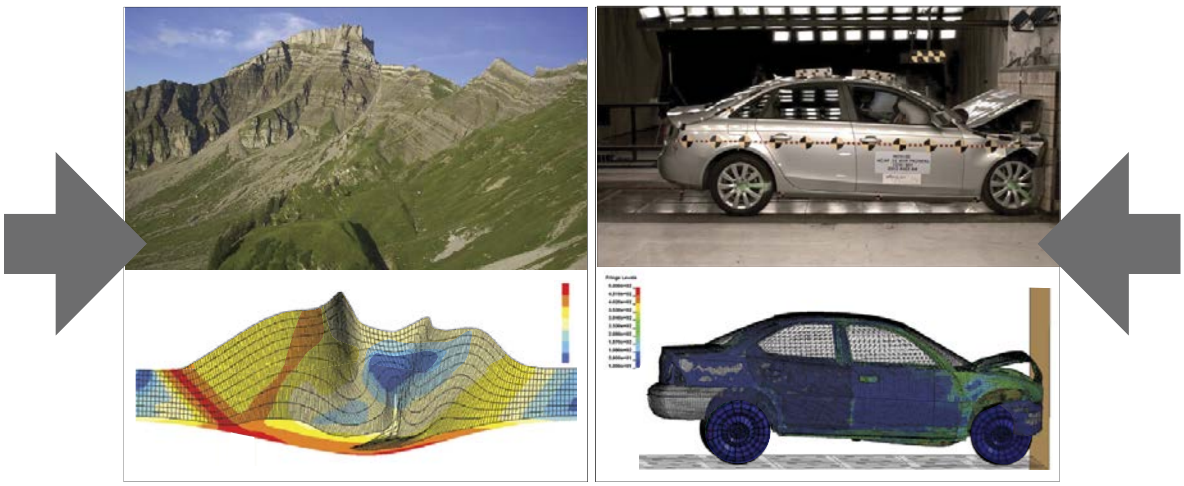
CA CCSS Math Connections: A-SSE.1.a–b, 3a–c; A-CED.1, 2, 4; F-IF.7a–e; S-ID.1; N-Q.1–3; MP.2, MP.4

CA CCSS for ELA/Literacy Connections: RST.11–12.1, 7, 8, 9; WHST.9–12.7, 9

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

What does a mountain peak have in common with a pickup truck (figure 8.29)? If the vehicle is involved in a crash, its hood could crumple and bend under the force of the collision. Mountain ranges like the Himalayas are shortened and pushed upwards just like the hood of a crashed car. Even though the two processes occur at very different **scales [CCC-3]**, both are governed by Newton's Laws.

Figure 8.29. Collisions Occur in a Variety of Contexts



Mountains and car crashes involve collisions whose movement and forces can be modeled in computer simulations (bottom). *Sources*: Cinedoku Vorarlberg 2009; National Highway Traffic Safety Administration 2016; Willett 1999; Livermore Software Technology Corporation 2017
Long description of Figure 8.29.

Newton's laws (table 8.7) provide a basis for understanding forces and motion and, therefore, serve as a foundation for a study of physics. Engineers and scientists apply Newton's laws **mathematically [SEP-5]** or with **computational models [SEP-2]** to predict the motion of objects. These calculations (such as depicted in the bottom panels of figure 8.29) enable applications as diverse as building safer automobiles and providing more reliable forecasts of earthquake hazard. Applying Newton's laws becomes quite complicated when considering the forces within deforming bodies like in figure 8.29, but these simple laws lie at the heart of even the most sophisticated computer simulations.

Table 8.7. Newton's Laws of Motion

First Law **Law of Inertia**	Every object in a state of uniform motion tends to remain in that state of motion unless it is subjected to an unbalanced external force.
Second Law **Definition of Force**	$F = ma$. An object's acceleration, a, depends on its mass, m, and the applied force, F.
Third Law **Law of Reciprocity**	For every action, there is an equal and opposite reaction. When one body exerts a force on a second body, the second body simultaneously exerts a force equal in magnitude and opposite in direction on the first body.

Opportunities for ELA/ELD Connections

As a foundation for the study of physics, have students create mini-lessons on Newton's Laws of Motion to present to the class. Each team or group of students uses at least two different sources to research a law of motion for a visual presentation to the class. The presentation should include a general description/definition of the law plus an example demonstrating the application of the principle. Visual presentations make strategic use of digital media to enhance findings, reasoning, evidence, and add interest.

CA CCSS for ELA/Literacy Standards: RST.9–12.2, 7; WHST. 9–12.6, 7, 8; SL.9–12.5
CA ELD Standards: ELD.PI. 9–12.6, 9

In the middle grades, students investigated forces to establish a relationship between force, mass, and changes in motion (MS-PS2-2) and designed solutions to minimize the impact of a collision (MS-PS2-1). These experiences form the basis of a solid conceptual model of Newton's laws. Now, they are ready to **extend these models [SEP-2]** using **mathematical thinking [SEP-5]** so that they can use their models to predict precise outcomes. This process begins with mathematical descriptions of motion.

High School Four-Course Model Physics Snapshot 8.6: Analyzing Motion in Video

Investigative phenomenon: (Students record and analyze the motion of everyday objects.)

Ms. K's students used phones or tablets to record different everyday objects moving (e.g., skateboard rolling down ramp, ball thrown up against basketball backboard, bird flying across the schoolyard, car coming to a stop at a stop sign). They **analyzed [SEP-4]** the video clips using a free frame-by-frame video analysis tool (see D. Brown Tracker video analysis and modeling tool from 2015 at https://www.cde.ca.gov/ci/sc/cf/ch8.asp#link34) to track the position, velocity, and acceleration over time. Ms. K gave a short lecture describing how the program used the formulas for velocity and acceleration to calculate the quantities. Students practiced a few calculations by hand to see if they matched the software's output. Students found that the skateboard's velocity increased linearly but its acceleration remained constant. The bird moved at a reasonably constant speed as it glided between flaps but then sped up when it was flapping. The basketball bounced off the backboard a tiny bit slower than it traveled toward the backboard. The car's acceleration was always negative but oscillated up and down (close to zero and then more negative again) as it approached the stop sign. Each group of students chose one graph that yielded an interesting observation (position, velocity, or acceleration plotted versus time) to **describe [SEP-8]** to the class. Ms. K ensured that students described the axes (including highlighting the **scale [CCC-3]** of their results and how slow or fast the objects moved) and any **trends [CCC-1]**. Each team also had to share one **question [SEP-1]** they had generated when they were looking at the data; they would use that questions as the basis for a new investigation: Did the acceleration change when someone sat instead of stood on the skateboard? Would the ball bounce back at a faster speed if we pumped it up? Would the car's speed change more smoothly if we pushed the brake pedal really evenly? Over the next few weeks, Ms. K returned to these questions in an order that followed the conceptual flow of her curriculum. She had the class refine each question and used it to **plan and conduct an investigation [SEP-3]** to answer the question.

Performance expectation HS-PS2-1 requires students to "analyze data to support the claim that Newton's second law of motion describes the mathematical relationship among the net force on a macroscopic object, its mass, and its acceleration." Before jumping into quantitative calculations, teachers should help students engage with their preconceptions about forces and motion through conceptual challenges. Teachers can administer the Force Concept Inventory (Hestenes 1998) to assess students' knowledge at the beginning of the course. Guided inquiry tutorials (see University of Maryland Physics Education Research Group, Tutorials in Physics Sense-Making at https://www.cde.ca.gov/ci/sc/cf/ch8.asp#link35) help students refine their conceptual models and are specifically designed for students to confront misconceptions. With these foundations, students **analyze and interpret [SEP-4]** tables or graphs of position as a function of time, or velocity as a function of time for objects subjected to a constant, net unbalanced force and compare their observations to predictions from the mathematical model (HS-PS2-1). Given the force and the mass, students learn to calculate the acceleration of an object. Given the mass and the acceleration, students should be able to calculate the net force on the object. Accordingly, students should be able to analyze simple free-body diagrams to calculate the net forces on known masses and, subsequently, determine their acceleration. The standard formulas of velocity, acceleration, and Newton's Second Law are all mathematical **models [SEP-2]**. In the CA NGSS, students should be able to use models to make predictions. Curriculum should therefore provide students with opportunities to not only perform calculations but to test them using hands-on activities and computer simulations.

Students extend their study of forces and motion to include collisions and the concept of momentum. The law of conservation of linear momentum states that for a collision occurring between object one and object two in an isolated **system [CCC-4]**, the total momentum of the two objects before the collision is equal to the total momentum of the two objects after the collision. Again, students will use **mathematical representations [SEP-5]** of these systems as **models [SEP-2]**. They should be able to apply these models to a range of scenarios.

High School Four-Course Model Physics Snapshot 8.7: Predicting Baseball Speeds

Investigative phenomenon: A baseball changes direction as it collides with a bat.

Ms. K's students rolled marbles on tracks to explore momentum and collisions, but her students wanted to see if the equations worked in a real-world scenario. They would use video analysis software to predict how fast the ball would go when it was hit. They set up a camera on a tripod and had the school's star softball pitcher practice throwing consistent, easy-to-hit pitches. Meanwhile, they had the school's leading baseball hitter swing the bat over and over again. They recorded swings using several bats (including aluminum and wood) and pitches with two different balls (a baseball and a softball). Ms. K wouldn't let the batter hit the balls yet, though. They took the video clips back to the classroom and calculated the average speed of the ball and the bat and then measured their masses. Students then used equations of momentum conservation to predict the speed the ball would go in different cases. They verified their calculations using an online simulator of one-dimensional collisions (see PhET, Collision Lab, at https://www.cde.ca.gov/ci/sc/cf/ch8.asp#link36) and used it to get a sense of how much the speed would vary if the speeds during an actual pitch were equal to the average they had used in their calculations. They then returned to the field and let the batter hit several pitches using different ball and bat combinations. Upon analyzing the video data, students realized that the actual balls travel at a much lower speed than their predictions. This leaves students **asking questions [SEP-1]** about what **caused [CCC-2]** this difference. The class converged on two possible mechanisms: 1) the ball absorbed some of the energy, or 2) the ball was hit off center. Ms. K split students into groups and assigned half of them to **obtain information [SEP-8]** about the "coefficient of restitution" in an inelastic collision and then **design an investigation [SEP-3]** to calculate it for the baseball while another group used the online simulator in two dimensions to predict the ball's speed when the collision wasn't "head on." The class reconvened and groups presented a **claim [SEP-7]** about whether or not their mechanism could explain the observed velocities, citing evidence from the video and their follow-up investigations. These follow-up investigations went beyond the assessment boundary of HS-PS2-2 but were excellent examples of how an authentic investigation leads to authentic questions. Students found that both mechanisms could potentially explain the speed reduction, but they did not have enough information to distinguish between them. They finished thinking the same thing professional scientists often think, "If only we had more data!" and they dream of adding sensors to the ball and bat.

Engineering Connection: Minimizing the Effects of Collisions

Equipped with a basic understanding of classical mechanics, including Newton's three laws of motion and the momentum conservation principle, students should now be able to "apply scientific and engineering ideas to design, evaluate, and refine a device that minimizes the force on a macroscopic object during a collision" (HS-PS2-3). A classic activity that meets this performance expectation is the egg-drop contest, in which students are challenged to develop devices that protect raw eggs from breaking when dropped from significant heights (figure 8.30). In the process, students demonstrate competence with HS-ETS1-1 when they start by considering a complex problem such as automobile collisions or sports injuries, and then they **define the problem [SEP-1]** in terms of qualitative and quantitative criteria and constraints for solutions. With teacher guidance the students can then break down the problem into smaller, more manageable problems that can be solved through engineering (HS-ETS1-2). The students should be encouraged to **generate multiple solutions [SEP-6]**, and to evaluate their ideas based on prioritized criteria and trade-offs (see the section on Decision Matrices in the "Instructional Strategies" chapter of this framework), taking into account cost, safety, and reliability as well as social, cultural, and environmental impacts (HS-ETS1-3). Students then build and test a model of their most promising idea and then modify it based on the results of the tests. Testing can include computer simulations that model how solutions function under different conditions (HS-ETS1-4).

Figure 8.30. Engineering Solutions to an Egg Drop Challenge

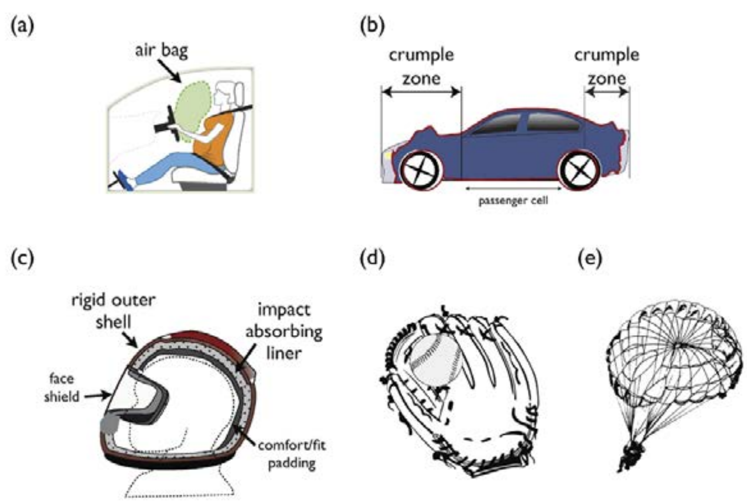
Students learn physics principles such as impulse and momentum while simultaneously learning engineering design and testing principles while designing and developing devices for challenges such as the classic egg-drop contest. *Source*: Buggy and Buddy 2014
Long description of Figure 8.30.

Engineering Connection: Minimizing the Effects of Collisions

Throughout the process, students should **justify [SEP-7]** their design choices and revisions in terms of physics concepts, rather than using trial and error or guesswork. The engineering solutions students create are examples of **systems [CCC-4]** of interacting components. Students discover that the exact physical **structure [CCC-6]** (the arrangement of the components) can have a large impact on the function of their design. Students can draw pictorial **models [SEP-2]** showing the direction forces act and can label the role each piece plays in their solution.

Engagement in this activity also tests student understanding of the momentum-impulse connection: $F\Delta t = m\Delta v$, where F = *force*, t = *time*, m = *mass*, and v = *velocity*. The product of force and the time over which the force is applied is known as the impulse ($F\Delta t$) and is equal to the change in momentum of the object to which the force is applied ($m\Delta v$). One can decrease the force necessary to bring a moving object to rest by increasing the time over which the force is applied. For example, air bags, car crumple zones, helmets, parachutes, and padded catcher's mitts (figure 8.31) reduce the potential for injury by decreasing the force necessary to bring objects to a halt by increasing the time over which such forces are applied.

Figure 8.31. Real-World Engineering Applications of Momentum-Impulse Connections



The product of force and the time over which the force is applied is known as the impulse ($F\Delta t$), and is equal to the change in momentum of the object to which the force is applied ($m\Delta v$). One can decrease the force (F) necessary to bring a moving object to rest by increasing the time (Δt) over which the force is applied, such as is accomplished by (a) an automobile air bag, (b) a helmet, (c) a baseball catcher's mitt, or (d) a parachute. *Sources*: M. d'Alessio with images from National Highway Traffic Safety Administration 2015; adapted from KTEditor 2014; adapted from OpenClipart-Vectors 2013b; Clker-Free-Vector-Images 2012; OpenClipart-Vectors 2013a; Headquarters Department of the Army 2012

Long description of Figure 8.31.

IS2 Physics Instructional Segment 2: Types of Interactions

Instructional segment 1 introduces the concept of force as an influence that tends to change the motion of a body. Instructional segment 2 builds upon this foundation by examining types of forces or interactions. Scientists know of only four fundamental interactions, also known as *fundamental forces* or *interactive forces*: gravitational, electromagnetic, strong nuclear, and weak nuclear. Students have no everyday knowledge of these nuclear forces, but the strong nuclear force ensures the **stability [CCC-7]** of ordinary matter by binding the atomic nucleus together, while the weak nuclear force mediates radioactive decay. By contrast, we interact with gravitational and electromagnetic forces on a daily basis, so students are already familiar with their pushes or pulls. In the middle grades, students provided evidence that gravity is a force that attracts objects together and its strength depends on the mass of the objects (MS-PS2-4). In this instructional segment, students will use the **mathematical models [SEP-2]** of Newton's Law of Gravitation to describe and predict the gravitational attraction between two objects.

PHYSICS INSTRUCTIONAL SEGMENT 2: TYPES OF INTERACTIONS

Guiding Questions

- At the most fundamental level, how do objects interact with one another?
- How do interactions affect the structure, nature, and properties of matter?

Performance Expectations

Students who demonstrate understanding can do the following:

HS-PS2-4. Use mathematical representations of Newton's Law of Gravitation and Coulomb's Law to describe and predict the gravitational and electrostatic forces between objects. [Clarification Statement: Emphasis is on both quantitative and conceptual descriptions of gravitational and electric fields.] [*Assessment Boundary: Assessment is limited to systems with two objects.*]

HS-PS2-5. Plan and conduct an investigation to provide evidence that an electric current can produce a magnetic field and that a changing magnetic field can produce an electric current. [*Assessment Boundary: Assessment is limited to designing and conducting investigations with provided materials and tools.*]

PHYSICS INSTRUCTIONAL SEGMENT 2: TYPES OF INTERACTIONS

HS-PS2-6. Communicate scientific and technical information about why the molecular-level structure is important in the functioning of designed materials.* [Clarification Statement: Emphasis is on the attractive and repulsive forces that determine the functioning of the material. Examples could include why electrically conductive materials are often made of metal, flexible but durable materials are made up of long chained molecules, and pharmaceuticals are designed to interact with specific receptors.] [*Assessment Boundary: Assessment is limited to provided molecular structures of specific designed materials.*]

*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-3] Planning and Carrying Out Investigations [SEP-5] Using Mathematics and Computational Thinking [SEP-8] Obtaining, Evaluating, and Communicating Information	PS2.B: Types of Interaction PS3.A: Definitions of Energy ETS1.A: Defining and Delimiting Engineering Problems	[CCC-1] Patterns [CCC-2] Cause and Effect: Mechanism and Explanation [CCC-6] Structure and Function Influence of Science, Engineering, and Technology on Society and the Natural World Interdependence of Science, Engineering, and Technology

CA CCSS Math Connections: A-SSE.1a–b, 3a–c; N-Q.1–3; MP.2, MP.4

CA CCSS for ELA/Literacy Connections: RST.11–12.1; WHST.9–12.2a–e, 7; WHST.11–12.8, 9

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

Newton's Law of Gravitation is expressed as $F=Gm_1m_2/r^2$, where F represents the gravitational force, m_1 and m_2 represent the masses of two interacting objects, r represents the distance (radius) between the centers of mass of these two objects, and G is the universal gravitational constant.

Opportunities for Mathematics Connections: Rearranging Formulas

Students should be able to “rearrange formulas to highlight a quantity of interest, using the same reasoning as in solving equations” (CA CCSSM A-CED.4). Thus, given G and any three of the variables, students should be able to apply basic algebra to **calculate [SEP-5]** the value of the remaining variable. Students are expected to make quantitative predictions using this equation, and they must also be able to understand it qualitatively (HS-PS2-4).

Mathematical models provide the opportunity for students to conceptualize complex physical principles using elegant equations. All mathematical **models [SEP-2]** in science are based on physical principles of relationships between **scale, proportion, and quantity [CCC-3]**. To introduce mathematical models of gravitation, students can begin this instructional segment by exploring computer simulations of gravity. They gather evidence about which factors affect the gravitational force so that they can begin to construct Newton’s Law of Gravitation, $F=Gm_1m_2/r^2$, where F represents the gravitational force, m_1 and m_2 represent the masses of two interacting objects, r represents the distance (radius) between the centers of mass of these two objects, and G is the universal gravitational constant. To assess understanding of such models, teachers can ask questions like, “What happens to the force of gravity if one doubles the mass?” or “What happens to the force of gravity if the distance between the centers of mass of the two objects is doubled?” In the middle grades, students argued that gravity always attracts objects together, but they only had empirical evidence and could not describe any mechanism for this behavior. Students can **explain [SEP-6]** why gravity is always attractive by referring to Newton’s Law of Gravitation (noting that mass can never be negative, so all terms are positive).

Working together, electricity and magnetism are a constant presence in daily life: electric motors, generators, loudspeakers, microwave ovens, computers, telephone systems, static cling, the warm glow of the Sun, maglev trains, and electric cars, to name a few.

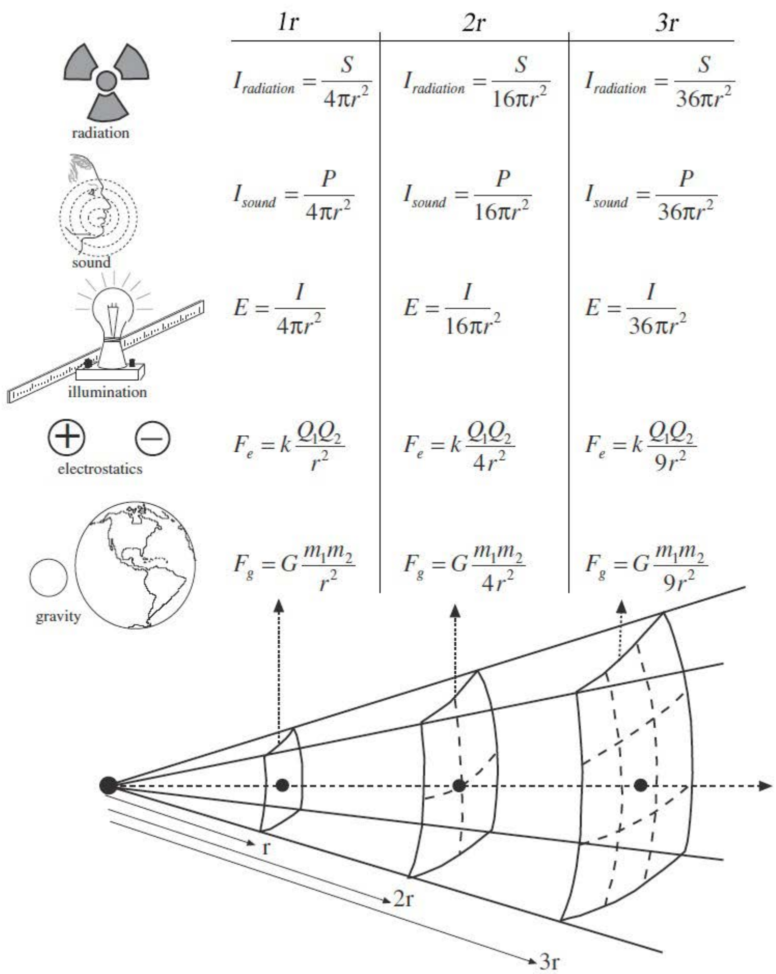
Asking students to identify the scientific principles that engineers apply to design and improve such technologies provides opportunities to review prior learning and recognize the value of science in everyday life. It also opens the door to understanding the **interdependence of science, engineering, and technology [CCC about nature of science]** in which scientists aid engineers through discoveries that can be incorporated into new devices, while engineers develop new instruments for observing and measuring phenomena that help further scientific research. In the high school chemistry course, students create a model describing how electromagnetic forces are ultimately responsible for holding atoms together in chemical bonds.

Students likely have experience with magnetic latches and are aware of static electricity, but they will need firsthand experiences with electrostatic forces. Are they always attractive like gravity? Students can explore conceptual hands-on tutorials (see the University of Maryland Physics Education Research Group Tutorials in Physics Sense-Making at https://www.cde.ca.gov/ci/sc/cf/ch8.asp#link37) and interactive simulations (see the Concord Consortium Electrostatics at https://www.cde.ca.gov/ci/sc/cf/ch8.asp#link38).

Students should be able to use the simple equation in Coulomb's Law to predict electrostatic forces between two electrically charged objects (HS-PS2-4). Coulomb's Law states: $F = k(q_1q_2)/r^2$, where F is the electrostatic force, k is Coulomb's constant, q_1 and q_2 are the magnitudes of the charges, and r is the distance between the charges. Given k and any three of the variables, students should be able to calculate the value of the remaining variable.

Students should notice that Coulomb's Law is strikingly similar to Newton's Universal Law of Gravitation. Both forces apparently have an infinite range and are directly proportional to the magnitude of the component parts (the two masses or the two charges), and inversely proportional to the square of the distance between them. With guidance, students apply **computational and mathematical thinking [SEP-5]** to conclude that gravitational and electrostatic forces share a common geometry, radiating out as spherical shapes from their point of origin. This geometry is similar to throwing a rock into a glassy-smooth pond. Waves emanate in all directions from the point where the rock hits the surface of the pond. As a wave moves from the point of impact, the same energy is spread over an increasingly large area. Initially the waves are tall, but as the waves get farther from the source, they stretch over a longer perimeter but are shorter in height. Although the water waves are confined to the surface of the water, point sources that spread their influence equally in all directions such as gravitational force, electric field, light, sound, and radiation display a similar attenuation with distance (figure 8.32).

Figure 8.32. Many Physical Processes Follow the Inverse Square Law



The intensity of radiation, sound, illumination, electrostatic interaction, and gravity vary as a function of distance (radius, *r*) from the source. *Source*: Herr 2008, 285
Long description of Figure 8.32.

High School Four-Course Model Physics Snapshot 8.8: Newton's Law of Gravitation and Coulomb's Law

The ability to **develop and use models [SEP-2]** is emphasized as a science and engineering practice in the CA NGSS, as well as a Standard for Mathematical Practice (MP) in the CA CCSSM. MP.4 states, "By high school, a student might use geometry to solve a design problem or use a function to describe how one quantity of interest depends on another." Having taught for a number of years, Mr. H realized that his physics students generally memorized Coulomb's Law and Newton's Universal Law of Gravitation without understanding the common geometric principles upon which both are based. Understanding the importance of crosscutting concepts, Mr. H developed a one-day lesson as part of a larger instructional segment on forces to help students discover the predictive power of the geometric principles underlying energy or forces that radiate from an origin. Prior to his lesson, Mr. H collaborated with the math teachers in his school to ensure that students in his physics class will have had familiarity with the geometry of a sphere and understand how the surface area of a sphere is calculated.

Investigative phenomenon: The surface area of a sphere depends on its radius.

As the class opened, students were engaged in a warm-up activity that required them to estimate the surface area of ping pong balls, baseballs, tennis balls, volleyballs, soccer balls, and basketballs. Although there was initially some confusion, students soon realized that they could estimate the radius of each ball with a ruler and subsequently estimate its surface area using the formula $A = 4\pi r^2$. (MP.2, MP.4). Mr. H had prepared a dynamic, Internet-based collaborative spreadsheet to which students submitted their measurements using smartphones. The measurements were automatically added to a plot of surface area as a function of radius, and Mr. H projected these measurements at the front of the class. Students observed that the shape of the surface-area-to-radius graph that developed as students entered data resembled one-half of a parabola.

Investigative phenomenon: Waves get weaker as you move farther from their source.

With figure 8.32 projected on the screen (equations that show how the intensity of radiation, sound, illumination, electrostatic interaction, and gravity vary as a function of distance), students electronically submitted written observations of **patterns [CCC-1]** between each phenomenon and within each phenomenon as distances were scaled up (CA CCSS for ELA/Literacy RST.11–12.9). Scanning student responses, Mr. H formatively assessed the **mathematical thinking [SEP-5]** of his class and noticed that the majority observed that each equation had an r-squared value in the denominator. He then selected

High School Four-Course Model Physics Snapshot 8.8: Newton's Law of Gravitation and Coulomb's Law

Sophia, a student who had not had an opportunity to share in the last few days, to explain her observations. Sophia was confident that she had something significant to share because she knew that Mr. H pre-screened student responses in the cloud and only called on students who had demonstrated understanding of the question. Sophia explained that the intensities vary as the inverse square of the radius from the source. (CA CCSS for ELA/Literacy SL.11–12.4).

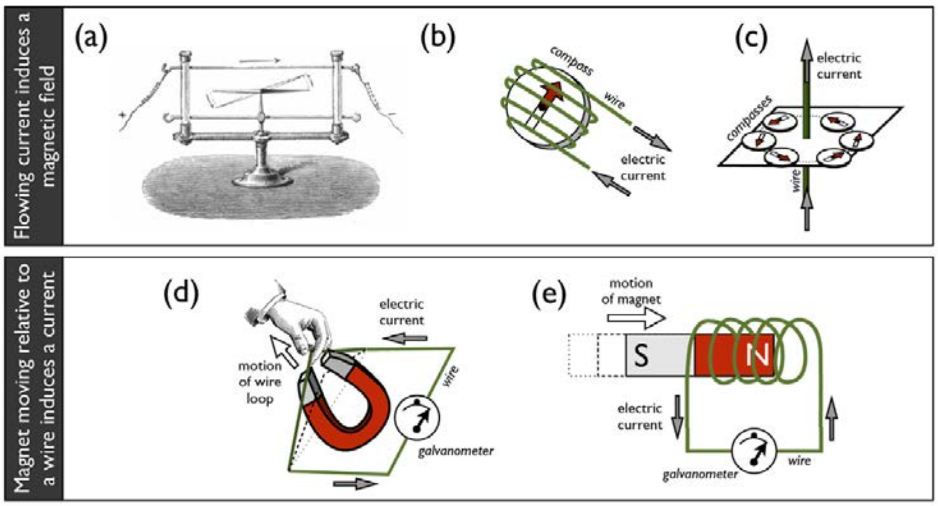
Mr. H provided students access to all the equipment in the lab and asked them to **develop a model [SEP-2]** that illustrated how intensity varies with distance. Tom and Min had used a marker to color a square on a balloon and were proceeding to inflate the balloon to observe how the color of the square got lighter as the balloon was inflated. As Joshua and Maria observed Tom and Min, they got the idea to do the same but used their cell phones to video their balloon as it was inflated so that they would have a permanent record to share with the class. Julia and Tae realized that Joshua and Maria had a good idea but were lacking a scale; they improved on their design by including a ruler in the background. Mr. H subsequently asked all three teams to share their ideas, and then asked Julia and Tae to wirelessly send their movie to the data projector so the class could observe the model (CA CCSS for ELA/Literacy SL.11–12.5). Students then estimated the surface area of the balloon at three different radii and noted how the intensity of the marker color decreased significantly with increasing radius.

Once again, Mr. H opened a cloud-based form, asking students to explain what they had observed and learned through this activity. Mr. H checked the responses and selected students to engage in Socratic questioning based on their submissions. He led the class in the development of a collective model of the inverse square law and an understanding of how it applies to forces such as gravity and electrostatic forces. Mr. H emphasized the value of collaboration and the iterative process of designing, building, testing, analyzing, and redesigning in engineering endeavors (the nature of science CCC that "[s]cience is a human endeavor"). Students then completed an online quiz in which they used **mathematical [SEP-5]** representations of Newton's Law of Gravitation and Coulomb's Law to describe and predict the gravitational and electrostatic forces between objects (HS-PS2-4).

For many years, scientists considered electric and magnetic forces to be independent of each other, but in 1820 Hans Christian Ørsted discovered that electric current generates a magnetic force, and in 1839 Michael Faraday showed that magnetism could be used to generate electricity. Finally, in 1860 James Clerk Maxwell derived equations that show how electricity and magnetism are related. Students will follow in their footsteps to **plan and carry out investigations [SEP-3]** that illustrate the relationship between electricity and magnetism (HS-PS2-5).

Students might recreate Ørsted's simple **investigation [SEP-3** in which he noticed that a compass needle would be deflected from magnetic north when an electric current passed through a wire that was held above the magnet (figure 8.33a). They can be given the challenge of getting the compass needle to deflect a fixed amount (e.g., so that it points northeast at 45° instead of north). They will need to explore what happens when they change the direction of the wire, the voltage through the wire, or the number of winds of the wire around the compass (figure 8.33b) or move the compass to different locations around the wire (figure 8.33c). Students should then be able to create an informative poster **communicating [SEP-8]** how each of these variables **affects [CCC-2]** the compass needle.

Figure 8.33. Magnetic Fields and Electric Currents



(a): Ørsted's experiment illustrates that an electric current generates a magnetic field. (b and c): Sensitive compasses can detect the magnetic field surrounding a current-carrying wire. (d): Moving a looped wire through a magnetic field generates a current within the wire. (e): Moving a magnet through a looped wire generates an electric current. *Source*: M. d'Alessio with images from Privat-Deschanel 1876, 656, fig. 456 and OpenClipart-Vectors 2013c.
Long description of Figure 8.33.

After gathering evidence that an electric current creates a magnetic field, students should investigate if the reverse is also true. They **plan and carry out an investigation [SEP-3]** to see if a changing magnetic field can induce an electric current. The simplest investigation requires connecting a galvanometer in a loop and moving the far side of the loop back and forth between two strong magnets (figure 8.33d). Students will observe the galvanometer needle deflect in opposite directions depending on which way the wire is moved (indicating that the electric current flows in different directions as the wire moves in different directions). Students can use this equipment to explore other variables. For example, they may coil the wire and move the magnet through the center of the coil and see a similar response (figure 8.33e). This principle is important for creating electric generators. While students may not be able to make that leap themselves, they should be able to **construct an explanation [SEP-6]** about how this principle could be used to make a generator in which there is a constant flow of electricity. Their explanation could rely on diagrams (pictorial **models [SEP-2]**).

Up to this point, this instructional segment has focused on interactions *between* different objects via electrostatic, electromagnetic, and gravitational forces. Now, students look at how forces work *within* materials at the microscopic level to explain macroscopic properties. In the middle grades, students developed conceptual models of atoms and molecules making up the **structure [CCC-6]** of solids, liquids, and gases. Here they **develop and refine those models [SEP-2]**, and understand that the **stability [CCC-7]** and properties of solids depend on the electromagnetic forces between atoms, and thus on the **types and patterns [CCC-1]** of atoms and molecules within the material.

Most collegiate STEM education is highly departmentalized, with students majoring in biology, chemistry, geology, astronomy, physics, engineering, mathematics, or related fields. Students may inadvertently assume that particular topics belong to one discipline or another and may fail to see the elegance and power of crosscutting concepts that have applications in a variety of fields. Teachers and students of physics may therefore have difficulty understanding the relevance of HS-PS2-6 which focuses on how the "molecular-level structure is important in the functioning of designed materials." This performance expectation sounds like it belongs in a chemistry course because it deals with molecular-level structure or perhaps in engineering because it deals with the functioning of designed materials. In reality, this performance expectation, like many, can be equally valuable in many different disciplines of science and engineering. An emphasis on material strength allows this content to flow well from the previous material in this course.

Students can begin by **investigating [SEP-3]** materials with macroscopic structure such as rope, yarn, knitted fabrics, individual clay bricks, clumps of soil, wood, or handmade paper. Students can sort the objects based on common **patterns [CCC-1]** in their structures. Rope, yarn, and wood all have fibers that run dominantly in one direction while knitted fabrics and paper both have fibers going in multiple directions. Clay bricks and clumps of soil have tiny particles in a three-dimensional matrix. All materials also have structure at the atomic level. These structures are held together by attractions caused by electromagnetic forces that can be different strengths (just as a clump of soil is weaker than a brick that has a similar internal structure because the forces holding the soil particles together are weak). Hence, different materials have different properties that are determined by features at the molecular level.

To develop a model of molecular level structure, students must first refine their model of the substructure of an atom. The mass of the atom is determined by its nucleus, but its electronic structure extends far outside the region where the nucleus sits. An important idea here is that the geometric size of more massive atoms is not very different from that of a hydrogen atom. An explanation for this is the fact that the higher charge of the nucleus pulls the electrons more strongly, so though there are more electrons, and their **patterns [CCC-1]** are more complex, there is a roughly common size **scale [CCC-3]** for all atoms. Models for materials help make the importance of this fact visible, as students see that you can fit many different combinations of atoms together in space and, thus, make a great variety of molecules and materials. For HS-PS2-6, students need only a qualitative, not quantitative understanding.

Performance expectation HS-PS2-6 requires students to **obtain, evaluate, and communicate information [SEP-8]** related to the properties of various materials and their consequent usefulness in particular applications. The role of engineering in this activity is not to make a design, but to use engineering thinking to **explain [SEP-6]** how the substructure relates to the macroscopic properties of the material and then **communicate [SEP-8]** that understanding. Performance expectation HS-PS2-6 emphasizes the skills in appendix M ("Connections to the Common Core State Standards for Literacy in Science and Technical Subjects") of the CA NGSS:

> Reading in science requires an appreciation of the norms and conventions of the discipline of science, including understanding the nature of evidence used, an attention to precision and detail, and the capacity to make and assess intricate arguments, synthesize complex information, and follow detailed procedures and accounts of events and concepts. [Students] need to be able to gain knowledge from elaborate diagrams and data that convey information and illustrate scientific concepts. Likewise, writing and presenting information orally are key means for students to assert and defend claims in science, demonstrate what they know about a concept, and convey what they have experienced, imagined, thought, and learned. (NGSS Lead States 2013a)

Students may **obtain information [SEP-8]** about the molecular-level interactions of various electrical conductors, semiconductors, and insulators to explain why their unique properties make them indispensable in the design of integrated circuits or urban power grids. For example, if students understand that the fundamental structure of metals, such as copper, aluminum, silver, and gold, can be described as a myriad of nuclei immersed in a “sea of mobile electrons,” they can then explain that these materials make good conductors because the electrons are free to migrate between nuclei under applied electromagnetic forces. By contrast, when students investigate the molecular level properties of covalent compounds, such as plastics and ceramics, they should note that these compounds behave as electrical insulators because their electrons are locked in bonds and therefore resistant to the movement that is necessary for electric currents. As students learn to communicate such information, they obtain a better appreciation of **cause and effect [CCC-2]**. For example, students should be able to explain that electromagnetic interactions at the molecular level (causes) result in properties (**effects [CCC-2]**.) at the macro-level and that these properties make certain materials good candidates for specific technical applications.

Students will build on their model of the structure of atoms from earlier in this instructional segment in IS3 when students explore nuclear processes and nuclear energy.

IS3

Physic Instructional Segment 3: Energy

According to the NGSS storyline:

> The Performance Expectations associated with the topic Energy help students formulate an answer to the question "How is energy transferred and conserved?" The disciplinary core idea expressed in the *Framework for PS3* is broken down into four sub-core ideas: Definitions of Energy, Conservation of Energy and Energy Transfer, the Relationship between Energy and Forces, and Energy in Chemical Process and Everyday Life. Energy is understood as quantitative property of a system that depends on the motion and interactions of matter and radiation within that system, and the total change of energy in any system is always equal to the total energy transferred into or out of the system. Students develop an understanding that energy at both the macroscopic and the atomic scale can be accounted for as either motions of particles or energy associated with the configuration (relative positions) of particles. In some cases, the energy associated with the configuration of particles can be thought of as stored in fields. Students also demonstrate their understanding of engineering principles when they design, build, and refine devices associated with the conversion of energy. The crosscutting concepts of cause and effect; systems and system models; energy and matter; and the influence of science, engineering, and technology on society and the natural world are further developed in the performance expectations associated with PS3. In these performance expectations, students are expected to demonstrate proficiency in developing and using models, planning and carry out investigations, using computational thinking, and designing solutions; and to use these practices to demonstrate understanding of the core ideas. (NGSS Lead States 2013f)

PHYSICS INSTRUCTIONAL SEGMENT 3: ENERGY

Guiding Questions

- What is energy and how does it relate to and interact with matter?
- How do nuclear reactions illustrate conservation of energy and mass?
- What is the relationship between energy and force?
- How can you model force fields?

Performance Expectations

Students who demonstrate understanding can do the following:

HS-PS1-8. Develop models to illustrate the changes in the composition of the nucleus of the atom and the energy released during the processes of fission, fusion, and radioactive decay. [Clarification Statement: Emphasis is on simple qualitative models, such as pictures or diagrams, and on the scale of energy released in nuclear processes relative to other kinds of transformations.] [*Assessment Boundary: Assessment does not include quantitative calculation of energy released. Assessment is limited to alpha, beta, and gamma radioactive decays*.]

HS-PS3-2. Develop and use models to illustrate that energy at the macroscopic scale can be accounted for as a combination of energy associated with the motions of particles (objects) and energy associated with the relative position of particles (objects). [Clarification Statement: Examples of phenomena at the macroscopic scale could include the conversion of kinetic energy to thermal energy, the energy stored due to position of an object above the earth, and the energy stored between two electrically-charged plates. Examples of models could include diagrams, drawings, descriptions, and computer simulations.]

HS-PS3-3. Design, build, and refine a device that works within given constraints to convert one form of energy into another form of energy.* [Clarification Statement: Emphasis is on both qualitative and quantitative evaluations of devices. Examples of devices could include Rube Goldberg devices, wind turbines, solar cells, solar ovens, and generators. Examples of constraints could include use of renewable energy forms and efficiency.] [*Assessment Boundary: Assessment for quantitative evaluations is limited to total output for a given input. Assessment is limited to devices constructed with materials provided to students.*]

HS-PS3-5. Develop and use a model of two objects interacting through electric or magnetic fields to illustrate the forces between objects and the changes in energy of the objects due to the interaction. [Clarification Statement: Examples of models could include drawings, diagrams, and texts, such as drawings of what happens when two charges of opposite polarity are near each other.] [*Assessment Boundary: Assessment is limited to systems containing two objects.*]

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

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

HS-ETS1-3. Evaluate a solution to a complex real-world problem based on prioritized criteria and trade-offs that account for a range of constraints, including cost, safety, reliability, and aesthetics as well as possible social, cultural, and environmental impacts.

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

PHYSICS INSTRUCTIONAL SEGMENT 3: ENERGY

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

Highlighted Science and Engineering Practices	Highlighted Disciplinary Core Ideas	Highlighted Crosscutting Concepts
[SEP-1] Asking Questions and Defining Problems [SEP-2] Developing and Using Models [SEP-6] Constructing Explanations (for science) and Designing Solutions (for engineering)	PS1.C: Nuclear Processes PS3.A: Definitions of Energy PS3.C: Relationship Between Energy and Forces PS3.D: Energy in Chemical Processes and Everyday Life ETS1.A: Defining and Delimiting Engineering Problems ETS1.B: Developing Possible Solutions ETS1.C: Optimizing the Design Solution	[CCC-2] Cause and Effect: Mechanism and Explanation [CCC-5] Energy and Matter: Flows, Cycles, and Conservation Influence of Science, Engineering, and Technology on Society and the Natural World

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

CA CCSS Math Connections: N-Q.1–3; MP.2, MP.4

CA CCSS for ELA/Literacy Connections: SL.11–12.5; RST.11–12.1, 7, 8, 9; WHST.9–12.7, 9; WHST.11–12.8

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

Perhaps the most unifying CCC in physics and all other science is the **conservation of energy [CCC-5]**, expressed in the first law of thermodynamics, which states that the total energy of an isolated system is constant, and that although energy can be transformed from one form to another, it cannot be created or destroyed. **Conservation of energy [CCC-5]** requires that changes in energy within a **system [CCC-4]** must be balanced by **energy flows [CCC-5]** into or out of the system by radiation, mass movement, external forces, or heat flow. Students need multiple experiences to build qualitative **models [SEP-2]** of energy in its various forms (such as thermal, electrical, chemical, wind, and radiant energy) to see that it involves a mixture of particle-motion (subatomic to molecular scale), radiation, and potential energy due to interactions between particles. Students should apply energy concepts to explain and interpret phenomena such as why your hands get warm when you rub them together or why engines are always less than 100 percent efficient at using the energy of combustion to achieve desired changes in kinetic or potential energy. The general concept that every system transfers energy to the surrounding environment through both contact forces (friction) and radiation must be developed through examples. Once students have explored a variety of energy forms, they can begin to see how they can convert from one to another.

HIGH SCHOOL FOUR-COURSE MODEL PHYSICS VIGNETTE 8.3: ENERGY CONVERSION

Performance Expectations

Students who demonstrate understanding can do the following:

HS-PS3-3. Design, build, and refine a device that works within given constraints to convert one form of energy into another form of energy.* [Clarification Statement: Emphasis is on both qualitative and quantitative evaluations of devices. Examples of devices could include Rube Goldberg devices, wind turbines, solar cells, solar ovens, and generators. Examples of constraints could include use of renewable energy forms and efficiency.] [*Assessment Boundary: Assessment for quantitative evaluations is limited to total output for a given input. Assessment is limited to devices constructed with materials provided to students.*]

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

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

HS-ETS1-3. Evaluate a solution to a complex real-world problem based on prioritized criteria and trade-offs that account for a range of constraints, including cost, safety, reliability, and aesthetics, as well as possible social, cultural, and environmental impacts.

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

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

Highlighted Science and Engineering Practices	Highlighted Disciplinary Core Ideas	Highlighted Crosscutting Concepts
[SEP-1] Asking Questions and Defining Problems [SEP-6] Constructing Explanations (for science) and Designing Solutions (for engineering)	PS3.A: Definitions of Energy PS3.D: Energy in Chemical Processes ETS1.A: Defining and Delimiting Engineering Problems ETS1.B: Developing Possible Solutions ETS1.C: Optimizing the Design Solution	[CCC-5] Energy and Matter: Flows, Cycles, and Conservation Influence of Science, Engineering, and Technology on Society and the Natural World

HIGH SCHOOL FOUR-COURSE MODEL PHYSICS VIGNETTE 8.3: ENERGY CONVERSION

Highlighted California Environmental Principles and Concepts:

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

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

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

CA CCSS Math Connections: N-Q.1–3; MP.2, MP.4

CA CCSS for ELA/Literacy Connections: RST.9–12.2; WHST.9–12.6, 7, 10; SL.11–12.1

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

Introduction

A three-dimensional (3D) learning environment in the CA NGSS encourages students to reason and plan like scientists and engineers. The following vignette illustrates 3D learning while addressing DCIs related to energy. Although this lesson focuses on the physics of energy conversion (HS-PS3-3), it also touches on all four high school engineering, technology, and applied science standards, as students employ engineering solutions to address complex real-world problems.

Length and position in course: This vignette illustrates a sample two-week learning event in IS3. Prior to this learning event, students had explored various forms of energy including electrical, chemical, kinetic, light, and thermal energies. In addition, they had gained experience **developing and using models [SEP-2]**, and applying the CCC of **flows, cycles, and conservation of energy and matter [CCC-5]**.

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

Day 1: Energy Conversion in My Life

Students use a phone app to track their personal energy use during daily life and exercise. They relate these energy quantities to the energy in different foods. Students use Rube Goldberg machines as a conceptual model to think about energy conversion.

Day 2: Patterns in Electricity Usage

Students analyze their home energy usage and look for patterns. They use energy monitoring devices to track energy usage of specific appliances in the classroom.

Days 3–4: Models of Energy Conversion in The Earth System

Students draw a diagram tracking the flow of energy within the Earth system and tracing it back to the Sun. This pictorial model includes energy conversion processes within both the natural world and built objects.

HIGH SCHOOL FOUR-COURSE MODEL PHYSICS VIGNETTE 8.3: ENERGY CONVERSION

Days 5–9: Solar Oven Design Challenge

Motivated by major global problems, students design a device that converted energy from the Sun to thermal energy that could cook food. Students went through an entire design challenge including defining the problem, developing solutions, and optimizing those solutions.

Day 10: Publish and Learn from Others

Students communicate their design approach to other students in the class. As part of the peer review process of these lab reports, students learn from others and revise their designs for a second competition.

Day 1: Energy Conversion in My Life (Engage)

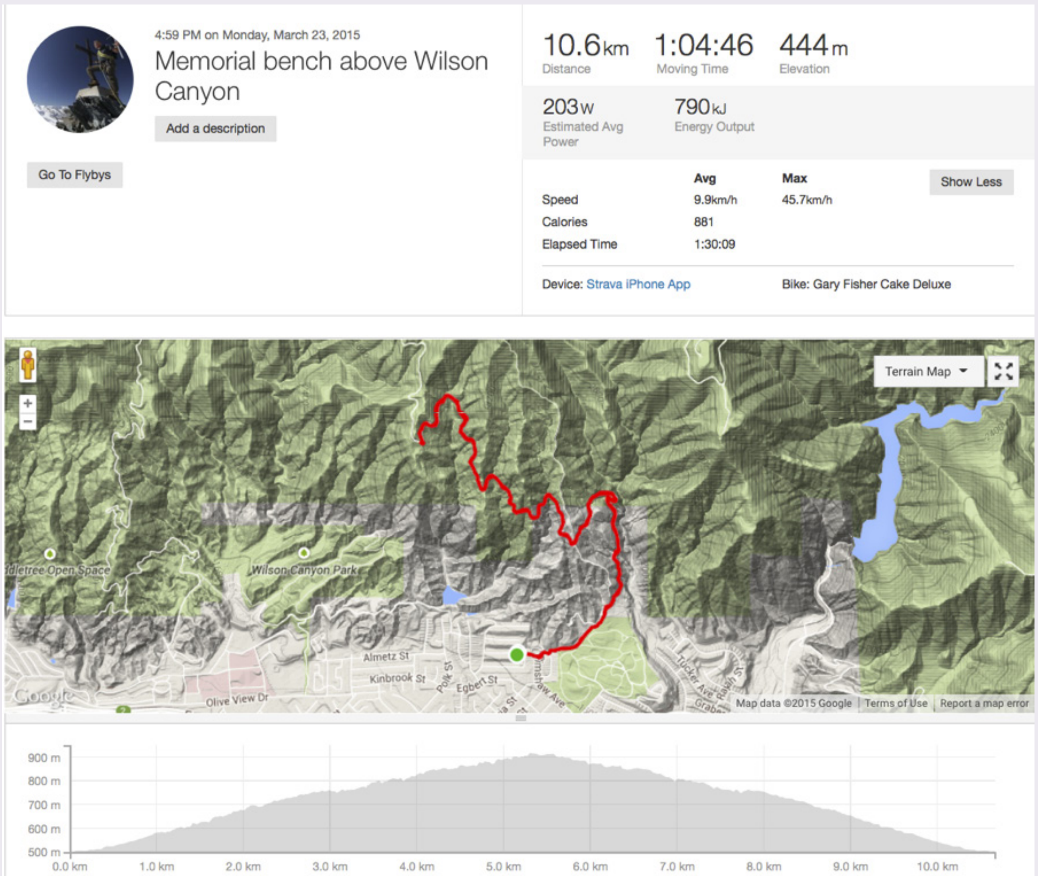
Anchoring phenomenon: Food labels report the stored energy of food in Calories and a GPS smartphone app reports how much energy students burn by doing different exercises.

One of the many ways to engage students in learning is to introduce them to surprising and interesting facts and concepts related to a topic of personal relevance. High school students are familiar with food and sports but may have little understanding about the energy-based connections between them. For example, they have probably never pondered how many French fries must be consumed to provide enough energy to run a 5K race. To engage students in a lesson on energy conversion, Mr. H provided an activity that helped answer such questions.

Students with smartphones were encouraged to download free cell phone global positioning system (GPS)-tracking apps (e.g., Strava®) that mapped routes, analyzed motion, and estimated energy expenditure (figure 8.34). He then encouraged them to activate the app while walking, jogging, or cycling and to submit their results anonymously to a common database. The results were subsequently posted on a lesson Web site, and students were asked to rank the various activities in terms of energy expenditure. On the same Web page, students found a link to a Web site that provided nutritional information for various fast foods. Mr. H then directed students to select foods and portions that would provide equivalent energy content to fuel selected activities. As the lesson progressed, one could hear exclamations such as “Wow, I had no idea that a medium fries could give me enough energy to walk for nearly two hours!” or “Oh no, I need to run 40 minutes just to burn off the 380 calories I acquired from those fries!” Such comments indicated that the students were engaged in the lesson and ready to talk about exploring the concept of energy conversion.

HIGH SCHOOL FOUR-COURSE MODEL PHYSICS VIGNETTE 8.3: ENERGY CONVERSION

Figure 8.34. Screenshot of an App Tracking a Student's Movement

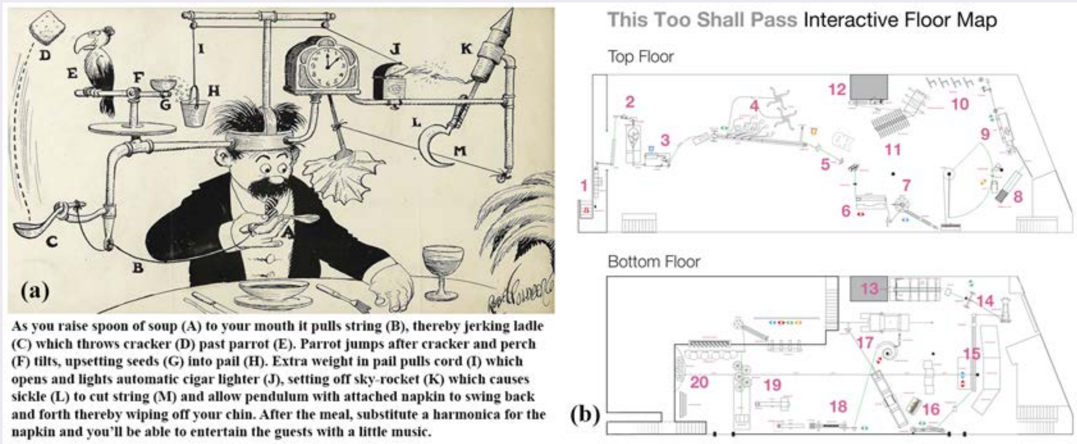


A screenshot from ®Strava showing students' movement with a 2D map, elevation profile, speed profile, and estimated energy expenditure for various exercises. *Source*: Strava 2015
[Long description of Figure 8.34.](#)

Before beginning the exploration phase, students watched online videos of modern Rube Goldberg machines. Rube Goldberg machines are purposely over-engineered contraptions that perform simple tasks through indirect, convoluted means (figure 8.35). For example, Goldberg's "Self-Operating Napkin" is activated when soupspoon (A) is raised to mouth, pulling string (B) and thereby jerking ladle (C), which throws cracker (D) past parrot (E). The parrot jumps after cracker and perch (F) tilts, upsetting seeds (G) into pail (H). Extra weight in pail pulls cord (I), which opens and lights automatic cigar lighter (J), setting off skyrocket (K) which causes sickle (L) to cut string (M) and allow pendulum with attached napkin to swing back and forth, thereby wiping chin. These amusing devices engage learners and provide an opportunity to discuss processes of energy transfer through a long series of events or interactions.

HIGH SCHOOL FOUR-COURSE MODEL PHYSICS VIGNETTE 8.3: ENERGY CONVERSION

Figure 8.35: Examples of Rube Goldberg Machines



Rube Goldberg machines, such as (a) the Self-Operating Napkin or (b) the immensely popular Internet video This Too Shall Pass by Mindshare LA. Pictured is a screen shot of an interactive floor plan from the video. *Sources*: Adapted from Goldberg 1931; Mitch Said n.d.
Long description of Figure 8.35.

Day 2: Patterns in Electricity Usage (Explore)

Investigative phenomenon: Students use different amounts of electricity in their homes.

On day 2 students investigated processes of energy conversion with inanimate objects. Returning to the class assignment Web page, students found a form prompting them for information regarding energy consumption in their homes. Students recorded the amount of energy consumed during a 24-hour period (as reported on their home electric meters) as well as the approximate number of minutes each light, appliance, and utility operated during this period. As Mr. H projected students' energy usage on the board, they observed a huge range. Mr. H asked students, "What questions do you have when you see such a large range like this?" The questions start general ("What causes the differences?"), but Mr. H prompted students to ask more specific questions that they might be able to answer using their data (e.g., "Can we predict the amount of energy used knowing just the number of minutes lights were on?" and "Do people that watch more TV use more energy overall?"). Students opened up the collaborative spreadsheet containing all their data and started to **analyze the data [SEP-4]** for **patterns [CCC-1]** that might answer their questions.

While they were able to identify some trends, they decided they needed more specific measurements of energy usage. Mr. H introduced them to a device that monitored electricity usage of any appliance plugged into it (e.g., Kill a Watt®). They placed devices on the data

HIGH SCHOOL FOUR-COURSE MODEL PHYSICS VIGNETTE 8.3: ENERGY CONVERSION

projector, fan, instructor computer, and other electric-powered devices within the classroom and recorded the amount of energy each used during the class period. Students reported the energy usage in an online form that also asked them to identify the energy conversions that each device accomplished. For example, fans converted electrical energy into the kinetic energy of the fan blades, while a toaster converted electrical energy to heat energy, and a data projector converted electrical energy to light energy. While looking at the data, students tried to identify **patterns [CCC-1]**—devices that generated a lot of heat seemed to use more energy. Students decided to take turns bringing the devices home to figure out which appliances used the most electricity in their own households.

Days 3–4: Models of Energy Conversion in the Earth System (Explain)

Using their discoveries from the exploration phase, students generated **explanations [SEP-6]** regarding energy conversion processes. They began by revisiting a task they completed in grade five. They drew a pictorial **model [SEP-2]** tracing the **flow of energy [CCC-5]** within the Earth **system [CCC-4]** back to the Sun. At this level, their model began with thermonuclear energy in the Sun, included the chemical potential energy changes in combustion reactions, and described the energy conversion in cars, computers, and TVs (figure 8.36).

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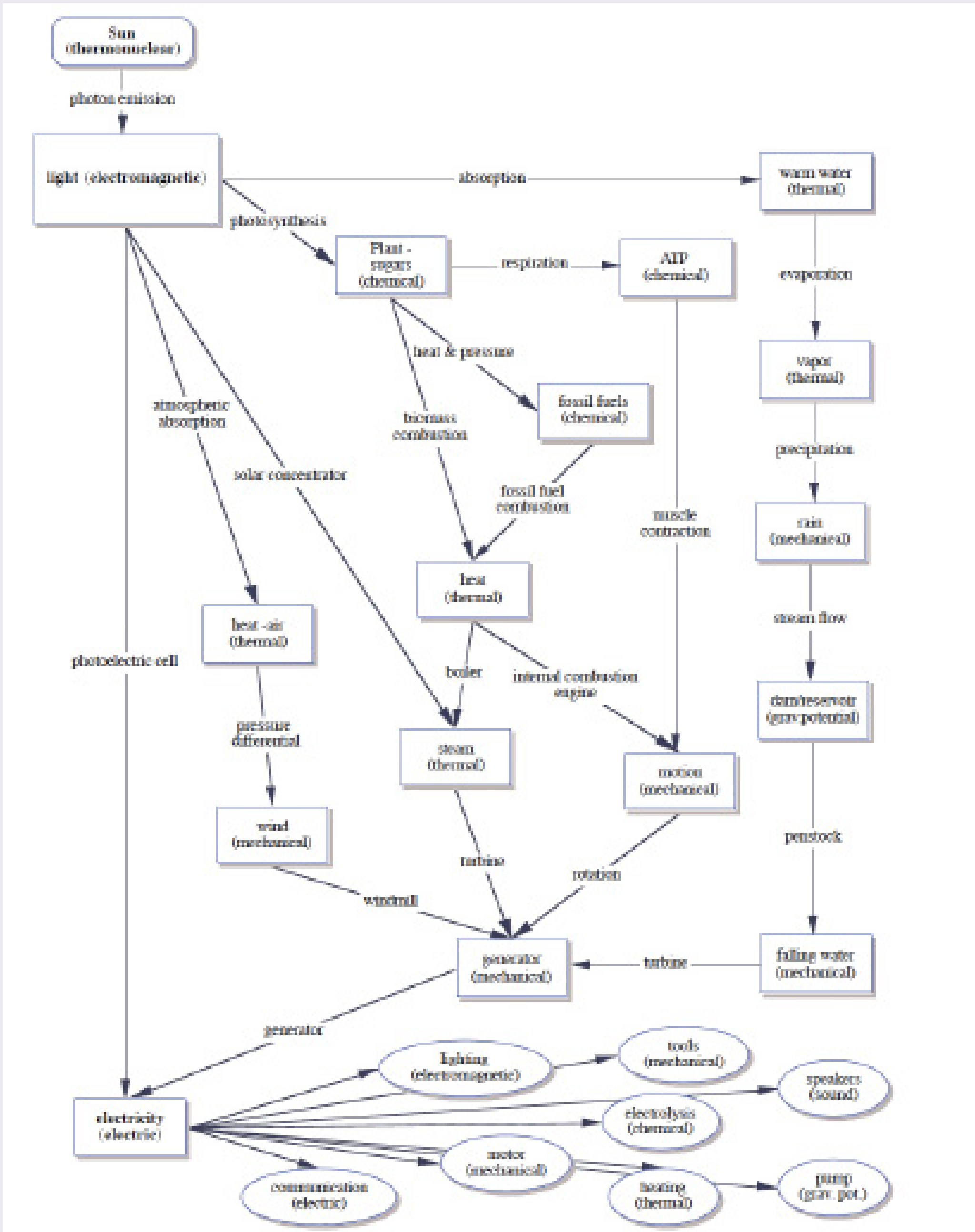
Figure 8.36. Model of Energy Conversion within the Earth System



Learners can generate explanations of energy conversion processes using flow charts and other types of concept maps. *Source*: Herr 2008, 180

Long description of Figure 8.36.

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Investigative phenomenon: Students observe different energy conversion devices.

Students observed and analyzed demonstrations, diagrams, and simulations to better understand the physics of energy conversion in such things as waterwheels (gravitational potential to kinetic), photovoltaic cells (solar to electric), solar ovens (solar to thermal), generators (mechanical to electrical), wind turbines (kinetic to electrical), heating coils (electrical to thermal), burners (chemical potential to thermal), motors (electrical to mechanical), and loud speakers (electromagnetic to sound). Note that each of the above can be applied to the task of designing, building, and refining an energy conversion device that meets the demands of HS-PS3-3.

Students gained further understanding of energy transfer by manipulating variables and observing **effects [CCC-2]** in online simulations (PhET 2015). Mr. H assessed student understanding of energy conversion by offering quizzes associated with these simulations (figure 8.37).

Figure 8.37: Example of Online Simulation of Energy Conversion

Online simulations provide the opportunity to quickly manipulate variables and observe and study effects of complex systems. *Source*: PhET 2015
[Long description of Figure 8.37.]()

Days 5–9: Solar Oven Design Challenge (Extend, Elaborate)

Investigative phenomenon: How do we provide clean and plentiful energy for people to cook so that they don't need to cut down trees?

Now that students had a basic understanding of the physics of energy transfer, they were prepared to address performance expectation HS-PS3-3, which extended student understanding

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of energy conversion by requiring learners to “design, build, and refine a device that worked within given constraints to convert one form of energy into another form of energy.”

Mr. H introduced this lesson with a series of statistics and photos on the global ecological problem of deforestation, and then read the following paragraph from the World Wildlife Fund:

> Forests cover 31% of the land area on our planet. They produce vital oxygen and provide homes for people and wildlife. Many of the world’s most threatened and endangered animals live in forests, and 1.6 billion people rely on benefits forests offer, including food, fresh water, clothing, traditional medicine, and shelter. But forests around the world are under threat from deforestation, jeopardizing these benefits. Deforestation comes in many forms, including fires, clear-cutting for agriculture, ranching and development, unsustainable logging for timber, and degradation due to climate change. This impacts people’s livelihoods and threatens a wide range of plant and animal species. Some 46–58 thousand square miles of forest are lost each year—equivalent to 36 football fields every minute. Forests play a critical role in mitigating climate change because they act as a carbon sink—soaking up carbon dioxide that would otherwise be free in the atmosphere and contribute to ongoing changes in climate **patterns [CCC-1]**. Deforestation undermines this important carbon sink function. It is estimated that 15% of all greenhouse gas emissions are the result of deforestation. (World Wildlife Fund 2015)

Mr. H then discussed the problem of desertification, the process in which fertile land is transformed into desert as a result of deforestation, drought, or inappropriate agriculture. He explained that some desertification in developing countries is caused by people cutting and burning vegetation for fuel (EP&C I, II). Those who do not have access to natural gas, coal, or electricity, collect and burn firewood to keep warm, cook food, and purify water. Their resource extraction exacerbates the problem of deforestation and desertification, but they also put their own health at risk when they burn wood inside their homes and breathe the exhaust. Mr. H showed students a video that describes how as many as 4 million people die each year from illnesses related to inhaling this smoke (KQED 2014). The problems of deforestation and the health impacts of indoor cooking are examples of the kind of complex real-world problems that students are expected to analyze to meet performance expectation HS-ETS1-1. Mr. H then explained that a number of organizations are encouraging the use of solar cookers in developing countries to reduce the need for firewood. He then proceeded with the following solar cooker engineering challenge. Breaking down a complex real-world problem into manageable problems that can be solved through engineering is the skill called for in HS-ETS1-2 (figure 8.38).

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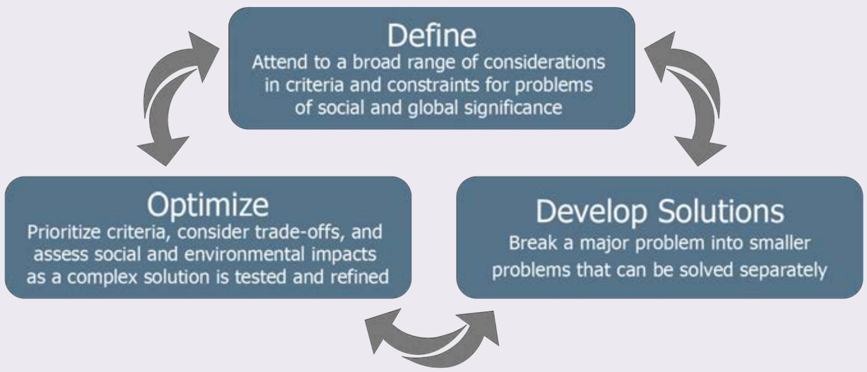
Figure 8.38. A Simplified View of the Engineering Design Process



Source: NGSS Lead States 2013
Long description of Figure 8.38.

Solar Cooker Engineering Challenge

Investigative phenomenon: How can we design a solar cooker that gets hot enough to cook food?

All engineering projects have criteria for success as well as constraints in design and construction. Mr. H introduced the criteria and constraints for this activity in the context of the CA NGSS high school engineering cycle. First, the problem was defined as a competition: Design and build a solar cooker that reached a higher temperature in 10 minutes than any other design. Student engineers had to direct the maximum amount of sunlight to the food by reflection where it was converted to thermal energy. In addition, they had to employ insulation to minimize heat loss from the food. To emphasize engineering constraints, students were required to design their solar ovens using only resources provided by the instructor, in quantities specified by the instructor. Mr. H presented a variety of resources including scissors, string, straws, infrared thermometers, cardboard boxes, tape, aluminum foil, plastic food wrap, paint of various colors, paint brushes, poster board, brass brads, pencils, nuts, bolts, stiff copper wire, wire cutters, small mirrors, rubber cement, white glue, duct tape, utility knife, felt marker, meter sticks, oven bags, paper, and chocolate squares. Before students could start the build, they had to submit a digital photo of their design with a rationale for all of its features. Once the instructor had approved plans, students were given the opportunity to implement and test their designs. The minimum criterion for success was the ability to melt chocolate squares within 10 minutes of exposure to the sunlight. (Note that the amount of time is variable depending on air temperature and the amount of solar radiation.) Although many oven designs might have been successful in meeting this basic criterion, there was competition for the hottest oven, as measured through the use of infrared thermometers (figure 8.39). During this process, students touched on ideas that related to performance

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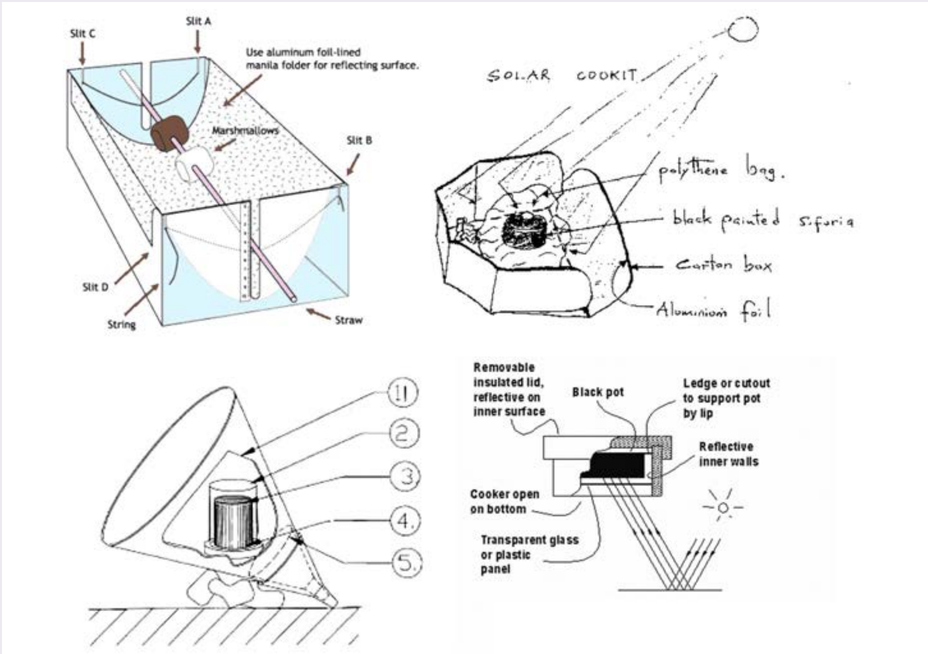
expectations in other disciplines, including heat flow within systems (HS-PS3-4) and convection (HS-ESS2-3) and the fact that a property of waves is that they can reflect (HS-PS4-3). The background information required is tangential to each of those performance expectations but could be useful in helping students achieve them.

Figure 8.39. Sample Designs of a Solar Oven



Sample designs for solar ovens for converting light energy into thermal energy. Students can get ideas for optimizing their own designs by examining the designs of their peers. *Source*: Used by the permission of The University of Texas McDonald Observatory 2014; Solar Cookers International 2005; Ligtenberg n.d.; Delaney 2003

Long description of Figure 8.39.

Day 10: Publish and Learn from Others (Evaluate)

Once the competition was complete, students wrote lab reports that **communicated [SEP-8]** their design, rationale, results, and recommendations for improvement. The lab reports were presented in collaborative online documents that were shared with their classmates.

Students were then instructed to read the online lab reports of their classmates and redesign their solar ovens based upon these “published” data. They had to edit their online lab reports to include the new designs with written justifications, making certain to cite the findings and lab reports of their peers. Mr. H evaluated the reports based on how well the students described how the structure of their solar oven enabled it to convert energy more efficiently into usable heat for cooking. He evaluated their ability to communicate using

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academic language and incorporate relevant ideas related to thermal energy and the energy conversion process such as radiation, reflection, conduction, convection, insulation, temperature, and energy transfer.

Investigative phenomenon: How can we improve a solar cooker design?

Optimization: A second competition was scheduled and once again students recorded maximum temperatures and wrote addendums to their lab reports describing features used to optimize their designs. Following the second competition, students recorded and compared their results. Next, they were allowed to **change [CCC-7]** only one variable at a time, recording the maximum temperature attained with each change and evaluating the **effect [CCC-2]** of each **change [CCC-7]**. After three adjustments, a third competition was conducted. This iterative process of designing, building, testing, analyzing, and redesigning is illustrative of the competence described in HS-ETS1-3, which also includes the idea that even successful designs must be socially and culturally acceptable and have minimal environmental impacts.

Vignette Debrief

Mr. H's lessons addressed three of the four high school ETS performance expectations. This lesson addressed the global challenges (HS-ETS1-1) of deforestation and desertification. Students addressed these complex real-world problems as they designed solar ovens, examining the **effect [CCC-2]** of single variables at a time ("smaller, more manageable problems") (HS-ETS-2). Finally, each of the solar ovens was designed and built within specified constraints (HS-ETS-3). The fourth performance expectation involved use of a computer simulation to model the impact of proposed solutions for a complex real-world problem, which could certainly be added to these activities

SEPs. As students proceeded through the engineering cycle in this activity, they employed most of the CA NGSS SEPs. First they **defined the problem [SEP-1]** to develop the most efficient solar oven given constraints of resources and time. Next, they **developed and employed models [SEP-2]** as they designed and built their solar ovens. They then **planned and carried out investigations [SEP-3]** to determine the rate at which their solar oven would heat food. They then **analyzed and interpreted data [SEP-4]** recorded by their classmates to determine factors related to the efficiency of solar oven designs. Using these data and concepts of *energy transfer* (HS-PS3-3), they **constructed explanations and designed improved solutions [SEP-6]** and **engaged in arguments from evidence [SEP-7]** to defend their new designs. Throughout the activity, students **obtained and evaluated the data of others [SEP-8]** and **communicated their own findings [SEP-8]**.

DCIs. To complete the design challenge, students needed an understanding of the DCIs related to energy (PS3.A, PS3.B, PS3.D). In addition, they relied on their ability to apply all three engineering, technology, and applications of science DCIs. They defined and delimited the engineering problem (ETS1.A) while setting criteria and constraints for their solar ovens.

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They then developed possible solutions (ETS1.B) and shared their findings with the class. Finally, students optimized their design solutions (ETS1.C) using evidence from their own experiments as well as those of others.

CCCs. This vignette had a clear focus around the **flow of energy [CCC-5]**, but they also employ other CCCs. Students looked for **patterns [CCC-1]** in data as they examined other lab reports prior to the redesign of their ovens. After evaluating such data, they defended their redesigns by providing arguments of presumed **cause and effect [CCC-2]**. Finally, they described the **structure and function [CCC-6]** of their designs as they **developed and explained their models [SEP-2]** of energy transfer.

EP&Cs. Even though this was a physical science lesson about energy flow, Mr. H made a strong connection to an environmental issue when he introduced the design challenge. Deforestation has affected the natural system (EP&C I), which in turn has affected the survival of humans that depend on the forest for fuel (EP&C II).

CA CCSS Connections to English Language Arts and Mathematics. Throughout vignette, students were engaged in collaborative discussions with their classmates (SL.11.12.1). They read informational text about deforestation to identify the major impacts it has had on the planet (RST.9-12.2). They also wrote and revised lab reports to reflect new findings (WHST.9-12.6, 7, 10). The students recorded data about their own personal energy use (exercise) and home energy use, and analyzed that data to find patterns and trends (N-Q.1-3).

Resources

Goldberg, Rube. 1931. "Self-Operating Napkin (Rube Goldberg Cartoon with Caption)." Posted at *Wikimedia Commons*, https://www.cde.ca.gov/ci/sc/cf/ch8.asp#link39.

Herr, Norman. 2008. *The Sourcebook for Teaching Science—Strategies, Activities, and Instructional Resources*. San Francisco: Jossey-Bass.

KQED. 2014. "Darfur Stoves Project." https://www.cde.ca.gov/ci/sc/cf/ch8.asp#link40.

Mitch Said. n.d. This Too Shall Pass Interactive Floor Map. https://www.cde.ca.gov/ci/sc/cf/ch8.asp#link41.

NGSS Lead States. 2013. Appendix I. Engineering Design in the NGSS. https://www.cde.ca.gov/ci/sc/cf/ch8.asp#link42.

PhET. 2015. Energy Forms and Changes. https://www.cde.ca.gov/ci/sc/cf/ch8.asp#link43.

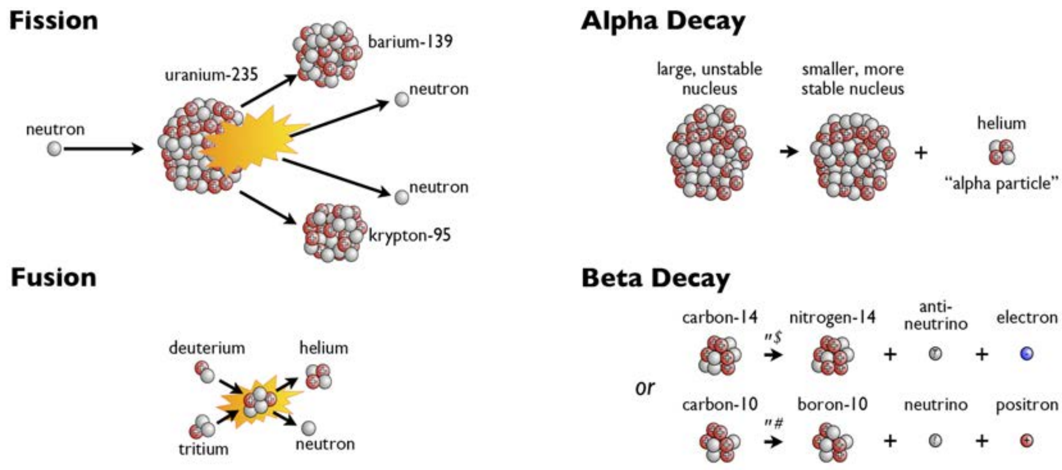
Strava. 2015. https://www.cde.ca.gov/ci/sc/cf/ch8.asp#link44.

World Wildlife Fund. 2005. Threats: Deforestation. https://www.cde.ca.gov/ci/sc/cf/ch8.asp#link45.

While students have direct experience with many of the forms of energy discussed so far, processes at the atomic scale also exhibit the same principles of conservation of **energy and matter [CCC-5]**. Nuclear fission, fusion, and radioactive decay of unstable nuclei involve the release or absorption of energy. These nuclear processes play a role in many phenomena such as nuclear power generation, nuclear medicine, nuclear fusion in stars, and radiometric dating. Students probably have some preconceptions about nuclear processes from popular culture. Teachers should motivate this section by finding out what students know and then try to focus instruction around addressing that knowledge. How does radiation cause cancer? What makes nuclear waste hazardous? How does burying it underground help protect us from these hazards? Their awareness of these macroscopic phenomena will motivate investigation of subatomic processes using data from real-world contexts and simulations. Depending on their local context, students could investigate the decommissioning of one of California's nuclear reactors, the protective concrete shield over the failed Chernobyl reactor, radioactive dye tracers in medical imaging, or ways that radioactive materials are used to induce mutations for developing new agricultural crop varieties (Novak and Brunner 1992).

Performance expectation HS-PS1-8 states that students should be able to **develop models [SEP-2]** to illustrate the **changes [CCC-7]** in the composition of the nucleus of the atom and the energy released during the processes of fission, fusion, and radioactive decay. Such models could be in the form of equations or diagrams of fission, fusion, and alpha, beta, or gamma radioactive decay (figure 8.40). Although it is not necessary to include quantitative calculations, the **models [SEP-2]** should include both energy flows and particles and convey the **scale [CCC-3]** of energy involved in these processes. These concepts can generally not be explored in direct experimentation in the classroom, so students will need to **analyze data [SEP-4]** from external sources and simulations to develop these models. Students can start to see that nuclear fission could be more dangerous than alpha decay because the mass of the particles and energy releases differs so dramatically (an alpha particle is relatively tiny and is ejected with much less kinetic energy than the fast-moving and massive fission products). How do other radiation sources compare?

Figure 8.40. Models of Nuclear Processes in Atoms



Sources: Adapted from Stefan-XP 2009; adapted from Pbech 2008; adapted from Thomas Jefferson National Accelerator Facility—Office of Science Education 2015a, 2016b
Long description of Figure 8.40.

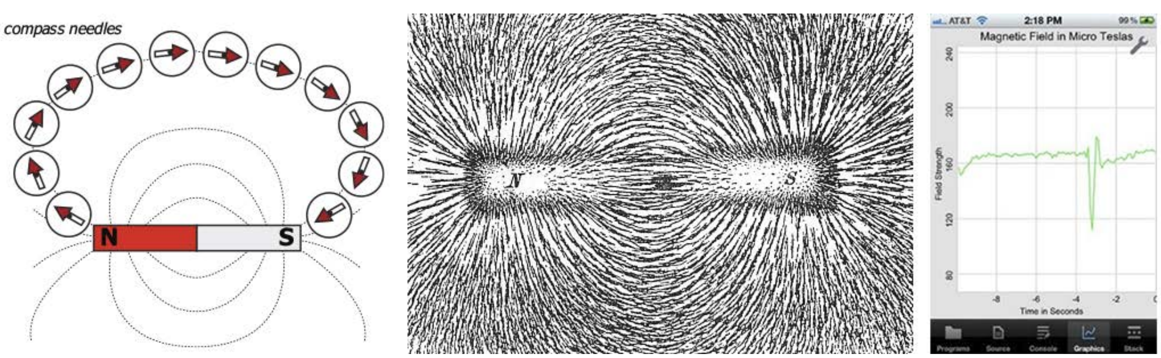
Students must revise their conceptual **model [SEP-2]** of **matter and energy [CCC-5]** in order to **explain [SEP-6]** nuclear processes. They apply the principle of mass-energy equivalence ($E=mc^2$) to revise the view that matter is conserved as atoms, to a more accurate view that the number of nucleons (sum of protons and neutrons) is conserved. Neither mass nor the number of atoms of each type is conserved in nuclear processes. Although such mass conservation "laws" are applicable to gravitational and electromagnetic processes, they must be revised and refined as students examine nuclear processes. This revision and refinement process should be stressed as an aspect of the nature of science.

Given that energy is conserved, then it follows that the energy we measure at a macroscopic **scale [CCC-3]** must be accounted for as a combination of energy of its component parts at the microscopic scale. Performance expectation HS-PS3-2 states that students should be able to **"develop and use models [SEP-2]** to illustrate that energy at the macroscopic **scale [CCC-3]** can be accounted for as a combination of energy associated with the motions of particles (objects) and energy associated with the relative position of particles (objects)." In other words, the sum of the kinetic and potential energy of component particles (energy of motion and position) must total the bulk energy measured at the macroscopic level. Using diagrams, drawings, descriptions, and/or computer simulations, students should be able to illustrate this summative relationship. This performance expectation is designed to help students bridge concepts traditionally associated with chemistry (e.g., the energy of atoms and molecules) with the concepts traditionally associated with physics (e.g., the energy of macroscopic objects).

Energy is the capacity for doing work and may exist in potential, kinetic, thermal, electrical, chemical, nuclear, or other forms. Energy is a property of matter that can be **modeled [SEP-2]** in “fields,” or regions, which surround matter and are influenced by matter. A gravitational field is a model used to explain the influence that mass extends into the surrounding space, yielding attractive forces on masses in that space. Similarly, an electric field is a model used to explain the influence that a charge extends into the surrounding space, yielding attractive or repulsive forces on surrounding charges. Similarly, a magnetic field is a region around a magnetic material or a moving electric charge within which the force of magnetism acts.

Performance expectation HS-PS3-5 states that students should be able to “develop and use a model of two objects interacting through electric or magnetic fields to illustrate the forces between objects and the changes in energy of the objects due to the interaction.” For example, students can map a magnetic field surrounding a bar magnet by placing magnetic compasses at various points in the region surrounding the magnet. At each point tested, the compass shows the direction of the magnetic field (figure 8.41a). They can then investigate the strength of the magnetic field by sprinkling iron filings on a glass plate that lies on top of the bar magnet (figure 8.41b). As students tap on the plate, the filings align with the magnetic field, with greater concentrations moving to those locations where the field is stronger. Equipped with data about the direction and relative magnitude of the field, students can draw a pictorial **model [SEP-2]** of the magnetic field using vectors at various locations around the bar magnet. In such a model, the direction of the arrows indicates the direction of the field, while the length of each arrow indicates its magnitude.

Figure 8.41. Investigating Magnetic Fields



Students can investigate magnetic fields with such things as (a) compasses, (b) magnets and iron filings, or (c) apps on mobile devices. *Sources*: M. d’Alessio; Black and Davis 1913, 242, figure 200; Byteworks 2011

Long description of Figure 8.41.

Engineering Connection: Build an Energy Conversion Device

Humans are natural engineers. We learn to modify our environment to solve specific problems, as seen when a child moves a chair to access the cookie jar or when a young person designs props for the school play. Engineering skills can be developed while studying science as students define and design solutions to real-world problems in chemistry, physics, biology, and the Earth and space sciences. Science students can demonstrate competence in all three phases of the engineering process: **defining problems [SEP-1]**, **designing solutions [SEP-6]** to these problems, and optimizing design solutions. HS-PS3-3 requires students to "design, build, and refine a device that works within given constraints to convert one form of energy into another form of energy." Equipped with a basic understanding of the laws of thermodynamics, students understand that energy can be converted from less useful forms to more useful forms. This performance expectation challenges students to design and build devices such as wind turbines, solar ovens, or electric generators to transform energy from less useful forms, such as wind, sunlight, or motion, into electricity, the most convenient and useful form of energy in our modern world.

Students deepen their understanding of the core ideas of science as they increase their competence in engineering design through such activities. Students should first consider the major global challenge of providing affordable electrical energy (HS-ETS1-1). Designing, building, and improving energy conversion devices that are more efficient or that pollute less involves breaking down the complex global problem into more manageable problems that can be solved through engineering (HS-ETS1-2). In the laboratory, students learn to work within engineering constraints as they strive to maximize efficiency (minimize energy loss) while designing and building devices with limited resources in a limited timeframe. Students can measure outputs and then refine their designs to maximize efficiency given constant inputs. As they make decisions, students need to keep in mind prioritized criteria and trade-offs (HS-ETS1-3). As a follow-up to the laboratory, students can explore the acceptability of different solutions to the global energy problem, taking into account social, cultural, and environmental impacts (HS-ETS1-3). Students can also use existing computer simulations to investigate the impact of different energy solutions (HS-ETS1-4).

IS4

Physics Instructional Segment 4: Waves and Electromagnetic Radiation

In this instructional segment, students build basic mathematical **models [SEP-2]** of waves, understand how these models relate to and predict certain properties of actual physical waves, and learn the influence of waves in the natural world as well as how waves are employed in a variety of technologies. Students learn how analog technologies encode information as superposition of waves (e.g., radio signals) while digital technologies encode information as waves pulses.

PHYSICS INSTRUCTIONAL SEGMENT 4: WAVES AND ELECTROMAGNETIC RADIATION

Guiding Questions

- How can we describe waves in a way that helps us predict their behavior?
- How have humans harnessed electromagnetic radiation to fuel innovations, both literally and figuratively?
- Is electromagnetic radiation dangerous?

Performance Expectations

Students who demonstrate understanding can do the following:

HS-PS4-1. Use mathematical representations to support a claim regarding relationships among the frequency, wavelength, and speed of waves traveling in various media. [Clarification Statement: Examples of data could include electromagnetic radiation traveling in a vacuum and glass, sound waves traveling through air and water, and seismic waves traveling through the Earth.] [*Assessment Boundary: Assessment is limited to algebraic relationships and describing those relationships qualitatively.*]

HS-PS4-2. Evaluate questions about the advantages of using a digital transmission and storage of information. [Clarification Statement: Examples of advantages could include that digital information is stable because it can be stored reliably in computer memory, transferred easily, and copied and shared rapidly. Disadvantages could include issues of easy deletion, security, and theft.]

HS-PS4-3. Evaluate the claims, evidence, and reasoning behind the idea that electromagnetic radiation can be described either by a wave model or a particle model, and that for some situations one model is more useful than the other. [Clarification Statement: Emphasis is on how the experimental evidence supports the claim and how a theory is generally modified in light of new evidence. Examples of a phenomenon could include resonance, interference, diffraction, and photoelectric effect.] [*Assessment Boundary: Assessment does not include using quantum theory.*]

PHYSICS INSTRUCTIONAL SEGMENT 4: WAVES AND ELECTROMAGNETIC RADIATION

HS-PS4-4. Evaluate the validity and reliability of claims in published materials of the effects that different frequencies of electromagnetic radiation have when absorbed by matter. [Clarification Statement: Emphasis is on the idea that photons associated with different frequencies of light have different energies, and the damage to living tissue from electromagnetic radiation depends on the energy of the radiation. Examples of published materials could include trade books, magazines, web resources, videos, and other passages that may reflect bias.] [*Assessment Boundary: Assessment is limited to qualitative descriptions.*]

HS-PS4-5. Communicate technical information about how some technological devices use the principles of wave behavior and wave interactions with matter to transmit and capture information and energy.* [Clarification Statement: Examples could include solar cells capturing light and converting it to electricity; medical imaging; and communications technology.] [*Assessment Boundary: Assessments are limited to qualitative information. Assessments do not include band theory.*]

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

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

Highlighted Science and Engineering Practices	Highlighted Disciplinary Core Ideas	Highlighted Crosscutting Concepts
[SEP-1] Asking Questions and Defining Problems [SEP-5] Using Mathematics and Computational Thinking [SEP-7] Engaging in Argument from Evidence [SEP-8] Obtaining, Evaluating, and Communicating Information	PS3.D: Energy in Chemical Reactions PS4.A: Wave Properties PS4.B: Electromagnetic Radiation PS4.C: Information Technologies and Instrumentation	[CCC-2] Cause and Effect: Mechanism and Explanation [CCC-4] Systems and System Models [CCC-7] Stability and Change Influence of Engineering, Technology, and Science on Society and the Natural World

CA CCSS Math Connections: A-SSE.1a–b, 3a–c; A.CED.4; MP.2, MP.4

CA CCSS for ELA/Literacy Connections: RST.11–12.1, 7, 8; RST.9–10.8; WHST.9–12.2a–e; WHST.11–12.8

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

According to the NGSS storyline:

> The Performance Expectations associated with the topic Waves and Electromagnetic Radiation are critical to understand how many new technologies work. As such, this disciplinary core idea helps students answer the question "How are waves used to transfer energy and send and store information?" The disciplinary core idea in PS4 is broken down into Wave Properties, Electromagnetic Radiation, and Information Technologies and Instrumentation. Students are able to apply understanding of how wave properties and the interactions of electromagnetic radiation with matter can transfer information across long distances, store information, and investigate nature on many scales. Models of electromagnetic radiation as either a wave of changing electric and magnetic fields or as particles are developed and used. Students understand that combining waves of different frequencies can make a wide variety of patterns and thereby encode and transmit information. Students also demonstrate their understanding of engineering ideas by presenting information about how technological devices use the principles of wave behavior and wave interactions with matter to transmit and capture information and energy. The crosscutting concepts of cause and effect; systems and system models; stability and change; interdependence of science, engineering, and technology; and the influence of engineering, technology, and science on society and the natural world are highlighted as organizing concepts for these disciplinary core ideas. In the PS4 performance expectations, students are expected to demonstrate proficiency in asking questions, using mathematical thinking, engaging in argument from evidence, and obtaining, evaluating and communicating information; and to use these practices to demonstrate understanding of the core ideas. (NGSS Lead States 2013f)

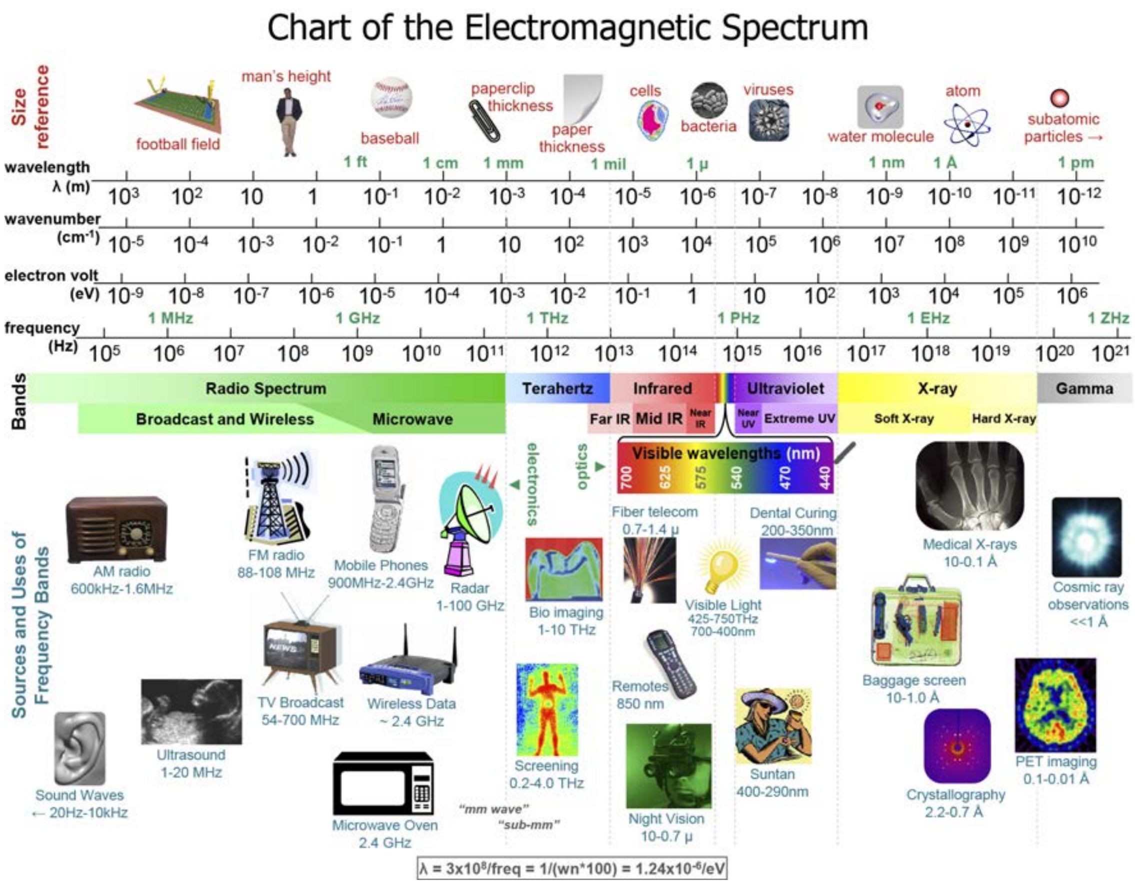
In many physics books, light, sound, and other wave phenomena are described as "ways energy is transmitted without an overall flow of matter." Such descriptions are important for understanding such things as the transmission of energy from nuclear reactions in the Sun across space to the photosynthetic cells of plants or the transmission of sound energy from a performer on stage through the air to listeners throughout an auditorium. A second aspect of light, sound, and other wave phenomena is also important, namely that they encode information and, hence, are a critical tool for how we learn about and interact with the world around us. Waves not only provide information to our natural senses, as stressed in earlier grades, but also for the tools and technologies that we build and use. Starting from telescopes and microscopes (optics and lenses) and going on to computers, cell phones, and ever more refined measurement and observation tools in science laboratories and hospitals, we have engineered sophisticated devices that rely on the properties of light and sound. In other words, the study of waves illustrates the **interdependence of science, engineering, and technology [CCC on nature of science]**. The science of waves has made it possible to develop myriad technologies, while the development of new technologies that sense waves has made it possible to make new discoveries in science.

Students started developing models of wave amplitude and wavelength in grade four (4-PS4-1A) and extended those models to include simple mathematical representations of waves in the middle grades (MS-PS4-1). In high school, students extend this model further to include **mathematical representations [SEP-5]** of waves, including relationships involving their speed and frequency.

At the high school level, students can describe a wave as a disturbance or oscillation that transmits energy without transmitting matter. Mechanical waves travel through a medium, temporarily deforming the material. Restoring forces caused by elastic properties in the medium then reverse this deformation. For example, sound waves in the atmosphere propagate when molecules in the air hit neighboring particles and then recoil to their original condition. These collisions prevent particles from traveling in the direction of the wave, ensuring that energy is transmitted without the movement of matter. The second type of wave, electromagnetic, does not require a medium for transmission.

Electromagnetic waves consist of periodic oscillations of electrical and magnetic fields. Electromagnetic waves can travel through empty space. The frequency (or conversely, the wavelength) of electromagnetic waves determines the properties of the waves. There is a spectrum of electromagnetic radiation from the lowest frequency radio waves to microwaves, infrared radiation, visible light, ultraviolet radiation, X-rays, and up to the highest frequency gamma rays (figure 8.42). Electromagnetic waves with different frequencies have different uses. Gamma rays are used to kill cancer cells in radiation therapy, X-rays are used to create noninvasive medical imagery, ultra-violet light is used to sterilize equipment, visible light is used for photography, infrared light is used for night vision, microwaves are used for cooking, and radio waves are used for communication. Plants capture visible electromagnetic radiation (sunlight) and use the energy to fix carbon into simple sugars during photosynthesis.

Figure 8.42. The Electromagnetic Spectrum



As students learn the physics of electromagnetic radiation, they also should learn the variety of applications that improve our quality of life, a few of which are illustrated in this diagram. *Source*: Southwestern Universities Research Association 2006
Long description of Figure 8.42.

Performance expectation HS-PS4-1 states that students should be able to "**use mathematical [SEP-5]** representations to support a claim regarding relationships among the frequency, wavelength, and speed of waves traveling in various media." For example, students should be able to evaluate the claim that doubling the frequency of a wave is accomplished by halving its wavelength. To evaluate such claims, students should be able to construct basic mathematical models of waves such as $v = f\lambda$ (where v = wave velocity, f = frequency, and λ=wavelength), given that $f = 1/T$ (where T = the period of the wave). Students should be able to solve for frequency, wavelength, or velocity given any of the other two variables. It is important that students realize that the equation for periodic waves is applicable to both mechanical and electromagnetic waves. For example, it can be used to describe seismic waves moving through different types of rock, sound waves traveling through air and water, visible light traveling through air and glass, and water waves moving through deep and shallow water.

Even though electromagnetic radiation can clearly be described using waves and its behavior in most situations can be predicted using this model, over the years scientists have discovered certain cases where light acts more like a collection of discrete particles than a wave. Students **obtain, evaluate, and communicate information [SEP-8]** pertaining to the wave/particle duality of electromagnetic radiation, which has been one of the great paradoxes in science (HS-PS4-3). As early as the seventeenth century, Christiaan Huygens proposed that light travels as a wave, while Isaac Newton proposed that it traveled as particles. This apparent paradox ultimately led to a complete rethinking of the nature of **matter and energy [CCC-5]**. Taken together, the work of Max Planck, Albert Einstein, Louis de Broglie, Arthur Compton, Niels Bohr, and many others suggests all particles also have a wave nature, and all waves have a particle nature.

Opportunities for ELA/ELD Connections

Students examine experimental evidence that supports the claim that light is a wave phenomenon, and **evidence [SEP-7]** that supports the claim that light is a particle phenomenon. After **analyzing and interpreting data [SEP-4]** from classic experiments on resonance, interference, diffraction, and the photoelectric effect, students should be able to **construct an argument [SEP-7]** defending the wave/particle model of light. The students write a well-developed argument focused on the claim that light is a wave phenomenon, including the introduction of the claim, an organization that sequences the claim, any counterclaims, reasons, and evidence, develop claim with relevant data, provide a conclusion that supports the argument presented, and use an objective tone and formal style. (Note: Some English learners hit a plateau in the development of English when they become functionally proficient or when their English is good enough to get by. Encourage these students to continue to develop their proficiency by asking them to expand and enrich their ideas verbally and in their writing.

CA CCSS for ELA/Literacy Standards: WHST.9–12.1
CA ELD Standards: ELD.PI.9–12.10

One of the primary pieces of evidence for the particle nature of light is the photoelectric effect, the observation that many metals emit electrons when light shines on them. If light acts as a wave, electrons should be emitted for any frequency of light as long as the amplitude is high enough (i.e., if the wave carries enough energy). Data, however, show that electrons are only dislodged for light above a certain threshold frequency regardless of the intensity of the light. This result suggests that light is actually made of discrete particles (photons). The visual intensity of light depends on the number of particles arriving in a given time, but an electron only gets dislodged when an individual photon crashes into the metal with energy greater than the energy that binds the electron to the metal. Each photon has energy (E) proportional to its frequency (f). Expressed algebraically, we now accept that $E = hf$ where h is Planck's constant (a physical constant from quantum mechanics). Students can make a physical **model [SEP-2]** of the photoelectric effect with water representing continuous waves of light energy and different size marbles and ball bearings representing different frequencies of discrete photons of light energy. Additional marbles gently taped to a tabletop represent the electrons bound to the metal. Under the wave model of light, the electron marbles should stay still for a tiny stream of water (low-intensity light), but will roll away if the water gets poured fast enough (high-intensity light). In the particle model of light, intense light can be represented by lots of particles being dropped down at once. If those particles are small like ball bearings, no individual particle has enough energy to dislodge the electron marbles. However, a single large marble (a low-intensity light at a high frequency) can dislodge an electron.

In physics, radiation simply means the emission of energy. In IS3, students created models of radiation related to nuclear processes and asked questions about possible health impacts of that radiation. In IS4, they examined electromagnetic radiation. Does it have possible health impacts as well? Students know that they can get sunburned from ultraviolet (UV) radiation, so it is natural for them to be concerned about the effects of other types of radiation like radio waves from cell phones or wireless Internet. Performance expectation HS-PS4-4 requires students to evaluate the validity and reliability of claims in published materials of the effects that different frequencies of electromagnetic radiation have when absorbed by matter. To meet this performance expectation, students can **obtain and evaluate information [SEP-8]** and arguments put forth in books, magazines, Web sites, and videos. While the damaging effects of high-energy gamma rays, X-rays, and UV rays are well documented, the potentially damaging effects of microwave radiation (which includes the frequencies used by most mobile phones) are much more questionable. Students apply their model of the particle nature of light from the photoelectric effect to evaluate these claims. Microwave photons are lower frequency and therefore lower energy than damaging UV light, so they do not have enough energy to break chemical bonds. Students know that they can sit beneath regular lights all day long and do not get a sunburn. Analogous to the photoelectric effect, microwaves, with even lower energy photons, are still absorbed by the body causing it to heat up. Could this slight heating cause health impacts? Students can read an article (for example, the UC Museum of Paleontology 2016 article "A Scientific

Approach to Life: A Science Toolkit" at https://www.cde.ca.gov/ci/sc/cf/ch8.asp#link46) about how to identify credible sources of scientific information in the popular media. Then, each student can search and find one Internet resource about the topic. Students then conduct a virtual gallery walk during which they copy and paste the resource into a collaborative Web document, and other students make digital comments on the document, highlighting and identifying which aspects of the resource make it more or less credible and where the text refers to scientific concepts from the course. (Students could also print the resources and post them around the room so that peers can comment on them using sticky notes for a physical gallery walk).

Many technological devices rely on electromagnetic radiation to communicate over long distances, but what properties of waves enables people to encode, transmit, and capture information? Students **obtain information [SEP-8]** about these devices and then apply their models of how electromagnetic radiation interacts with matter to create an explanation of how they work. Students must then synthesize their ideas and **communicate [SEP-8]** this information (HS-PS4-5). Students can focus on a single technology such as solar panels, medical imaging, digital or film photography, radio communication, wireless Internet, or many other devices and processes.

One example of how students might meet HS-PS4-5 would be for students to read a story about the historical discovery of X-rays. In 1895 the German physicist Wilhelm Röntgen discovered a high-energy, invisible form of light known as X-rays. Röntgen noticed that a fluorescent screen in his laboratory began to glow when a high-voltage fluorescent light was turned on, even though the fluorescent screen was blocked from the light. Röntgen hypothesized that he was dealing with a new kind of ray that could pass through some solid objects, such as the screen surrounding his light. Röntgen had an engineering mind and realized that there could be practical applications of this newly discovered form of radiation, particularly when he made an X-ray image of his wife's hand, showing a silhouette of her bones. Röntgen immediately communicated his discovery through a paper and a presentation to the local medical society, and the field of medical imaging was born. Students then must find a way to **communicate [SEP-8]** information like the story of how X-rays work in a poster or short fact sheet that includes labeled diagrams (pictorial **models [SEP-2]**) illustrating key interactions between waves and matter. They can then orally present their posters to the class.

HS-PS4-5 requires that students be able to provide qualitative **explanations [SEP-6]** for how X-rays and/or other electromagnetic radiation interact with matter. Students do not need to discuss advanced topics such as Compton or Rayleigh scattering, but they should be able to describe how electromagnetic radiation interacts differentially with matter. For example, X-rays can penetrate soft tissue such as muscles and fat, but are blocked by the inorganic materials in bones, providing a silhouette image of the bones.

Engineering Connection: Using Waves to Transmit Information

Performance expectation HS-PS4-5 is closely tied to the ETS standard HS-ETS1-2: "Design a solution to a complex real-world problem by breaking it down into smaller, more manageable problems that can be solved through engineering." Students may meet both the physical science and the ETS performance expectations by designing their own devices where electromagnetic waves interact with matter to transmit and capture information.

As students research different technologies, they should also **develop models [SEP-2]** of how these devices encode information (not just transmit and receive energy). While Heinrich Hertz is probably the first engineer to develop a radio transmitter, Guglielmo Marconi is usually credited as the father of radio because he harnessed radio waves to transmit information. Hertz himself is credited with stating that electromagnetic radiation is "of no use whatsoever" (Norton 2000, 83). Engineers have learned how to encode information on radio waves in a variety of manners, including pulsating transmission to send Morse code, modulating frequency in FM radio transmission, modulating amplitude in AM radio transmission, and propagating discrete pulses of voltage in digital data transmission. Wireless transmission has revolutionized human communication and is at the heart of the Information Revolution.

Performance expectation HS-PS4-2 requires students to "evaluate questions about the advantages of using digital transmission and storage of information." By **analyzing and interpreting data [SEP-4]** about digital information technologies and similarly purposed analog technologies, students can meet this performance expectation. By comparing and contrasting such features as data transmission, response to noise, flexibility, bandwidth use, power usage, error potential, and applicability, students can assess the relative merits of digital and analog technologies. This performance expectation requires students to ponder the influence of those technologies that have shaped our modern world. As students evaluate digital transmission and storage of information, they begin to understand the **influence of science, engineering, and technology on society and the natural world [CCC about the nature of science]**, learning how scientists and engineers have applied physical principles to achieve technological goals and how the resulting technologies have gained prominence in the marketplace and have influenced society and culture.

Concept Map of Physics Disciplinary Core Ideas

In meeting the performance expectations selected for this instructional segment, instructors must introduce some DCIs as well as build on the DCIs introduced in the middle grades. Figure 8.43 shows a concept map with the relationships between DCIs introduced during the middle grades and high school level. This concept map is *not* a conceptual flow with a specific order or sequence, nor is it a comprehensive illustration of all ideas that should be taught in the courses. Nor does it illustrate interdisciplinary connections that should be drawn. It may, however, be helpful in identifying how DCIs build from middle grades to high school and relate to one another. This map is explicitly placed at the end of the unit so that readers view it with a full appreciation of how these DCIs must be explored using the other two dimensions of CA NGSS as outlined in the course above. The concept map is limited only to DCIs, so even if students had a full appreciation of the content of these maps, they also need practice in doing science and engineering (SEPs) and identifying big-picture relationships to other disciplines (CCCs).

Figure 8.43. Relationship of DCIs in Physics including High School and Middle Grades Content

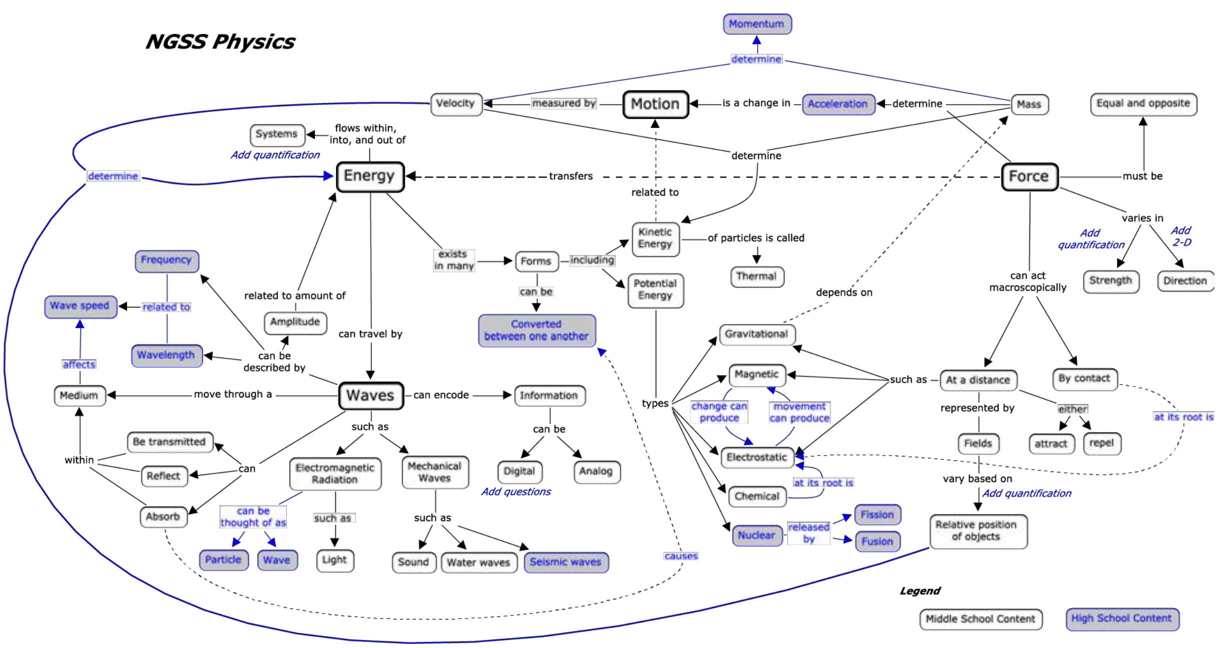


Diagram by M. d'Alessio

Long description of Figure 8.43.

High School Four-Course Model: Earth and Space Sciences

Introduction to the Earth and Space Sciences Course

According to the Next Generation Science Standards:

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

By the time students enter high school, they are able to develop a sophisticated understanding of processes that shape the world around them. Earth science is a central part of the CA NGSS, and this document lays out a rigorous high school laboratory course that addresses the new standards.

The emphasis within the CA NGSS is on the processes that shape our Earth. These processes are best understood when thinking about the Earth as a "system of systems." A **system [CCC-4]** includes component parts, interactions between those parts, and exchanges of energy and matter to the world outside the system. Each of the following Earth systems is shaped by its internal workings and its interactions with the other systems:

- Atmosphere: gases around the Earth (i.e., our air)
- Hydrosphere: all the water (sometimes ice is considered separately as the cryosphere)
- Geosphere: inorganic rocks and minerals
- Biosphere: all life

- Anthrosphere: humanity and all of its creations (This sphere is not specifically mentioned in the *NRC Framework* because it is primarily part of the biosphere. Separating this sphere out emphasizes the significant influences humans have on the rest of Earth's systems and is consistent with the Environmental Principles and Concepts [EP&Cs] that are part of the CA NGSS.)

The CA NGSS has titled this discipline Earth and space sciences (ESS) to emphasize that while Earth exists as a singular planet, its systems are strongly influenced by interactions with the broader universe.

While the DCIs explore a range of interactions, the NGSS authors state that interactions between the anthrosphere and the other **systems [CCC-4]** should always be a large part of the discussion: "The performance expectations strongly reflect the many societally relevant aspects of ESS (resources, hazards, environmental impacts) with an emphasis on using engineering and technology concepts to design solutions to challenges facing human society" (NGSS Lead States 2013c).

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. Many of the phenomena selected illustrate California's EP&Cs, which are an essential part of the CA NGSS (see chapter 1 of this framework). However, the phenomena chosen for this statewide document will not be ideal for every classroom in a state as large and diverse as California. When bringing the CA NGSS to their classroom, Earth science teachers have great opportunities to make the subject matter regionally relevant. Coastal communities may wish to focus on different spheres of interaction than farming communities in the Central Valley. Despite these regional differences, a large fraction of California's students live in densely urban communities where ties to the natural environment are less apparent. When describing possible directions for meeting the performance expectations, this chapter identifies options most relevant for urban youth and also includes an entire segment to explore urban geoscience issues.

This example course is divided into instructional segments centered on questions about observations of a specific phenomenon. Different phenomena require different amounts of investigation to explore and understand, so each instructional segment should take a different fraction of the school year. As students achieve the performance expectations within the instructional segment, they uncover DCIs from Earth and space sciences and engineering. Students engage in multiple practices in each instructional segment, not only those explicitly indicated in the performance expectations. Students also focus on one or two CCCs as tools to make sense of their observations and investigations; the CCCs are recurring themes in all disciplines of science and engineering and help tie these seemingly disparate fields together.

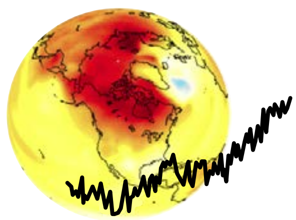
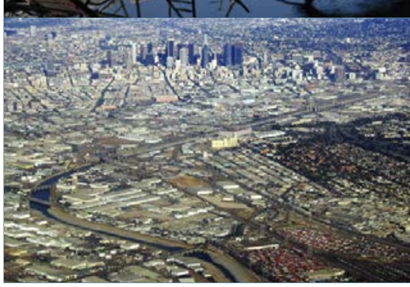
This chapter clarifies the general level of understanding required to meet each performance expectation, but the exact depth of understanding expected of students depends on this course's place in the overall high school sequence. Teachers could modify the content and complexity so that the course serves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

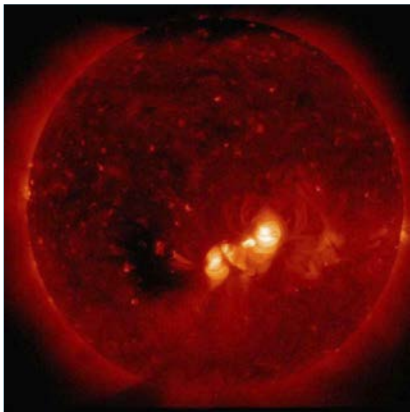
Example Course Mapping for an Earth and Space Sciences Course

The CA NGSS DCIs for ESS are intentionally organized by scale and sequence: from the beginning of the universe toward the present and from the inside of the Earth to the outside. While this sequence is an excellent framework for organizing the present-day state of knowledge about ESS, it does not fully reflect the process of scientific discovery nor is that sequence consistent with the stated emphasis to "design solutions to challenges facing human society" (NGSS Lead States 2013c). While topics such as the origin of our universe inspire great curiosity, their solutions have less direct and tangible impact on human lives. A large focus of this course is on energy and climate issues (table 8.8; figure 8.44). The course begins with a tangible and relevant example of a phenomenon that illustrates Earth's interacting systems, the formation and extraction of fossil fuels such as oil and gas. That instructional segment then motivates the study of climate change, IS2, because it illustrates a direct **cause and effect [CCC-2]** relationship between human activities and the natural climate system. Subsequent instructional segments explore other interactions within Earth's systems and then revisit the issue of how climate change could impact those particular Earth systems.

Despite this overall emphasis on the interaction between Earth systems and humans today, the course ends with two instructional segments that discuss the Earth's place in the universe. These instructional segments address fundamental questions related to our origin and emphasize that the human desire to understand is also an essential part of scientific practice.

Table 8.8. Overview of Instructional Segments for High School Earth and Space Sciences

	**1 Oil and Gas** Oil and gas are resources that allow us to harness energy from ancient life but also cause us to unleash ancient carbon into the atmosphere.
	**2 Climate** Data reveal that carbon in our atmosphere has a big impact on global temperatures and climate. Humans, in turn, have a big impact on carbon in our atmosphere.
	**3 Mountains, Valleys, and Coasts** Water shapes and sculpts our landscapes. The process is sometimes thought of as slow and steady but often occurs as catastrophic events when driving forces exceed resisting forces.
	**4 Water and Farming** California depends on its precious water resources to sustain its people and its farms.
	**5 Causes and Effects of Earthquakes** Earthquakes and motion at the surface give clues to what goes on deep inside the Earth.
	**6 Urban Geo-science** The majority of California residents live in urban areas that are shaped by the natural environment. Our urban expansion in these areas requires that we also think about how human activity in turn affects the natural environment.



7 Star Stuff

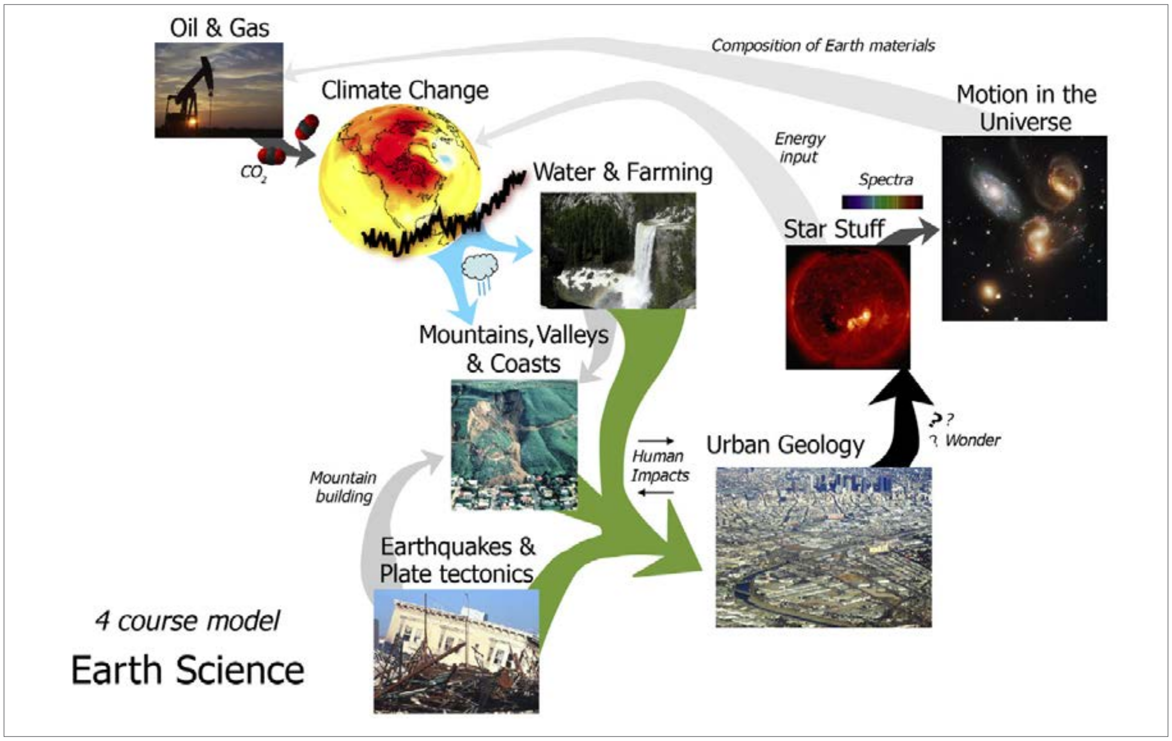
Everything on Earth is made of "star-stuff." Earth depends on its closest star, the Sun, for almost all its energy. The light from all stars provides clues about what they are and how they shine.

8 Motion in the Universe

The structure of objects in our universe and the motions of all bodies within it are driven by the competition between the explosive force of the Big Bang and the attractive force of gravity.

Sources: Kounce 2008; adapted from Geophysical Fluid Dynamics Laboratory 2007; United States Geological Survey/Photo by R.L Schuster 2004; Seigmund 2006; United States Geological Survey/Photo by Charles E. Meyer 1999; Reiring 2009; National Astronomical Observatory of Japan, Institute of Space and Astronautical Science/Japan Aerospace Exploration Agency 2006; NASA, ESA, and the Hubble SM4 ERO Team/Space Telescope Science Institute 2009

Figure 8.44. Conceptual Flow of Instructional Segments in High School Earth and Space Sciences Course



Sources: Kounce 2008; adapted from Geophysical Fluid Dynamics Laboratory 2007; Seigmund 2006; United States Geological Survey/Photo by R.L Schuster 2004; United States Geological Survey/Photo by Charles E. Meyer 1999; Reiring 2009; National Astronomical Observatory of Japan, Institute of Space and Astronautical Science/Japan Aerospace Exploration Agency 2006; NASA, ESA, and the Hubble SM4 ERO Team/Space Telescope Science Institute 2009
Long description of Figure 8.44.

IS1

Earth and Space Sciences Instructional Segment 1: Oil and Gas

Without energy, California's transportation and commerce would come to a screeching halt. More than half of our electricity and almost all of our transportation is currently provided by fossil fuels. California holds about 10 percent of all the proven oil reserves in the United States and is currently the third largest oil producing state in the country. This instructional segment explores where those fuels came from and the effects that extracting and burning them have on our global climate.

EARTH AND SPACE SCIENCES INSTRUCTIONAL SEGMENT 1: OIL AND GAS

Guiding Questions

- Where do oil and gas come from?
- How are gas and oil deposits related to carbon cycling and Earth systems?
- What is the impact of driving cars and using other fossil fuels on the Earth systems?

Performance Expectations

Students who demonstrate understanding can do the following:

HS-ESS2-1. Develop a model to illustrate how Earth's internal and surface processes operate at different spatial and temporal scales to form continental and ocean-floor features. [Clarification Statement: Emphasis is on how the appearance of land features (such as mountains, valleys, and plateaus) and sea-floor features (such as trenches, ridges, and seamounts) are a result of both constructive forces (such as volcanism, tectonic uplift, and orogeny) and destructive mechanisms (such as weathering, mass wasting, and coastal erosion).] [*Assessment Boundary: Assessment does not include memorization of the details of the formation of specific geographic features of Earth's surface.*] (Introduced here, but revisited from in IS3 and again in IS4)

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

EARTH AND SPACE SCIENCES INSTRUCTIONAL SEGMENT 1: OIL AND GAS

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

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

Highlighted Science and Engineering Practices	Highlighted Disciplinary Core Ideas	Highlighted Crosscutting Concepts
[SEP-2] Developing and Using Models [SEP-7] Engaging in Argument from Evidence	ESS2.A: Earth Materials and Systems ESS2.B: Plate Tectonics and Large-Scale System Interactions ESS2.D: Weather and Climate ESS2.E: Biogeology ESS3.A: Natural Resources	[CCC-5] Energy and Matter: Flows, Cycles, and Conservation [CCC-7] Stability and Change

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

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

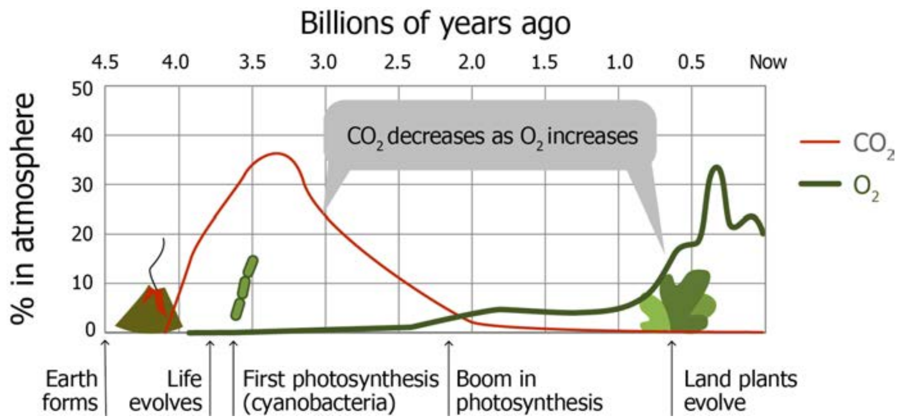
CA CCSS Math Connections: N-Q.1–3; MP.2, MP.4

CA CCSS for ELA/Literacy Connections: WHST.9–12.1a–e

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

Understanding the importance of fossil fuels begins with an understanding of the interactions among life, the atmosphere, and rocks over geologic time (ESS2.A, ESS2.E). When asked what the Earth might have looked like when it first formed 4.6 billion years ago, students' images might be informed by prior knowledge that may include nonscientific sources and may not be consistent with the scientific understanding that Earth was lifeless. Teachers may need to explicitly discuss existing ideas and their sources before beginning instruction. When Earth first formed, its interior was still very hot and its interior rapidly convected (ties to HS-ESS2-3). Hot magma rising up is part of convection, so rapid convection caused volcanic activity in Earth's early history. When these volcanoes erupted, they released large amounts of gas that built up our early atmosphere with CO_2. Around 3.4 billion years ago, organisms evolved that could perform photosynthesis, a process which disassembles CO_2. This marked the beginning of life's interaction with the global carbon cycle, an example of Earth's interacting **system [CCC-4]** of systems (biosphere interacts with atmosphere). In the CA NGSS, students must use evidence like the graph in figure 8.45 and their model of photosynthesis (HS-LS1-5) to construct an **argument [SEP-7]** that life has been an important influence on other components of the Earth system (HS-ESS2-7). Early on, ocean water and chemical reactions with rock material absorbed much of the oxygen that plants produced. By examining records from rock layers, students can reconstruct aspects of Earth's early history (HS-ESS1-6). They can see evidence of biosphere-geosphere interactions in deep red rock layers that accumulated at the bottom of the ancient ocean called "banded iron" (because they are rich in red iron oxides). The oldest banded iron formations provide evidence of when plants first evolved, and thick deposits of banded iron about 2.4–1.9 billion years ago reveal another major **change [CCC-7]**—the expansion of multicellular cyanobacteria and a boom in photosynthesis.

Figure 8.45. CO_2 and Earth's Atmosphere Over Time



Concentrations of CO_2 and O_2 in Earth's atmosphere over its history. Dramatic changes happened as plants used CO_2 to grow biomass and released O_2 during photosynthesis. Diagram by M. d'Alessio, based on data from Holland 2006
Long description of Figure 8.45.

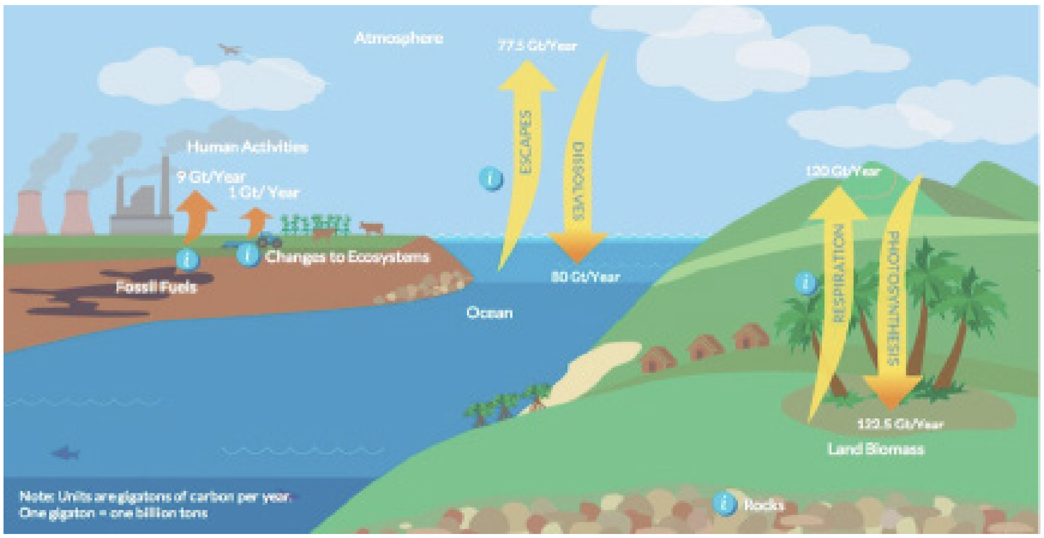
The exchange of carbon between the atmosphere and the biosphere is just one of many important interactions between Earth's **systems [CCC-4]** that involve the movement of carbon (EP&C III). In fact, one of the few additions that California made in adopting the CA NGSS was to add this sentence to the Clarification Statement for Performance Expectation HS-ESS2-6: "The carbon cycle is a property of the Earth system that arises from interactions among the hydrosphere, atmosphere, geosphere, and biosphere." Students are already familiar with cycles of matter within a system from the middle grades investigation of the water cycle (5-LS2-1, MS-ESS2-4). Scientists track the movement of carbon atoms through the carbon cycle much like they track the movement of water molecules through the water cycle. In both cases, scientists think about the **cycle of matter [CCC-5]** within a closed **system [CCC-4]** because at this point in Earth's history, very little water or carbon is leaving the planet or arriving from space. We simply need to track the movement of the matter that is already here.

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

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

Various representations exist for the carbon cycle, including simple diagrams like figure 8.46. Interactive animations (WGBH n.d.), hands-on experiments (see Oregon Museum of Science and Industry https://www.cde.ca.gov/ci/sc/cf/ch8.asp#link47), and kinesthetic activities build on the static illustrations to help students develop conceptual **models [SEP-2]** of the reservoirs and processes by which carbon is exchanged between these reservoirs.

Figure 8.46. The Carbon Cycle



Source: WGBH n.d.
Long description of Figure 8.46.

For example, students can develop a simple physical **model [SEP-2]** of the atmosphere–ocean **system [CCC-4]** by adding pH indicator to water in a closed container (see IS1 of the chemistry course). Students can use this model to **investigate [SEP-3]** what happens as a plant grows, a candle burns, or a person exhales through a straw into the water. They notice that pH changes as CO_2 from these sources interacts with the water to form carbonic acid. This same chemical reaction happens at the global scale with interactions between the atmosphere and the hydrosphere (PS1.B; IS6 of the chemistry course), making Earth's oceans one of the biggest reservoirs of carbon on the planet (see table 8.9. Carbon Reservoirs and Atmospheric Flows for the relative sizes of different reservoirs). Students will **explain [SEP-6]** how the concentration of CO_2 in the atmosphere affects the rate of the chemical reaction in HS-PS1-5 and the final concentration of acid in the ocean is an example of a system in equilibrium as explored in HS-PS1-6. Because the system is near equilibrium, massive amounts of carbon (~80 Gt) are absorbed into the ocean while massive amounts are also released back to the atmosphere. These opposite flows are similar in magnitude but do not balance out—the ocean absorbs about 2.5 Gt/yr more of carbon from the atmosphere. Then it releases back, causing the ocean to become more acidic. An acidic ocean can **cause [CCC-2]** major damage to plankton (which form the base of the ocean food chain, LS2.A, LS2.B) and coral reefs (which host a large portion of the ocean's biodiversity), both of which **affect [CCC-2]** sea life (LS3.C). Scientists use complex computer models to calculate the expected changes in ocean chemistry based on different human activities, and the CA NGSS pushes students to use simple computer representations of **models [SEP-2]** to illustrate the relationships between different Earth **systems [CCC-4]** and to **quantify [CCC-3]** how human activities change these systems (HS-ESS3-6; see IS2 for examples).

Table 8.9. Carbon Reservoirs and Atmospheric Flows

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

Table by Dr. Art Sussman, courtesy of WestEd

Table 8.9 also reveals that the single largest reservoir of carbon is not in the air or water, but in rocks. How does it get there? After students learn about the chemical composition of life (LS1.C), they are able to explain why carbon is so important for so many of life's **systems [CCC-4]** (HS-LS1-6). Living organisms are therefore a large reservoir of carbon. When those organisms die, the carbon stored in their bodies can accumulate in layers that are buried over geologic time. Students developed models of sedimentary rock formation as part of a broader rock cycle in the middle grades (MS-ESS2-1). In high school, students will connect that model to the processes that drive the cycle (HS-ESS2-1 and HS-ESS2-3) in IS3 and IS4. Just like students tracked materials through the rock cycle in the middle grades, they will track carbon through a cycle in this instructional segment.

Heat and pressure caused by burial speed up chemical reactions within organic material embedded in rocks, slowly reorganizing the carbon and other elements into new, easily combustible molecules that we call fossil fuels, including oil (petroleum) and natural gas (including methane). To ensure that students see the connection between past life and oil formation, students can draw the stages of oil formation to summarize an article presented in writing (National Energy Education Development Project 2012a). Extracting oil and gas from deep within the Earth and burning it harnesses energy that ancient plants and animals collected millions of years ago and that has been stored as chemical potential energy in materials trapped underground for millions of years. These materials are very valuable for generating electricity, fueling our vehicles, and generally enabling modern society to thrive. Unfortunately, fossil fuels form very slowly and only under specific conditions and are therefore considered "nonrenewable" because we consume them much more rapidly than they form. Access to fossil fuels occurs in specific places on Earth, and California has large deposits.

Opportunities for ELA/ELD Connections

Have students select and read a current article, from a scientific site or publication, about the different stages of oil formation and what it means to be a nonrenewable fuel source. Have students develop and use some type of note-taking guide based on the organization of the topic and subtopics in the article (cause/effect, Cornell notes, or summarizing key ideas using critical vocabulary) or a reading annotation system (highlighting main ideas or claims, underlining supporting evidence, circling critical vocabulary, and placing a question mark by unknown content).

CA CCSS for ELA/Literacy Standards: RST.9–12.2, 4, 5

CA ELD Standards: ELD.PI. 9–12.6

In the process of releasing **energy [CCC-5]**, burning fossil fuels also releases carbon into today's atmosphere that had been removed from the atmosphere by ancient plants and animals and trapped underground for millions of years. The release of carbon occurs when CO2 forms during combustion, which is one of the reaction types that students should be able to explain in HS-PS1-2. Students' quantitative **models [SEP-2]** of the carbon cycle must therefore include some measures of this human impact and its relative contribution to the planet's overall carbon budget. Human activities are, as of 2014, adding about 10 gigatons of carbon per year to the atmosphere, primarily from burning of fossil fuels. This means that our anthrosphere is adding more net carbon to the atmosphere than any of the other Earth **systems [CCC-4]**. Humans annually emit roughly 135 times more carbon than volcanoes, which originally supplied Earth's early atmosphere with a rich concentration of CO_2 (Gerlach 2011). Students will build on this understanding of both the natural cycling of carbon and their own impact on the carbon cycle in the next instructional segment about global climate.

IS2 Earth and Space Sciences Instructional Segment 2: Climate

The topic of global climate change offers an excellent opportunity to explore the concept of planet Earth as a system (ESS2.A) and to apply science and engineering practices to a very important and highly visible societal issue. While the details of global climate change are complex and technical, the underlying science is fundamentally simple and has been known for a long time. The main ideas relate to

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

EARTH AND SPACE SCIENCES INSTRUCTIONAL SEGMENT 2: CLIMATE

Guiding Questions

- What regulates weather and climate?
- What effects are humans having on the climate?

Performance Expectations

Students who demonstrate understanding can do the following:

HS-ESS2-2. Analyze geoscience data to make the claim that one change to Earth's surface can create feedbacks that cause changes to other Earth systems. [Clarification Statement: Examples should include climate feedbacks, such as how an increase in greenhouse gases causes a rise in global temperatures that melts glacial ice, which reduces the amount of sunlight reflected from Earth's surface, increasing surface temperatures and further reducing the amount of ice. Examples could also be taken from other system interactions, such as how the loss of ground vegetation causes an increase in water runoff and soil erosion; how dammed rivers increase groundwater recharge, decrease sediment transport, and increase coastal erosion; or how the loss of wetlands causes a decrease in local humidity that further reduces the wetland extent.]

EARTH AND SPACE SCIENCES INSTRUCTIONAL SEGMENT 2: CLIMATE

HS-ESS2-4. Use a model to describe how variations in the flow of energy into and out of Earth's systems result in changes in climate. [Clarification Statement: Examples of the causes of climate change differ by timescale, over 1-10 years: large volcanic eruption, ocean circulation; 10-100s of years: changes in human activity, ocean circulation, solar output; 10-100s of thousands of years: changes to Earth's orbit and the orientation of its axis; and 10-100s of millions of years: long-term changes in atmospheric composition.] [*Assessment Boundary: Assessment of the results of changes in climate is limited to changes in surface temperatures, precipitation patterns, glacial ice volumes, sea levels, and biosphere distribution.*]

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

HS-ESS3-2. Evaluate competing design solutions for developing, managing, and utilizing energy and mineral resources based on cost-benefit ratios.* [Clarification Statement: Emphasis is on the conservation, recycling, and reuse of resources (such as minerals and metals) where possible, and on minimizing impacts where it is not. Examples include developing best practices for agricultural soil use, mining (for coal, tar sands, and oil shales), and pumping (for petroleum and natural gas). Science knowledge indicates what can happen in natural systems—not what should happen.]

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

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

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

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

EARTH AND SPACE SCIENCES INSTRUCTIONAL SEGMENT 2: CLIMATE

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

Highlighted Science and Engineering Practices	Highlighted Disciplinary Core Ideas	Highlighted Crosscutting Concepts
[SEP-1] Asking Questions and Defining Problems [SEP-2] Developing and Using Models [SEP-4] Analyzing and Interpreting Data [SEP-5] Using Mathematics and Computational Thinking [SEP-7] Engaging in Argument from Evidence	ESS1.B: Earth and the Solar System ESS2.A: Earth Materials and Systems ESS2.D: Weather and Climate ESS3.A: Natural Resources ESS3.D: Global Climate Change ETS1.A: Defining and Delimiting Engineering Problems ETS1.B: Developing Possible Solutions	[CCC-2] Cause and Effect: Mechanism and Explanation [CCC-4] Systems and System Models [CCC-5] Energy and Matter: Flows, Cycles, and Conservation [CCC-7] Stability and Change Influence of Science, Engineering, and Technology on Society and the Natural World Connections to Nature of Science Science Addresses Questions About the Natural and Material World

Highlighted California Environmental Principles and Concepts:

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

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

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

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

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

CA CCSS Math Connections: N-Q.1–3; MP.2, MP.4

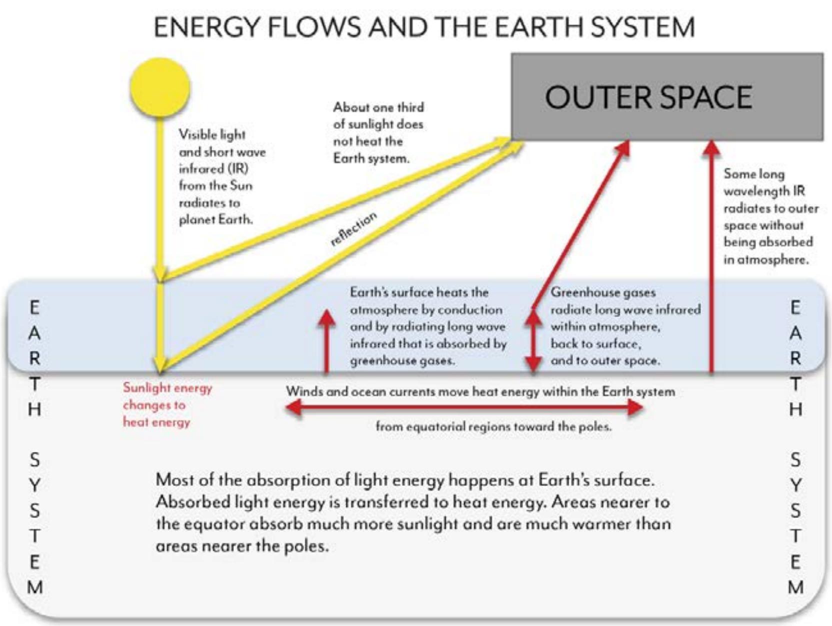
CA CCSS for ELA/Literacy Connections: SL.11–12.5; RST.11–12.1, 2, 7, 8

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

The performance expectations in this instructional segment build on significant work on DCIs related to weather and climate (ESS2.D) in the middle grades standards in which students learned that ocean and atmospheric currents are the equivalent of Earth's circulation system, transferring heat from the warm equator towards the cooler poles and bringing the planet closer to thermal balance (MS-ESS3-4). Students have also learned about the role that moving air masses play in determining short-term weather (MS-ESS2-5). They have been introduced to climate change and that global average temperatures have risen in the last century and have investigated possible causes (MS-ESS2-6). In this instructional segment they must delve into a more sophisticated understanding of Earth's **energy [CCC-5]** balance and its relationship to the global carbon **cycle [CCC-5]**.

The crosscutting concept of **systems [CCC-4]** is crucial to understanding Earth's climate. When scientists think about a system, they need to consider the **energy and matter [CCC-5]** that flow into or out of the system, as well as the inner workings of the system. In some systems, it is hard to decide where to draw the boundaries between what is considered inside the system and what is considered outside, but Earth's climate does not present such a challenge if we consider the entire planet as a system. Earth is somewhat isolated out in space, with relatively little matter entering or leaving the planet. **Energy [CCC-5]**, however, flows into and out of the Earth (figure 8.47).

Figure 8.47. Energy Flows in the Earth System



Energy flows in the Earth system, an illustration of a systems model. Diagram by Dr. Art Sussman, courtesy of WestEd.
Long description of Figure 8.47.

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

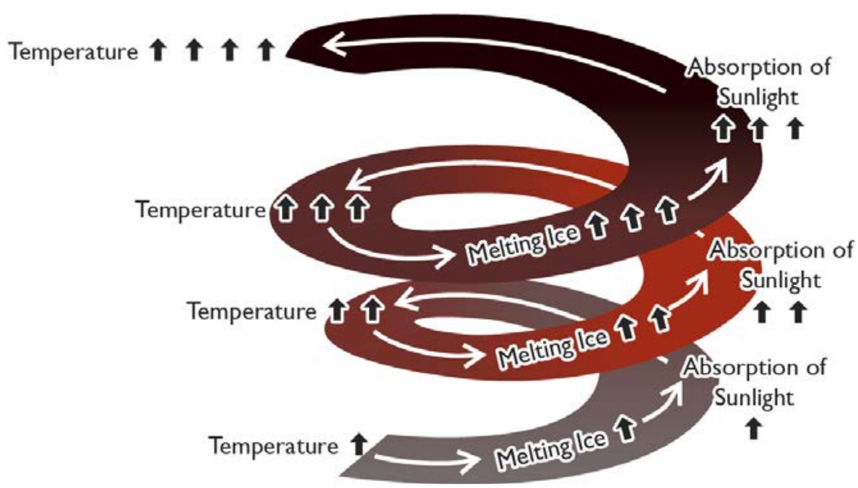
Earth's **energy [CCC-5]** input comes almost entirely from the Sun. While there is a small amount of radioactive decay within Earth's interior that generates heat, the flow of solar energy to Earth's surface is about 4,000 times greater than the flow of energy from Earth's interior to its surface. Relatively small changes in the solar input can result in an ice age or the melting of all of Earth's ice, much like the sudden arrival of a large group at an amusement ride can cause the line to quickly grow longer. The line will stabilize at this new length (without continuing to grow) as long as the influx of people returns back to its original rate. Planets can do the same thing, maintaining their temperature at a new value after a temporary disturbance.

Most of the sunlight that reaches Earth is absorbed and transformed to thermal **energy [CCC-5]**. If there were no atmosphere to hold that energy, it would radiate right back into space as infrared radiation (like an unpopular amusement park ride where people get on as soon as they arrive because there is no line). Gases in the atmosphere, such as CO_2, absorb infrared energy heading into space and **cause [CCC-2]** it to remain within the Earth system for a longer period of time. Because these gases have the same effect as a greenhouse where heat is trapped inside the system, gases like CO_2 are referred to as greenhouse gases. Calculations by scientists show that if Earth had no greenhouse gases, its surface temperature would be near 0°F (or -18°C) instead of its current value of a much warmer 59°F (15°C). The energy coming into the Earth is still balanced almost exactly by what is leaving the planet but there is enough heat trapped in the system to allow life to thrive (like the amusement park ride whose line is always the same length).

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

Amusement parks and planets are **systems [CCC-4]** with complicated inner workings. When lines for one ride at an amusement park get too long, visitors inside the park may respond by going to another ride or park operators may add additional workers or cars to help move people through more quickly. Similar changes happen in Earth's system of systems. While the greenhouse effect seems like a simple **cause and effect [CCC-2]** relationship viewed from outside the system, interactions *within* the system can often give rise to more complicated chains of cause and effect referred to as *feedbacks*. Climate scientists are particularly concerned about feedback effects that could increase the amount and rate of global climate change. One example is that global warming is clearly reducing the amount of ice on our planet (figure 8.48). Glaciers around the world are shrinking in size and even disappearing. The amount of ice covering the ocean in summer and fall is also shrinking. As the ice melts, the surface beneath it is darker in color and absorbs more incoming sunlight. More absorption causes more heating, and this heating causes even more absorption of sunlight. This kind of feedback loop amplifies or reinforces the change, and the distinction between **cause and effect [CCC-2]** begins to blur as each effect causes more change. The clarification statements in the CA NGSS and many scientists use the term *positive feedback*, but this term should be replaced because it leads to confusion—many *reinforcing feedbacks* have very negative outcomes.

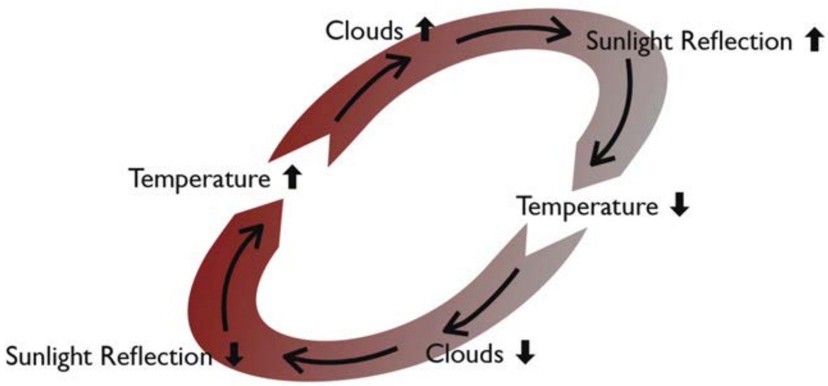
Figure 8.48. A Reinforcing Feedback in Earth's Climate



A reinforcing feedback in Earth's climate system. As the planet warms, more ice will melt, which will expose darker ground surfaces that absorb more sunlight, which will in turn make temperatures rise even more. Diagram by M. d'Alessio and A. Sussman.
[Long description of Figure 8.48.]

A *counterbalancing feedback loop* reduces the amount of change (figure 8.49). For example, warmer temperatures cause more water to evaporate, which enables more clouds to form. Since clouds reflect sunlight back into space, more clouds cause more incoming solar energy to be reflected before it has a chance to be absorbed by the planet. This causes decreasing global temperatures. More warming could cause more cloud formation and reflection, which would then lead to less warming again.[7] These changes are opposite and can balance each other out.

Figure 8.49. A Counterbalancing Feedback in Earth's Climate System



Temperature changes cause changes to the number of clouds because of evaporation. Clouds, in turn, reflect light. Diagram by M. d'Alessio and A. Sussman.
Long description of Figure 8.49.

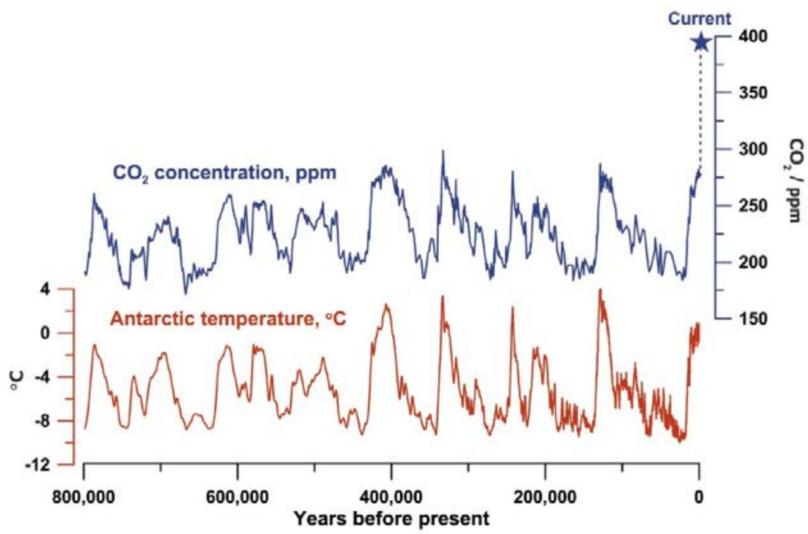
Scientists discover these complicated interactions between different components of Earth's **systems [CCC-4]** by looking for trends and **patterns [CCC-1]** in climate data. The CA NGSS have a strong emphasis on data analysis, especially in the sections related to weather and climate:

> An important aspect of Earth and space science involves making inferences about events in Earth's history based on a data record that is increasingly incomplete th[e] farther you go back in time … . Students can understand the analysis and interpretation of different kinds of geoscience data [that] allow students to construct explanations for the many factors that drive climate change over a wide range of time scales. (NGSS Lead States 2013c)

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

Some of the strongest **evidence [SEP-7]** about our changing climate comes from ice-core records (figure 8.50). As snow accumulates over time in glaciers around the globe, it traps both the water that recently fell as precipitation and air bubbles. These air bubbles act as tiny time capsules that allow scientists to study actual samples of the ancient atmosphere. Since snow and ice build up seasonally, the timing of each layer of ice and its trapped air bubbles can be counted like tree rings. Scientists make detailed chemical analyses of the water to reconstruct the global average temperature.[8]

Figure 8.50. Temperature and Carbon Dioxide Over the Last 800,000 Years



Source: The Royal Society 2014
Long description of Figure 8.50.

The temperature record from the last half-million years reveals some dramatic **patterns [CCC-1]** as temperatures go up and down with a periodicity of about 100,000 years, each low temperature an ice age (NOAA 2015). When students examine such data, they should be able to **ask questions [SEP-1]** about which parts of the climate **system [CCC-4]** might have **caused [CCC-2]** these changes. If students compare temperature reconstructions with reconstructions of the amount of **energy [CCC-5]** received from the Sun (which varies as the Earth's orbit wobbles and the Sun's energy output changes cyclically over time), they will discover that the data sets have a similar **pattern [CCC-1]**: many warm periods in the ice core data correspond to periods of higher solar energy input (EP&C II). This seems quite

8. Details of how this isotopic analysis provides a proxy for global temperature is beyond the scope of high school performance expectations, but is a fascinating example of physics, chemistry, and Earth science working together.

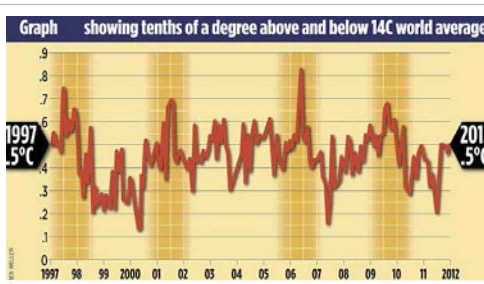
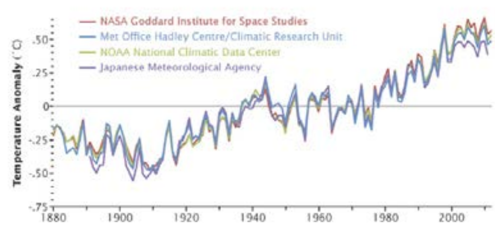
reasonable because the Sun's input should influence our temperature. However, there are also time intervals where the Earth was hot that do not correspond to high solar energy. The **pattern [CCC-1]** in the history of the concentration of CO_2 in Earth's atmosphere and temperatures is very similar; the two are highly correlated. This correlation is a key piece of **evidence [SEP-7]** that CO_2 also plays a role in affecting Earth's temperature. In a classroom, this correlation can motivate a discussion of Earth's energy budget and the greenhouse effect.

Earth and Space Science Snapshot 8.9: Letters to the Editor and Evaluating Climate Change Graphs

Anchoring phenomenon: Two news stories about the same scientific research have different headlines and are supported by different graphs of the same data set.

Earlier in the year, Ms. Q had her students read about how to **evaluate [SEP-8]** the scientific arguments made in media sources using a checklist called the Science Toolkit (see UC Museum of Paleontology at https://www.cde.ca.gov/ci/sc/cf/ch8.asp#link48). To begin this unit, she had them read two Internet articles with radically different headlines that each used a graph of global temperature as **evidence [SEP-7]**. Students worked in pairs to evaluate the two articles based on the criteria outlined in the Science Toolkit. As Ms. Q walked around the room, Fernando asked her about the sources: “This article is from NASA, but what is the Weekly Star? Who wrote it?” She encouraged him to do a quick internet search about the newspaper’s editorial board. A bit later, Cynthia mentioned that both articles use graphs (figure 8.51), but they look totally different.

Figure 8.51. Two Representations of the Same Data Set by Different Sources

Global warming stopped 16 years ago, reveals Met Office report quietly released ... and here is the chart to prove it	Long-Term Global Warming Trend Continues
	
Weekly Star (fictitious)	NASA’s Earth Observatory 2013

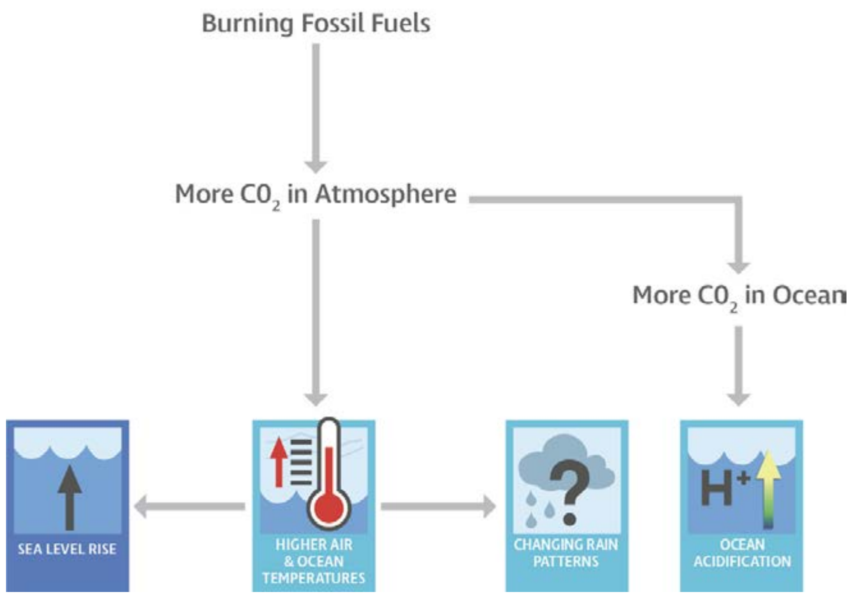
[Long description of Figure 8.51.](#)

Ms. Q then asked the whole class to discuss the graphs and construct an **argument [SEP-7]** about which graph contained stronger **evidence [SEP-7]**. Ali noticed that one graph included a much longer span of time, “and climate is supposed to be a long-term thing.” Jenni said, “This graph has four lines from scientists all over the world that all show the same ups and downs. That shows science is repeatable, and I like that.” To conclude the lesson, students wrote letters to the editor in response to the *Weekly Star* article articulating their **argument [SEP-7]**.

In the CA NGSS, students combine their general understanding with **computational thinking [SEP-5]** by using simple computer simulations (see PhET, *The Greenhouse Effect* at https://www.cde.ca.gov/ci/sc/cf/ch8.asp#link49) to model the **flow of energy [CCC-5]** into and out of the Earth and the role that CO_2 and other greenhouse gases play in that process (HS-ESS2-4). Scientists use simulators of Earth's climate called global climate **models [SEP-2]** (GCMs) that are much more detailed and include many other processes and interactions between Earth **systems [CCC-4]**. The assessment boundary of HS-ESS3-6 states that students should not be required to run their own **models [SEP-2]**, though simplified versions of GCMs exist for educational purposes (see Columbia University, Educational Global Climate Modeling Web site at https://www.cde.ca.gov/ci/sc/cf/ch8.asp#link50 and Java Climate Model at https://www.cde.ca.gov/ci/sc/cf/ch8.asp#link51). The advantage of these models is that they enable students to turn on and off different parts of the Earth system to see how they affect the climate. For example, students can compare a model of the Earth without the biosphere to a model that includes the biosphere. As CO_2 increases in the atmosphere, plant growth decreases the impact of global warming (a counterbalancing feedback). Comparing the predictions of a computer model that allows ice to melt with one in which ice is not allowed to melt is another form of **analyzing and interpreting data [SEP-4]** and can help build students' mental **models [SEP-2]** of the climate system. **Models [SEP-2]**, as defined in the CA NGSS, represent a system that allows for predicting outcomes, so the output of a computational model can sometimes be more useful at anticipating the future than simply examining historical data. Ultimately, students need to be able to communicate their mental model by describing specific feedbacks in the Earth system using an argument (HS-ESS2-2). In a classroom, various student teams could examine different elements of an Earth system using teacher-provided results of model runs or creating their own with educational GCMs. They could then compile brief reports to share with their classmates about the **effects [CCC-2]** of these different processes on global climate.

Another crucial observation about Earth's climate is that the concentration of CO_2 and other greenhouse gases in our atmosphere has been growing steadily since the dawn of the industrial era. Students should be able to make connections to the previous instructional segment and know that the vast majority of this increase comes from humans' extraction and combustion of fossil fuels. GCMs allow scientists and students to see how the climate is expected to change as greenhouse gases trap more energy in the atmosphere. Because of the linkages between different components of Earth's **systems [CCC-4]**, these impacts extend to all of Earth's systems. Figure 8.52 shows a few of these linkages. In a classroom, different student groups could **obtain information [SEP-8]** from library and Internet resources to construct a report on the impact predicted for different parts of the world so that the class as a whole could create a product to share with the rest of their school that summarizes the global impacts (HS-ESS3-6).

Figure 8.52. Cause and Effect Chains Illustrate How Human Activities Affect Natural Systems



One example of how humans affect the climate, which impacts all parts of Earth's systems. Illustration by Dr. Art Sussman, WestEd, and Lisa Rosenthal, WGBH.
Long description of Figure 8.52.

The remaining instructional segments in this course **investigate [SEP-3]** different Earth **systems [CCC-4]** and their interactions. By placing climate change early in the course, teachers can use climate impacts in California as a common thread that highlights the interdependence of Earth's systems (ESS2.A). This document describes specific climate impacts in each of the subsequent instructional segments.

EEI Curriculum units—*The Life and Times of Carbon* and *The Greenhouse Effect on Natural Systems* (https://www.cde.ca.gov/ci/sc/cf/ch8.asp#link52 and https://www.cde.ca.gov/ci/sc/cf/ch8.asp#link53)—explore human practices that can influence the global carbon cycle and how human activities affect quantities of greenhouse gases. These units can be used in conjunction with this instructional segment to provide materials that examine EP&Cs III and IV.

Engineering Connection: Evaluating Renewable Energy Options

Ultimately, any discussion of climate change should begin to explore technological solutions that could reduce emissions of greenhouse gases. In a classroom, students can calculate their own carbon footprints to further understand how they contribute to the human impacts on the global carbon cycle. They can explore renewable energy options and debate the pros and cons of each possible energy source for meeting society's needs (National Energy Education Development Project 2012b) (HS-ESS3-2, HS-ETS1-1). They can complete the project by creating another summary product for their school that **communicates [SEP-8]** some steps that individuals could take to reduce their impact on the climate system, or recommend broader actions that their school and community could take that will have an even larger effect.

IS3

Earth and Space Sciences Instructional Segment 3: Mountains, Valleys, and Coasts

Earth scientists look at landscape and **ask questions [SEP-1]** about the processes that shaped it and the specific sequence of events in the past when those processes occurred. Scientists **plan and carry out investigations [SEP-3]** to answer those questions, but investigations in Earth and space science cannot always take the same experimental form with the testing of hypotheses as they might in analytical chemistry or experimental physics. Many Earth processes take millions of years and cover thousands of miles of area occuring too slowly and at too big a scale to reproduce in a lab. Geologists often refer to the Earth as their natural laboratory, but they are only permitted to look at the final result of its ancient experiments (Earth's present-day landscape). These investigations often begin when Earth scientists make careful observations of what the Earth looks like today and then try to reproduce similar features in small-scale laboratory experiments or computer simulations.

EARTH AND SPACE SCIENCES INSTRUCTIONAL SEGMENT 3: MOUNTAINS, VALLEYS, AND COASTS

Guiding Questions

- How did California's landscape get to look the way it does today?
- What forces shape the Earth's surface?
- How do those processes affect humans?

Performance Expectations

Students who demonstrate understanding can do the following:

HS-ESS2-1. Develop a model to illustrate how Earth's internal and surface processes operate at different spatial and temporal scales to form continental and ocean-floor features. [Clarification Statement: Emphasis is on how the appearance of land features (such as mountains, valleys, and plateaus) and sea-floor features (such as trenches, ridges, and seamounts) are a result of both constructive forces (such as volcanism, tectonic uplift, and orogeny) and destructive mechanisms (such as weathering, mass wasting, and coastal erosion).] [*Assessment Boundary: Assessment does not include memorization of the details of the formation of specific geographic features of Earth's surface.*] (Revisited from IS1 and again in IS4)

HS-ESS2-5. Plan and conduct an investigation of the properties of water and its effects on Earth materials and surface processes. [Clarification Statement: Emphasis is on mechanical and chemical investigations with water and a variety of solid materials to provide the evidence for connections between the hydrologic cycle and system interactions commonly known as the rock cycle. Examples of mechanical investigations include stream transportation and deposition using a stream table, erosion using variations in soil moisture content, or frost wedging by the expansion of water as it freezes. Examples of chemical investigations include chemical weathering and recrystallization (by testing the solubility of different materials) or melt generation (by examining how water lowers the melting temperature of most solids).]

HS-ESS3-1. Construct an explanation based on evidence for how the availability of natural resources, occurrence of natural hazards, and changes in climate have influenced human activity. [Clarification Statement: Examples of key natural resources include access to fresh water (such as rivers, lakes, and groundwater), regions of fertile soils such as river deltas, and high concentrations of minerals and fossil fuels. Examples of natural hazards can be from interior processes (such as volcanic eruptions and earthquakes), surface processes (such as tsunamis, mass wasting and soil erosion), and severe weather (such as hurricanes, floods, and droughts). Examples of the results of changes in climate that can affect populations or drive mass migrations include changes to sea level, regional patterns of temperature and precipitation, and the types of crops and livestock that can be raised.]

HS-ESS3-4. Evaluate or refine a technological solution that reduces impacts of human activities on natural systems.* [Clarification Statement: Examples of data on the impacts of human activities could include the quantities and types of pollutants released, changes to biomass and species diversity, or areal changes in land surface use (such as for urban development, agriculture and livestock, or surface mining). Examples for limiting future impacts could range from local efforts (such as reducing, reusing, and recycling resources) to large-scale geoengineering design solutions (such as altering global temperatures by making large changes to the atmosphere or ocean).]

EARTH AND SPACE SCIENCES INSTRUCTIONAL SEGMENT 3: MOUNTAINS, VALLEYS, AND COASTS

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

HS-ETS1-3. Evaluate a solution to a complex real-world problem based on prioritized criteria and trade-offs that account for a range of constraints, including cost, safety, reliability, and aesthetics as well as possible social, cultural, and environmental impacts.

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

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

Highlighted Science and Engineering Practices	Highlighted Disciplinary Core Ideas	Highlighted Crosscutting Concepts
[SEP-2] Developing and Using Models [SEP-3] Planning and Carrying Out Investigations [SEP-4] Analyzing and Interpreting Data [SEP-6] Constructing Explanations (for science) and Designing Solutions (for engineering)	ESS2.A: Earth Materials and Systems ESS2.B: Plate Tectonics and Large-Scale System Interactions ESS2.C: The Role of Water in Earth's Surface Processes ESS3.A: Natural Resources ESS3.B: Natural Hazards ESS3.C: Human Impacts on Earth Systems ESS3.D: Global Climate Change ETS1.B: Developing Possible Solutions	[CCC-2] Cause and Effect: Mechanism and Explanation [CCC-7] Stability and Change Connections to Engineering, Technology, and Applications of Science Influence of Science, Engineering, and Technology on Society and the Natural World

Highlighted California Environmental Principles and Concepts:

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

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

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

EARTH AND SPACE SCIENCES INSTRUCTIONAL SEGMENT 3: MOUNTAINS, VALLEYS, AND COASTS

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

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

CA CCSS Math Connections: N-Q.1–3; MP.2, MP.4

CA CCSS for ELA/Literacy Connections: SL.11–12.5; RST.11–12.1, 2, 7, 8, 9; WHST.9–12.2a–e, 7

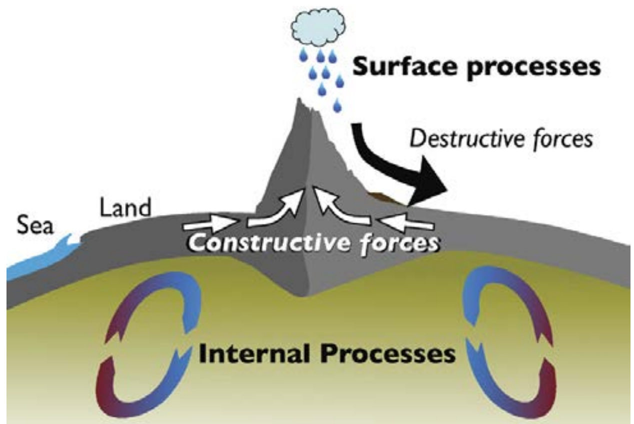
CA ELD Connections: ELD.PI.11–12.1, 5, 6a–b, 9, 10, 11a

Students can develop an Earth science mindset when they walk around their own schoolyard and make observations about the familiar processes that led to its present-day state (United States Geological Survey [USGS] 2015). Because they already have some familiarity with construction equipment and the everyday wear and tear that occurs on their school site, they will be able to recognize evidence of those past events. Most importantly, this process prompts them to realize that they can **ask questions [SEP-1]** about the world around them. Teachers can then introduce some of the natural geologic landscapes and processes that act on Earth.

Particular emphasis in this instructional segment is placed on the erosive power of water in shaping California's mountains, valleys, and coasts—the intersection between the hydrosphere and the geosphere (primarily addressed by ESS2.C). The effects of erosion include both the wearing down of surface features (destructive forces) and the building up surface features in other places (constructive forces). For example, as material is carved away from one place, it can pile up and collect in other places such as floodplains, deltas, and at the bases of landslides. Students should **develop models [SEP-2]** of how these surface processes shape features on land as part HS-ESS2-1.

HS-ESS2-1 is broadly written and encompasses a huge fraction of the processes in Earth science (constructive and destructive forces; surface processes and internal processes; features on land and the seafloor—all spanning a broad range of spatial and temporal scales). For this reason, it is revisited several times throughout this course. To reduce this vast performance expectation down to a scale that can be assessable in a classroom, teachers can select specific local features, and students can **draw models [SEP-2]** similar to figure 8.53 and figure 8.54 that **explain [SEP-6]** how the selected local landform was shaped over time. Or, teachers could take a broader view of this performance expectation and use it to explain global features like mountain chains, mid ocean ridges, and deep-sea trenches a part of a unit on plate tectonics.

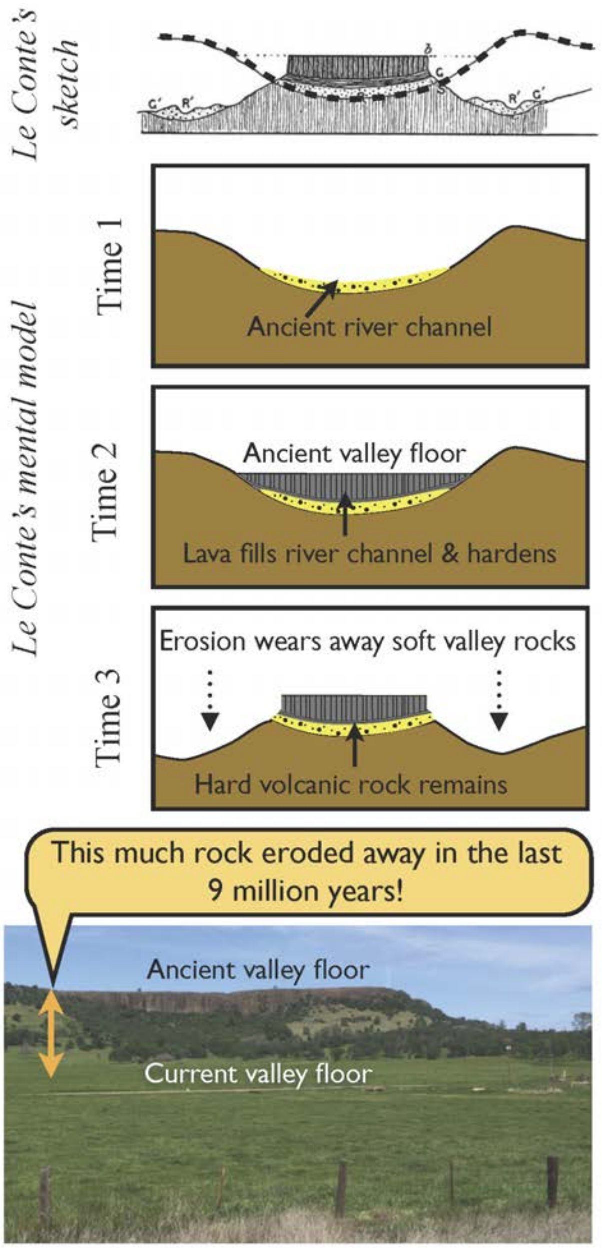
Figure 8.53. Forces that Shape Earth's Surface: Internal Versus External and Constructive Versus Destructive



Landscapes are shaped by the balance between constructive and destructive forces driven by processes inside the Earth and on the surface. In the CA NGSS, students are expected to develop a model of how these processes combine to shape the land surface and the seafloor (HS-ESS2-1). Diagram by M. d'Alessio.
Long description of Figure 8.53.

Today the tallest mountain in the contiguous United States is Mt. Whitney, but at one time the Sierra Nevada were much taller. Over time, layers of rock several miles thick have eroded away from these mountains. Early geologists conducted **investigations [SEP-3]** by making observations in the foothills of the Sierra Nevada and collected the first convincing evidence of this erosion. They observed ancient lava flows high above valley floors and named them "table mountains" because the flat tops of the lava flows resembled tables (figure 8.54). Since lava always flows to the lowest points in a landscape, such as river channels, geologists questioned what lava flows were doing on the top of the mountain. The best explanation is that lava flowed down river channels at the bottom of valleys. Then, water running off the slopes of the Sierra Nevada slowly eroded material away from these foothill locations. The lava was more resistant to erosion than the surrounding rocks, so erosion carried away the surrounding material and left the lava-filled meandering river channels sticking up. Two examples, each named Table Mountain, can be seen while driving along Highway 108 in Tuolumne County and Highway 70 in Butte County. These features allow visitors to visualize how much material has been carried away since the lava flows formed just a few million years ago. Where did that sediment go? Much of it was carried down to the Central Valley below, which has accumulated miles of deep sediment, including the top layer of fertile soil that gives the area its agricultural productivity (to be discussed in IS4 on Water and Farming).

Figure 8.54. Tuolumne Table Mountain Near Jamestown



Tuolumne Table Mountain near Jamestown, CA reveals how much soil and rock has eroded. Joseph LeConte sketched the drawing on the top for a textbook he wrote in 1882. *Source*: LeConte 1892; photo by Kirk Brown; illustration by M. d'Alessio

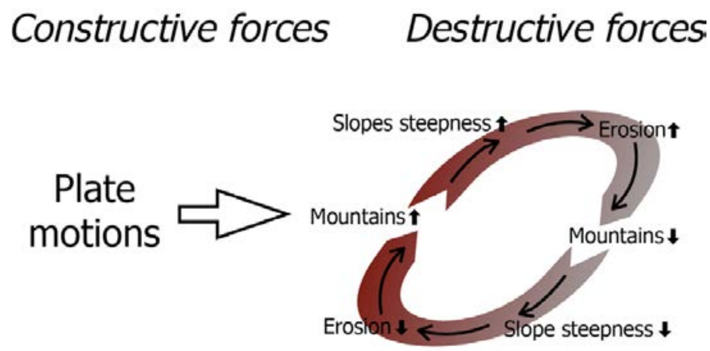
Long description of Figure 8.54.

In the 1850s, geologists in California like Joseph LeConte[9] began to look at landscapes and construct mental models of how landscapes developed and changed by erosion. These mental models required testing, so Earth scientists conducted small experiments of erosion in laboratories. A stream table (a sloped table or plastic bin covered with sand and other earth materials and flooded with water) is a platform for exploring erosional processes; it can be used for hands-on **investigation [SEP-3]** and as a physical **model [SEP-2]** that can predict possible outcomes. Teachers can use stream tables to help meet some of the performance expectations of the CA NGSS, including having students **ask questions [SEP-1]** and plan their own **investigations [SEP-3]** (HS-ESS2-5). Students can recreate California landforms such as the Sierra Nevada and Central Valley in a stream table and watch as sediment slowly accumulates in deep layers in the valley, or even be given a range of materials to see if they can produce the mesa-like features of Table Mountain.

While erosion appears to happen slowly and steadily over time, most erosion events are actually quite rapid changes taking place as catastrophic events like landslides. This example of **stability and change [CCC-7]** builds on ideas about the rates of Earth processes first introduced in second grade (2-ESS1-1) and erosional processes explored in fourth grade (4-ESS2-1). In high school, students put those two ideas together, noticing how balancing feedbacks prevent erosion from staying fast for very long. When the movement of water drives erosion, the steepness of the slope has a huge impact on the rate of erosion because water builds up more kinetic energy when accelerating down a steep hill (PS2.A). As the water molecules collide with the soil and rock, they can dislodge individual pieces and carry them away. Steeper slopes erode more quickly, causing the slopes to flatten and slowing erosion (figure 8.55). Erosion occurs when the driving forces suddenly exceed the resisting forces. A cliff can fall if either the resisting force is reduced (by undercutting the supporting material at the base of the cliff) or if the driving forces are increased (by higher waves, faster river flows, or additional weight from new construction or a slope saturated with heavy water from irrigation or a rainstorm). When designing new buildings or landscape projects, geotechnical engineers make careful calculations of how their projects affect both the driving forces and resisting forces.

9. LeConte was one of the first faculty at the University of California and a charter member of the Sierra Club. There are several schools in California named after him including ones in Los Angeles and Berkeley.

Figure 8.55. Balancing Feedback in Erosion



A counter-balancing feedback loop causes erosion to occur at a slow and steady rate. Diagram by M. d'Alessio.
Long description of Figure 8.55.

In a classroom, students can observe slow and steady erosion punctuated by rapid landslides as well as the balancing feedback in a stream table. The slow movement of sediment from the base of a cliff eventually hits a critical point and a massive piece of the cliff suddenly falls. The erosion rate then slows because the cliff erodes into a flatter slope. California's coastal bluffs repeatedly face this problem, often eroding many feet in a single storm and then remaining stable for decades. Students can **investigate [SEP-3]** actual coastal erosion rates using online collections of historical photos as found in Google Earth and the California Coastal Record to measure the impact of waves on the coastline (HS-ESS2-5). Figure 8.56 shows oblique aerial photos of Pacifica, California from Google Earth that are precise enough that students can measure the amount of coastline erosion as a classroom experiment.

Figure 8.56. Coastal Erosion in Pacifica

Changes over time in coastal bluffs in Pacifica, California. The yellow triangle shows the migration of the cliff top from year to year at a single position. By 2010, the cliff is located directly beside the apartment building. *Source*: Images from California Coastal Records Project 2017. Copyright © 2002-2015 Kenneth & Gabrielle Adelman, California Coastal Records Project, www.californiacoastline.org
Long description of Figure 8.56.

Engineering Connection: Mitigating Erosion Hazards

When the natural process of erosion affects humans, it becomes a natural hazard. Students can explain some of the common impacts of erosion in California (HS-ESS3-1). They can also engage in an engineering design problem to reduce these impacts (HS-ESS3-4). Students can design and build erosion control measures using stream tables as well as read about actual measures that are taken in places like Pacifica and locations all along the California coastline. The engineering solutions either involve (1) increasing the strength of the hillside (by adding plants with root systems to stabilize the hillside, building support walls, or covering the cliff with concrete); or (2) reducing the driving forces (by placing rocks or sea walls to reduce the speed of waves when they hit the natural hillslope and through better drainage). Students should compare and evaluate solutions based on prioritized criteria and tradeoffs that account for a range of constraints, including cost, safety, reliability, and aesthetics. (HS-ETS1-3; EP&C V). Sometimes, technologies that reduce the impact of erosion on people can have adverse impacts on ecosystems (EP&C III). Students should consider and evaluate the environmental impacts of their design and refine it to reduce those impacts (HS-ESS3-4).

Using the **models [SEP-2]** they have developed, the CA NGSS asks students to make predictions about the future of erosion if California's climate shifts (HS-ESS3-5). California may face rising sea levels and periods of intense drought followed by intense storms. Rising sea levels combined with high storm surges means there will be greater driving forces for coastal erosion. Even if California receives less rainfall overall, intense bursts of rainfall could lead to increased erosion overall. The high runoff from intense storms causes faster flow rates in rivers and over the land surface, which also increase the driving forces of erosion.

EEI Curriculum unit *Liquid Gold: California's Water* explores human impacts resulting from the methods used to move large amounts of water. This unit is available from https://www.cde.ca.gov/ci/sc/cf/ch8.asp#link54 and can be used in conjunction with this instructional segment to provide materials that examine California's EP&C V.

IS4

Earth and Space Sciences Instructional Segment 4: Water and Farming

California is the largest agricultural producer in the country. Its farming success depends on three main natural resources: its climate, fertile soil, and the availability of massive amounts of water for irrigation. Previous instructional segments in this course have discussed the climate system and the source of its fertile soils. This instructional segment focuses on the availability of water and how humans have impacted that availability.

EARTH AND SPACE SCIENCES INSTRUCTIONAL SEGMENT 4: WATER AND FARMING

Guiding Questions

- Why do droughts have such a strong impact on California and other parts of the world?
- How will changes in climate affect our water resources?

Performance Expectations

Students who demonstrate understanding can do the following:

HS-ESS3-1. Construct an explanation based on evidence for how the availability of natural resources, occurrence of natural hazards, and changes in climate have influenced human activity. [Clarification Statement: Examples of key natural resources include access to fresh water (such as rivers, lakes, and groundwater), regions of fertile soils such as river deltas, and high concentrations of minerals and fossil fuels. Examples of natural hazards can be from interior processes (such as volcanic eruptions and earthquakes), surface processes (such as tsunamis, mass wasting and soil erosion), and severe weather (such as hurricanes, floods, and droughts). Examples of the results of changes in climate that can affect populations or drive mass migrations include changes to sea level, regional patterns of temperature and precipitation, and the types of crops and livestock that can be raised.]

HS-ESS3-3. Create a computational simulation to illustrate the relationships among management of natural resources, the sustainability of human populations, and biodiversity. [Clarification Statement: Examples of factors that affect the management of natural resources include costs of resource extraction and waste management, per-capita consumption, and the development of new technologies. Examples of factors that affect human sustainability include agricultural efficiency, levels of conservation, and urban planning.] [*Assessment Boundary: Assessment for computational simulations is limited to using provided multi-parameter programs or constructing simplified spreadsheet calculations.*]

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

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

EARTH AND SPACE SCIENCES INSTRUCTIONAL SEGMENT 4: WATER AND FARMING

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

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

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

Highlighted Science and Engineering Practices	Highlighted Disciplinary Core Ideas	Highlighted Crosscutting Concepts
[SEP-1] Asking Questions and Defining Problems [SEP-3] Planning and Carrying Out Investigations [SEP-4] Analyzing and Interpreting Data [SEP-5] Using Mathematics and Computational Thinking [SEP-6] Constructing Explanations (for science) and Designing Solutions (for engineering)	ESS2.C: The Roles of Water in Earth's Surface Processes ESS3.A: Natural Resources ESS3.B: Natural Hazards ESS3.C: Human Impacts on Earth Systems ESS3.D: Global Climate Change ETS1.A: Defining and Delimiting Engineering Problems ETS1.C: Developing Possible Solutions	[CCC-2] Cause and Effect: Mechanism and Explanation [CCC-7] Stability and Change Connections to Engineering, Technology, and Applications of Science Influence of Science, Engineering, and Technology on Society and the Natural World

Highlighted California Environmental Principles and Concepts:

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

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

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

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

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

CA CCSS Math Connections: N-Q.1–3; MP.2, MP.4

CA CCSS for ELA/Literacy Connections: RST.11–12.1, 2, 7, 8, 9; WHST.9–12.2a–e, 7

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

The instructional segment begins by drawing on the knowledge students gained about the hydrologic cycle in the middle grades (MS-ESS2-4). They should already know that agriculture is by far the number one user of developed water (>75 percent of all consumed) and that the state gets its water from a combination of groundwater pumping (20-40 percent, depending on the year) and surface water from dams and reservoirs (Legislative Analyst's Office 2010). Articles about California's water supplies along with some hands-on demonstrations of the groundwater storage capacity of different Earth materials can serve as valuable review of these topics (see *Liquid Gold: California's Water* at https://www.cde.ca.gov/ci/sc/cf/ch8.asp#link55 and the EPA's, *Water Sourcebook: a Series of Classroom Activities for Grade Level 9–12* at https://www.cde.ca.gov/ci/sc/cf/ch8.asp#link56).

The high school performance expectations from the CA NGSS do not add any additional content knowledge tasks related to the internal processes of the hydrosphere. Instead they press students to apply the knowledge from previous grades to situations involving hydrosphere–anthrosphere interactions (EP&Cs I, II, & III). The focus of this instructional segment is to understand how California's water supply is limited and will be strongly influenced by climate **change [CCC-7]**. California is not alone in this situation, with water supplies being an increasing issue worldwide as populations and agricultural demands grow.

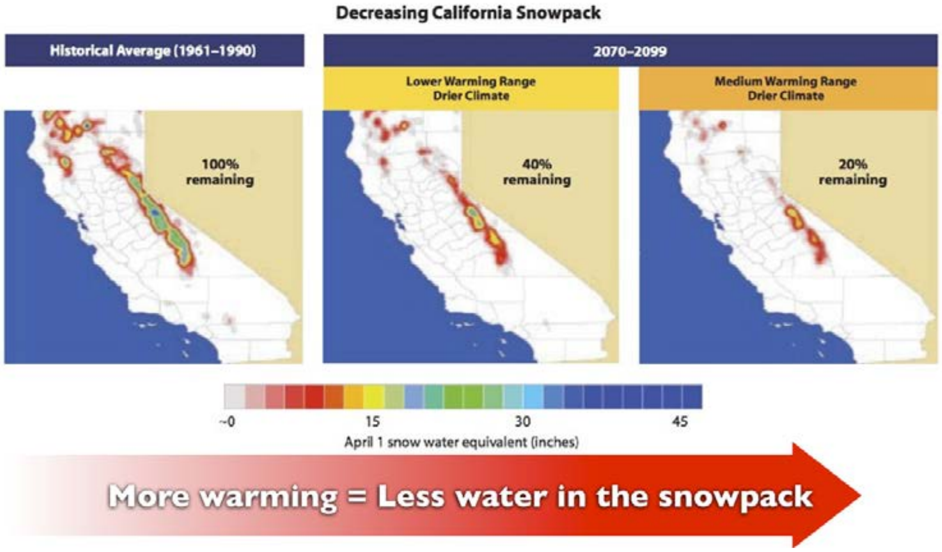
Climate Projections

Computer **models [SEP-2]** of global climate change predict that California is likely to be warmer and drier on average than at present. The California Natural Resources Agency publishes an assessment of projected climate impacts regularly as scientists constantly develop more accurate models. The 2012 report summarizes the projected changes as follows:

- The average annual temperature is projected to rise 2.5-8.5°F by 2100, and the range depends in part on how much greenhouse gas is emitted by humans around the world.
- Rainfall is projected to drop by as much as 10 percent below the historical levels, on average (Moser, Ekstrom, and Franco 2012).

This combination of warmth and dryness will cause significant changes to the amount of snow in the mountains. California relies on this snowpack because it uses more water during the summer but receives the majority of its precipitation in the winter. The state needs a way to store water for the hot summers. It currently depends on nature's storage system, snow that falls in the Sierra Nevada. The snow stays frozen until spring when warm weather melts it, filling our reservoirs just when we need them. A warmer and drier climate will cause a severe reduction in the snowpack (figure 8.57), so the state will need to come up with a new strategy for storing water for the hot summer.

Figure 8.57. Projected Decreases to California's Snowpack

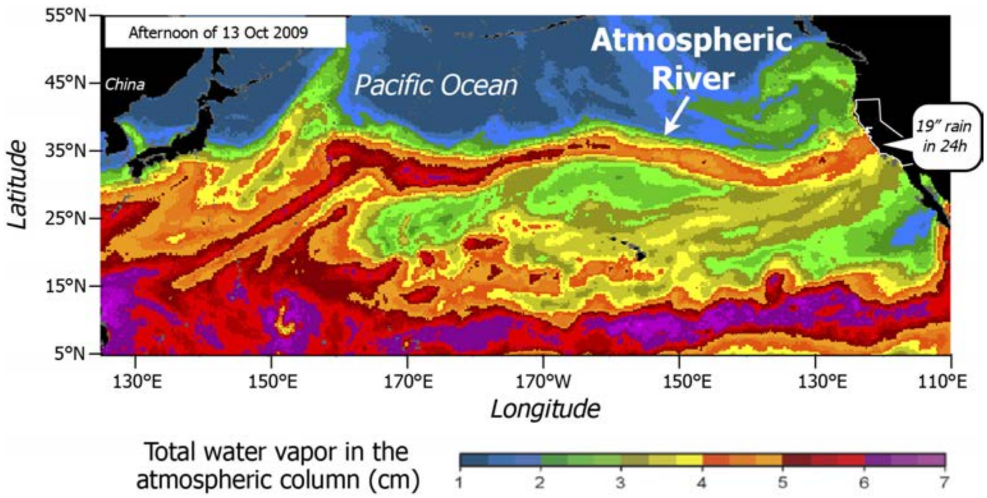


California should expect less water in the snowpack in the second half of the twenty-first century.
Source: California Climate Change Center 2006.
Long description of Figure 8.57.

California happens to lie in a unique position on the globe where even a small **change [CCC-7]** to the average rainfall amount may have a dramatic impact. Even though California receives less rainfall in an average year than many other states, the range between the wettest years and driest years is much more extreme than just about anywhere else in the country. This occurs because most of the state's rainfall arrives in relatively few short and intense storms. Despite our overall dryness, California receives some of the largest three-day storms in the country, rivaling the hurricane belt of the southeastern United States in rainfall intensity. "Thus, whether just a few large storms arrive or fail to arrive in California can be the difference between a banner year and a drought" (Dettinger et al. 2011). This dependence makes us particularly sensitive to small **changes [CCC-7]** in global climate.

California seems to receive these intense storms due to a unique atmospheric effect termed atmospheric rivers (figure 8.58). While it is common to have lots of moisture in the air over the Equator and tropics, there is typically less moisture in the air at the mid-latitudes where California lies. When unique conditions set up in the ocean and atmosphere, these atmospheric rivers act like narrow conveyor belts that push air containing excessive amounts of water vapor thousands of miles. Not all of California's storms are caused by atmospheric rivers, but many of the largest and most intense ones are. Scientists are still trying to figure out the exact conditions that give rise to atmospheric rivers, but small **changes [CCC-7]** in climate are likely to have substantial impact on whether or not they form and send moisture towards California. As a result, climate change will likely cause some years to be dramatically wetter than the past while other years will be much drier. The average will balance out to a smaller overall change, but our droughts could become even more severe.

Figure 8.58. Satellite Image of Atmospheric Water Vapor Reveals an Atmospheric River



Sources: National Oceanic and Atmospheric Administration, Earth System Research Laboratory 2015
Long description of Figure 8.58.

Managing Water Supplies

Computer simulations [SEP-2] serve as bookends to this instructional segment in which students explore issues in aquifer management (see The Basin Challenge at https://www.cde.ca.gov/ci/sc/cf/ch8.asp#link57) (HS-ESS3-3). When they engage in the activity at the beginning of the instructional segment, they can explore parameters and discover some of the issues and choices that affect water supplies. By the end of the instructional segment, they should have a more specific understanding of the processes involved in water availability, storage, and use. As a culminating assessment, students can conduct a role-playing negotiation in which they determine how much groundwater different communities are able to extract (HS-ESS3-1) (see the Environment and Sustainability Negotiation Role-Play from Harvard Law School's Program on Negotiation at https://www.cde.ca.gov/ci/sc/cf/ch8.asp#link58). Such scenarios are increasingly realistic as the demands of a growing urban population in California's Central Valley, agriculture, and protection of aquatic ecosystems have become increasingly competitive. Students can explore some of these issues of water supply and demand in several articles such as *Liquid Gold: California's Water* (https://www.cde.ca.gov/ci/sc/cf/ch8.asp#link59). They can analyze the human impacts resulting from the methods used to move large amounts of water and examine EP&C V. Appendix 3 of this framework provides a complete vignette guiding teachers through a way to teach skills of computer science in tandem with ESS DCIs. According to the developmental progressions in appendix 1 of this framework, high school students should be able to "create and/or revise a computational model or simulation" as part of **computational thinking [SEP-5]**.

Because agriculture is so dependent on water, it makes sense to explore the impact of climate **change [CCC-7]** on different crops (HS-ESS3-5). Students may select one of California's signature agricultural products (such as grapes, almonds, oranges, dairy, and avocados) and research the optimal growing conditions including the temperature and moisture requirements for such crops. They will **investigate [SEP-3]** where each crop is grown in California and why it is grown there. They can then refer to results from climate change **models [SEP-2]** that show how different regions will be affected by climate change. Will this increase or decrease productivity? Published simulations for specific crops are already available (Parker 2007; Hanson et al. 2010; Joyce et al. 2006), so students could compare their own assessment to these scientific models. By running their own climate simulations using published educational climate models, students can explore a range of different emissions scenarios to try to figure out if there is an acceptable threshold at which the crop would still achieve high productivity (HS-ETS1-4).

Water Quality

Even when California has enough water available, there are issues of water quality and contamination. Strict state and federal laws protect water, but the combination of accidents and infrastructure that predates those laws leave us with an ongoing legacy of contaminated water. Teachers should tailor activities about water quality around the local issues faced by their community.

Contamination comes from both individual sites (point sources) and the cumulative effect of water running off over large areas and picking up contaminants across these areas (nonpoint sources). The reason for making this distinction is that point sources are easy to identify and therefore eliminate. Industry, oil and gas production, and mining are the most common sources of point-source pollution. In most cases, nonpoint sources are actually caused by many individual point sources, but they are too small to track down. Lawns in a suburban neighborhood and farms in rural regions, both of which supply pesticides and excess fertilizer to runoff, are usually considered nonpoint sources, but it is important to note that individual people are actually responsible for all of these pollutants and could be educated to reduce this impact. In many cases in urban and suburban California, individual homeowners are partly responsible for water contamination. Students can prepare a brochure **communicating [SEP-8]** strategies for reducing water pollution and distribute it to homes in the neighborhood.

Students could obtain water-quality test kits and make measurements in natural waterways or in urban runoff. If they identify unacceptable levels of pollution, they can plan a more detailed investigation with strategically located water-quality samples that can help pinpoint the source(s).

Students can also **obtain information [SEP-8]** about larger pollution sources by looking up EPA Superfund sites in their area (that frequently have contaminated water; see https://www.cde.ca.gov/ci/sc/cf/ch8.asp#link60).

Engineering Connection: Water Filtration

California is home to state-of-the art water treatment plants and rigorously enforced regulations, but much of the rest of the world struggles to find clean and safe water. Students could **obtain information [SEP-8]** about water treatment and purification systems in their community, or be given engineering challenges to design water purification systems (such as Engineering is Elementary, *Water, Water Everywhere* at https://www.cde.ca.gov/ci/sc/cf/ch8.asp#link61). These systems have a lot in common with the natural groundwater system, which is an excellent filtration system. This is why digging groundwater wells can dramatically decrease health risks from waterborne pathogens in third-world countries (HS-ETS1-1). This framework calls on students to perform a similar design process in fifth grade, but students can return to the problem in high school with a broader understanding of the properties of water.

IS5 Earth and Space Sciences Instructional Segment 5: Causes and Effects of Earthquakes

California is famous for its earthquakes, but not because it has the most earthquakes or even the largest ones (Alaska holds both those titles among US states). It is probably most famous because its earthquakes impact more people than any other state. In this instructional segment, students learn about the effects of earthquakes, how earthquakes have shaped California's history and geography, and how forces deep within the Earth cause earthquakes.

EARTH AND SPACE SCIENCES INSTRUCTIONAL SEGMENT 5: CAUSES AND EFFECTS OF EARTHQUAKES

Guiding Questions

- What causes earthquakes?

Performance Expectations

Students who demonstrate understanding can do the following:

HS-ESS1-5. Evaluate evidence of the past and current movements of continental and oceanic crust and the theory of plate tectonics to explain the ages of crustal rocks. [Clarification Statement: Emphasis is on the ability of plate tectonics to explain the ages of crustal rocks. Examples include evidence of the ages oceanic crust increasing with distance from mid-ocean ridges (a result of plate spreading) and the ages of North American continental crust increasing with distance away from a central ancient core (a result of past plate interactions).]

HS-ESS2-1. Develop a model to illustrate how Earth's internal and surface processes operate at different spatial and temporal scales to form continental and ocean-floor features. [Clarification Statement: Emphasis is on how the appearance of land features (such as mountains, valleys, and plateaus) and sea-floor features (such as trenches, ridges, and seamounts) are a result of both constructive forces (such as volcanism, tectonic uplift, and orogeny) and destructive mechanisms (such as weathering, mass wasting, and coastal erosion).] [*Assessment Boundary: Assessment does not include memorization of the details of the formation of specific geographic features of Earth's surface.*]

HS-ESS2-3. Develop a model based on evidence of Earth's interior to describe the cycling of matter by thermal convection. [Clarification Statement: Emphasis is on both a one-dimensional model of Earth, with radial layers determined by density, and a three-dimensional model, which is controlled by mantle convection and the resulting plate tectonics. Examples of evidence include maps of Earth's three-dimensional structure obtained from seismic waves, records of the rate of change of Earth's magnetic field (as constraints on convection in the outer core), and identification of the composition of Earth's layers from high-pressure laboratory experiments.]

EARTH AND SPACE SCIENCES INSTRUCTIONAL SEGMENT 5: CAUSES AND EFFECTS OF EARTHQUAKES

HS-ESS3-1. Construct an explanation based on evidence for how the availability of natural resources, occurrence of natural hazards, and changes in climate have influenced human activity. [Clarification Statement: Examples of key natural resources include access to fresh water (such as rivers, lakes, and groundwater), regions of fertile soils such as river deltas, and high concentrations of minerals and fossil fuels. Examples of natural hazards can be from interior processes (such as volcanic eruptions and earthquakes), surface processes (such as tsunamis, mass wasting and soil erosion), and severe weather (such as hurricanes, floods, and droughts). Examples of the results of changes in climate that can affect populations or drive mass migrations include changes to sea level, regional patterns of temperature and precipitation, and the types of crops and livestock that can be raised.]

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

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

Highlighted Science and Engineering Practices	Highlighted Disciplinary Core Ideas	Highlighted Crosscutting Concepts
[SEP-2] Developing and Using Models [SEP-6] Constructing Explanations (for science) and Designing Solutions (for engineering) [SEP-7] Engaging in Argument from Evidence	PS1.C: Nuclear Processes PS4.A: Wave Properties ESS1.C: The History of Planet Earth ESS2.A: Earth Materials and Systems ESS2.B: Plate Tectonics and Large-Scale System Interactions ESS3.A: Natural Resources ESS3.B: Natural Hazards	[CCC-1] Patterns [CCC-2] Cause and Effect: Mechanism and Explanation [CCC-5] Energy and Matter: Flows, Cycles, and Conservation [CCC-7] Stability and Change

CA CCSS Math Connections: N-Q.1–3; MP.2, MP.4

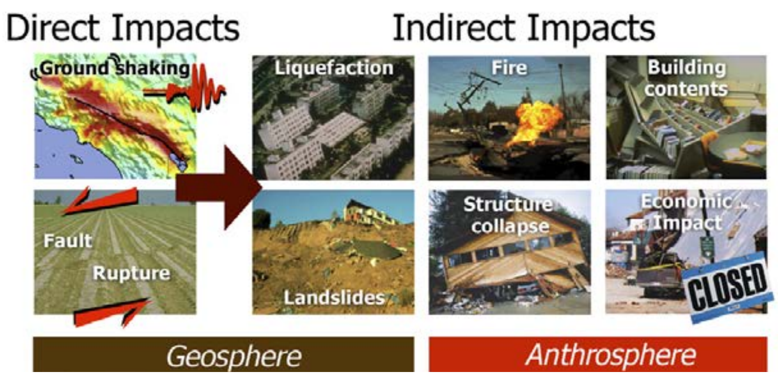
CA CCSS for ELA/Literacy Connections: SL.11–12.5; RST.11–12.1; WHST.9–12.2.a–e

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

The deadliest earthquake in US history was the 1906 earthquake in San Francisco (an estimated 3,000 people died), but many earthquake scientists argue that the 1906 earthquake was also the most scientifically valuable earthquake ever (USGS 2012). The CA NGSS push students to appreciate and be able to articulate the role of natural hazards in human history (ESS3.B), an example of geosphere-anthrosphere interactions. A historical overview of earthquakes in California helps illustrate those interactions and also motivates a deeper investigation of processes within the geosphere that cause earthquakes.

This instructional segment begins with students exploring the **evidence [SEP-7]** of how earthquakes affect people through a case study of a historical earthquake in California (HS-ESS3-1). Major earthquakes in Northern California (1989 Loma Prieta) and Southern California (1994 Northridge) make excellent case studies, as do smaller more local recent earthquakes. Internet image databases allow students to find images of a locally relevant earthquake (see The Earthquake Engineering Online Archive at https://www.cde.ca.gov/ci/sc/cf/ch8.asp#link62). Students can conduct independent research about this earthquake and compile a comprehensive list of hazards that earthquakes pose. Figure 8.59 shows an example of how these hazards can be classified. From the perspective of **cause and effect [CCC-2]**, earthquakes have only two effects that are caused directly by the earth movement: ground shaking and offset of land along fault ruptures. The rest of the disasters that occur during earthquakes are effects of those events, so events like tsunamis, fires, and building collapses are often referred to as indirect effects. Like many natural hazards, the events in the geosphere trigger a range of problems for the lives and property of humans (anthrosphere). In California, engineering designs have substantially reduced these indirect impacts. For example, the 1994 Northridge earthquake in Southern California was about the same magnitude as a 2003 earthquake in Bam, Iran. The impacts within the geosphere were similar, but the impact to the anthrosphere differed dramatically. Even though they both occurred in the center of cities in the early morning hours, fewer than 70 people died in California while more than 25,000 are estimated to have died in Iran because of widespread collapse of homes. The difference is primarily because laws adopted by California communities, called building codes, require builders to use innovative building designs that are strong enough to stand up to earthquakes. Building codes are updated regularly and enforced rigorously in California communities. Many countries around the world have adopted similar building codes, but in poorer nations they are not enforced because many of the measures require additional cost or expertise. Natural hazards usually impact poorer communities the most, and this remains true in California as much as the rest of the world.

Figure 8.59. Direct and Indirect Earthquake Impacts



Most earthquake impacts are indirectly caused by shaking and fault rupture. Figure by M. d'Alessio with images from USGS 2008, 15; National Oceanic and Atmospheric Administration/National Geophysical Data Center (NOAA/NGDC) 1964; San Francisco Fire Department 1989; NOAA/NGDC, U.S. Geological Survey 1980; NOAA/NGDC, University of Colorado at Boulder 1979; USGS 1995; USGS 2005; adapted from Hey Paul 2003

Long description of Figure 8.59.

Any discussion of earthquakes inevitably leads to the question of whether or not we can predict them; that requires knowing their root cause. The understanding of how Earth's internal processes cause earthquakes made some of its most important advances right here in California. A case study of the 1906 earthquake illustrates earthquake effects and ties to California history. As part of an effort to create accurate navigational charts, surveyors had mapped many parts of California in the mid-1800s. When the 1906 earthquake occurred, it was clear that the land had moved and there was great interest in the scientific community to see if there was a systematic pattern. Measurements taken shortly after the earthquake in 1906-07 showed that the Earth had moved up to 10 meters in some spots, and that locations west of the San Andreas fault all moved northwest while locations east of the fault moved the opposite direction. What was more dramatic was that surveys repeated several years later revealed that the Earth continued moving following this systematic pattern for years after the earthquake.

Opportunities for ELA/ELD Connections

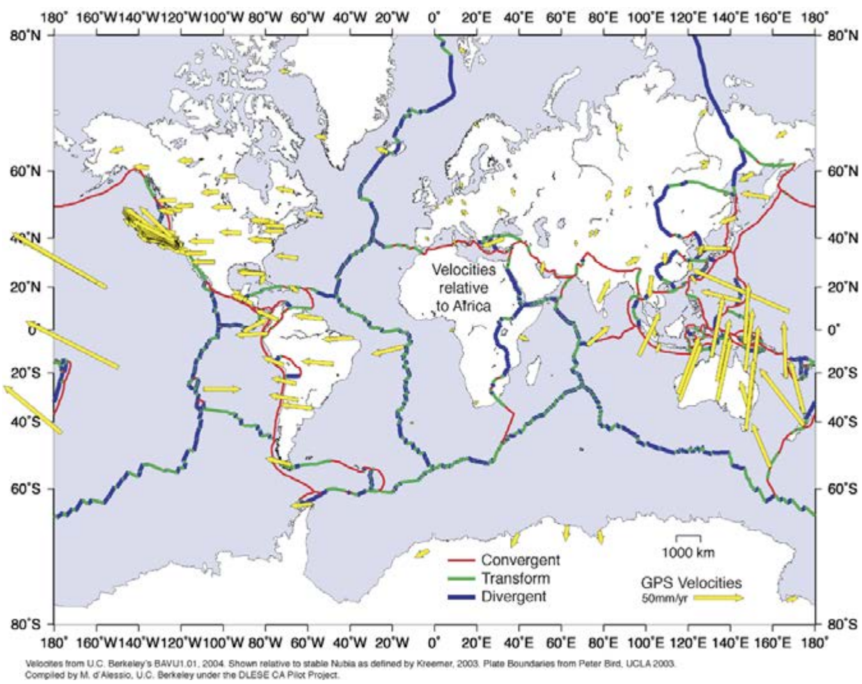
Students research and compare the cause(s) and effects of the 1906 San Francisco earthquake and a more recent earthquake, such as the 1989 Loma Prieta or the 1994 Northridge earthquakes. The informational report should include the potential impacts and hazards that earthquakes pose and any indirect effects of the earthquakes. Have students discuss which earthquake was more destructive than the other and support their views with evidence from the texts.

CA CCSS for ELA/Literacy Standards: WHST.9–12.2, 9; RST.9–12.1, 2, 9
CA ELD Standards: ELD.PI. 9–12.6, 10

Earth's systematic movements before, during, and after earthquakes are key pieces of evidence that establish the relationship between earthquake and broader plate motions. In middle grades, students already used continent shapes, fossils, and seafloor structures to provide evidence of past plate motions (MS-ESS2-3). In high school, students add a very modern piece of evidence from global positioning system (GPS) measurements throughout the world. These measurements work using the same system as navigation systems in cars and cell phones but are significantly more precise. Students examine real-time maps of motion around California and the globe recorded by these devices (see UNAVCO, Real-time velocity viewer, at https://www.cde.ca.gov/ci/sc/cf/ch8.asp#link63 or UNAVCO, Jules Verne Voyager Jr., at https://www.cde.ca.gov/ci/sc/cf/ch8.asp#link64).

These velocity maps (figure 8.60) reveal that large sections of the Earth all move together in the same direction at the same time (we call these section *plates*). Areas where the velocities of two adjacent sections are radically different are plate *boundaries* where dramatic things can happen. Students can identify plate boundaries on velocity maps and then relate them to the locations of earthquakes, volcanoes, mountains, and the shape of the ocean floor using either Google Earth or traditional paper maps (see Rice University Discovering Plate Boundaries at https://www.cde.ca.gov/ci/sc/cf/ch8.asp#link65). Students can use the relative motions shown by the velocity arrows along with these other surface features to discover that some plates move away from one another while others crash together or slide horizontally past one another (discovering the *types* of plate boundaries). Plate motions are one of the key constructive processes that build landscapes (figure 8.52) and extend the destructive processes explored in IS3. Using hands-on activities involving sandboxes (Feldman, Cooke, and Ellsworth 2010) or paper **models [SEP-2]** (Alpha and Lahr 1990), students visualize the deformation that occurs near the surface at these boundaries (HS-ESS2-1). Students use Google Earth to find real-world examples of topographic features such as linear mountain ranges or fault scarps. Students should be able to use the GPS velocity maps to identify those areas and use this information to explain the seafloor age patterns (HS-ESS1-5), which reveal locations where new magma rises up as plates spread apart forming new seafloor and where old seafloor dives under another plate when the plates crash together.

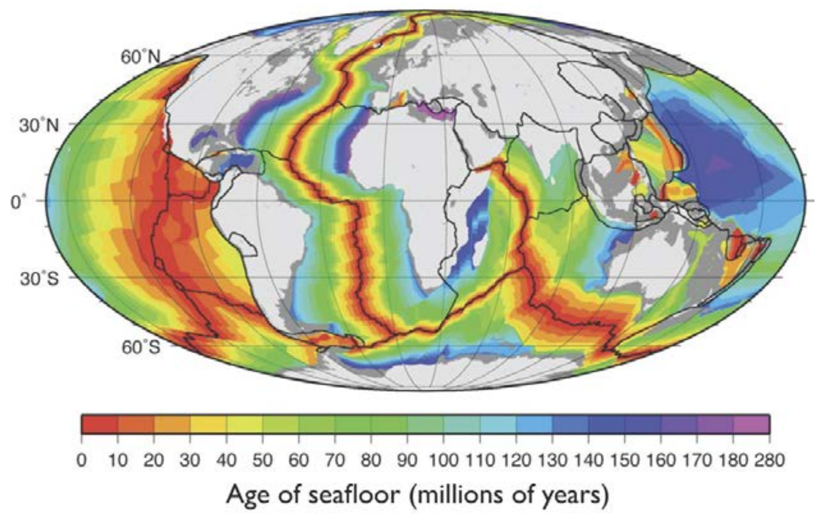
Figure 8.60. Present-Day Plate Motions



GPS velocities recorded at stations around the world reveal present-day plate motions. Arrow size relates to the speed of each point. Image credit: d'Alessio n.d.
Long description of Figure 8.60.

But why do plates move? One major clue comes from a key pattern in rock ages: the continents are much older than the oceans; the oldest continental rocks are more than 4 billion years old, but no seafloor is older than 280 million years (figure 8.61). We know that the Earth has had oceans for longer than that because pieces of ancient ocean floor can be found on land (Mehta 2007). So what is the difference between the continents and the ocean? One key observation is that continental rocks tend to have a lower density than oceanic rocks. This difference is important because we know of an important density-driven process that happens within the Earth: convection. Earth's interior is expected to be hot (from heat-generating radioactive elements in the interior) while its surface is adjacent to the cold emptiness of space. From physical science (HS-PS3-4), we know that heat will be transferred from the hot interior outward. Convection is an efficient heat transport mechanism that occurs when hot material rises upward, because it is less dense, while colder material sinks because it is more dense. The oceanic crust is cold and dense and sinks downwards at convergent plate boundaries. At the same time, hot magma, which is less dense, rises up at divergent plate boundaries. Plate motions are the surface expression of convection happening deep within the Earth. Students can create a model of convective heat transport (HS-ESS2-3) with a simple lava lamp or any of the various published demonstrations involving ice, warm water, and drops of food coloring. These **models [SEP-2]** do not capture the full complexity of convection in the Earth and its relationship to plate tectonics, but they are excellent visualizations of convection.

Figure 8.61. Seafloor Age



Sources: National Oceanic and Atmospheric Administration, National Centers for Environmental Information 2008
Long description of Figure 8.61.

Students should be able to use seafloor ages and surface motion rates as evidence that convection occurs in Earth’s interior. They can **communicate [SEP-8]** their **argument [SEP-7]** with a pictorial **model [SEP-2]** of Earth’s interior that has annotations to indicate how heat transfer drives movement within the Earth (HS-ESS2-3).

For communities in Northern California near Mt. Lassen and Mt. Shasta, it may be more appropriate to replace this instructional segment with an instructional segment on volcano hazards. While those areas also face significant earthquake hazard, their regional identity with these dramatic peaks makes volcanoes a more relevant topic. Teachers could develop an instructional segment helping students achieve the same performance expectations based on volcanoes instead of earthquakes.

IS6

Earth and Space Sciences Instructional Segment 6: Urban Geoscience

To culminate the study of Earth's **systems [CCC-4]** and how humans interact with them, this instructional segment describes a range of possible project ideas that make the geologic history of a region relevant even in areas where the closest thing to a rock is a small patch of dirt among a sea of pavement. Equally important is an exploration of some of the ways that humans shape the landscape when they build cities. These impacts are perfect opportunities for using engineering and technology to reduce negative impacts while making cities more livable places. A teacher can guide students towards topics that are most appropriate for their local area.

EARTH AND SPACE SCIENCES INSTRUCTIONAL SEGMENT 6: URBAN GEOSCIENCE

Guiding Questions

- How do Earth's natural systems influence our cities?
- How do cities affect Earth's natural systems?

Performance Expectations

Students who demonstrate understanding can do the following:

HS-ESS3-1. Construct an explanation based on evidence for how the availability of natural resources, occurrence of natural hazards, and changes in climate have influenced human activity. [Clarification Statement: Examples of key natural resources include access to fresh water (such as rivers, lakes, and groundwater), regions of fertile soils such as river deltas, and high concentrations of minerals and fossil fuels. Examples of natural hazards can be from interior processes (such as volcanic eruptions and earthquakes), surface processes (such as tsunamis, mass wasting and soil erosion), and severe weather (such as hurricanes, floods, and droughts). Examples of the results of changes in climate that can affect populations or drive mass migrations include changes to sea level, regional patterns of temperature and precipitation, and the types of crops and livestock that can be raised.]

HS-ESS3-4. Evaluate or refine a technological solution that reduces impacts of human activities on natural systems.* [Clarification Statement: Examples of data on the impacts of human activities could include the quantities and types of pollutants released, changes to biomass and species diversity, or areal changes in land surface use (such as for urban development, agriculture and livestock, or surface mining). Examples for limiting future impacts could range from local efforts (such as reducing, reusing, and recycling resources) to large-scale geoengineering design solutions (such as altering global temperatures by making large changes to the atmosphere or ocean).]

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

EARTH AND SPACE SCIENCES INSTRUCTIONAL SEGMENT 6: URBAN GEOSCIENCE

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

The 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-5] Using Mathematics and Computational Thinking [SEP-6] Constructing Explanations (for science) and Designing Solutions (for engineering)	ESS3.A: Natural Resources ESS3.B: Natural Hazards ESS3.C: Human Impacts on Earth Systems ETS1.B Developing Possible Solutions ETS1.C Optimizing Design Solutions	[CCC-2] Cause and Effect: Mechanism and Explanation [CCC-4] Systems and system models [CCC-7] Stability and Change

Highlighted California Environmental Principles and Concepts:

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

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

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

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

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

CA CCSS Math Connections: N-Q.1–3; MP.2, MP.4

CA CCSS for ELA/Literacy Connections: RST.11–12.1, 2, 7, 8, 9

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

Since the beginning of civilization, the locations of human settlements have been shaped by the natural landscape. Cities tend to be located near water sources, placed on hilltops for visibility and protection from invaders or are built with access to a particular natural resource such as a mine or fertile soil for farming. The location of cities is, in essence, an example of the CCC of **structure and function [CCC-6]**. San Francisco was built along San Francisco Bay because of its protection from ocean waves. The bay exists because of movement along faults on opposite sides of the bay. Sacramento sits at the intersection between two major rivers, including the place where gold was first discovered in California. Both the water and the gold washed down from the Sierra Nevada which was formed by an ancient collision between two plates. Los Angeles was founded around the Los Angeles River, which once flowed year-round before European settlers diverted all its water for irrigation. The beautiful views and pleasant outdoor opportunities such as hiking and biking that make California an attractive place to live are all a direct and positive consequence of the geologic history of the local area. Students can **investigate [SEP-3]** the early history of their city and see how it relates to the topography and other natural features.

The geologic history of an area determines the stability of the ground beneath a city's buildings. San Francisco is founded on ancient sand dunes, a particularly unstable material in earthquake country. But many other cities share a similar fate because most of them were built near rivers. From IS3 on Mountains, Valleys, and Coastlines, students know that rivers break apart rock from upstream mountains and deposit it in flatter valley areas downstream. During rainy seasons, rivers naturally flood, adding a new layer of loose sediment to the ground before the existing sediment has a chance to solidify. Those loose deposits make unstable foundations, and the closer a building is to a river, the more likely it is to be built on loose sandy soil. During earthquake shaking, wet, sandy soil begins to flow like a liquid (a process called liquefaction) and can no longer support buildings perched on top of it. Because of this risk, the state publishes maps showing areas with known liquefaction hazard (California Department of Conservation 2015). Students can use these maps to identify areas around their school that are at risk for liquefaction.

The same state hazard maps that show liquefaction hazard also show landslide hazard zones. Landslides are an example of rapid erosion and are worse in areas with steep mountains. California's coastal region, housing most of the state's population, runs along a plate boundary where plate motion uplifts mountains causing slopes to get steep more quickly than erosion and landslides can flatten them. A wide range of engineering solutions exists for protecting homes built in landslide hazard zones. For schools in neighborhoods where there is abundant landslide risk, students could explore some of these **solutions [SEP-6]**.

EARTH AND SPACE SCIENCE VIGNETTE 8.4: KEEPING IT COOL: ENGINEERING SOLUTIONS TO URBAN HEAT ISLANDS

Performance Expectations

Students who demonstrate understanding can do the following:

HS-ESS2-4 Use a model to describe how variations in the flow of energy into and out of Earth's systems result in changes in climate[Clarification Statement: Examples of the causes of climate change differ by timescale, over 1-10 years: large volcanic eruption, ocean circulation; 10-100s of years: changes in human activity, ocean circulation, solar output; 10-100s of thousands of years: changes to Earth's orbit and the orientation of its axis; and 10-100s of millions of years: long-term changes in atmospheric composition.] [*Assessment Boundary: Assessment of the results of changes in climate is limited to changes in surface temperatures, precipitation patterns, glacial ice volumes, sea levels, and biosphere distribution.*]

HS-ESS3-1. Construct an explanation based on evidence for how the availability of natural resources, occurrence of natural hazards, and changes in climate have influenced human activity. [Clarification Statement: Examples of key natural resources include access to fresh water (such as rivers, lakes, and groundwater), regions of fertile soils such as river deltas, and high concentrations of minerals and fossil fuels. Examples of natural hazards can be from interior processes (such as volcanic eruptions and earthquakes), surface processes (such as tsunamis, mass wasting, and soil erosion), and severe weather (such as hurricanes, floods, and droughts). Examples of the results of changes in climate that can affect populations or drive mass migrations include changes to sea level, regional patterns of temperature and precipitation, and the types of crops and livestock that can be raised.]

HS-ESS3-4. Evaluate or refine a technological solution that reduces impacts of human activities on natural systems.* [Clarification Statement: Examples of data on the impacts of human activities could include the quantities and types of pollutants released, changes to biomass and species diversity, or areal changes in land surface use (such as for urban development, agriculture and livestock, or surface mining). Examples for limiting future impacts could range from local efforts (such as reducing, reusing, and recycling resources) to large-scale geoengineering design solutions (such as altering global temperatures by making large changes to the atmosphere or ocean).]

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

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

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

HS-ETS1-3. Evaluate a solution to a complex real-world problem based on prioritized criteria and trade-offs that account for a range of constraints, including cost, safety, reliability, and aesthetics, as well as possible social, cultural, and environmental impacts.

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

EARTH AND SPACE SCIENCE VIGNETTE 8.4: KEEPING IT COOL: ENGINEERING SOLUTIONS TO URBAN HEAT ISLANDS

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

Highlighted Science and Engineering Practices	Highlighted Disciplinary Core Ideas	Highlighted Crosscutting Concepts
[SEP-1] Asking Questions and Defining Problems [SEP-2] Developing and Using Models [SEP-4] Analyzing and Interpreting Data [SEP-6] Constructing Explanations (for science) and Designing Solutions (for engineering)	ESS1.B: Earth and the Solar System ESS2.A: Earth Materials and Systems ESS2.D: Weather and Climate ESS3.A: Natural Resources ESS3.B: Natural Hazards ESS3.C: Human Impacts on Earth Systems ESS3.D: Global Climate Change ETS1.A: Defining and Delimiting Engineering Problems ETS1.B: Developing Possible Solutions	[CCC-2] Cause and Effect: Mechanism and Explanation [CCC-4] Systems and System Models [CCC-5] Energy and Matter: Flows, Cycles, and Conservation [CCC-7] Stability and Change Connections to Engineering, Technology, and Applications of Science Influence of Science, Engineering, and Technology on Society and the Natural World

Highlighted California Environmental Principles and Concepts:

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

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

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

CA CCSS Math Connections: S-ID.3, 5, 9; S-IC.6; MP.1, MP.2, MP.3, MP.4, MP.7

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

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

EARTH AND SPACE SCIENCE VIGNETTE 8.4:
KEEPING IT COOL: ENGINEERING SOLUTIONS TO URBAN HEAT ISLANDS

Introduction

By discovering that certain urban areas are much hotter than their surroundings, students apply and refine their existing model about Earth's energy balance. They articulate the mechanisms by which human activities can alter the local climate system and ultimately design measures to reduce that impact.

Length and position in course: This vignette describes two to three weeks of instruction and could serve as the first lesson in an instructional segment on urban geoscience. It describes how different land uses result in changes to surface materials. Activities related to the water cycle will naturally follow from this vignette because these same changes to the surface also have a dramatic impact on the hydrosphere.

Prior knowledge: This vignette could support and extend students' existing **models [SEP-2]** of Earth's energy balance (as introduced in IS2 of this course), or the vignette could provide students initial exposure to the factors that affect a system's temperature (that could later be extended to the global **scale [CCC-3]** of Earth's climate).

Students will need basic skills in navigating digital maps (such as Google Earth). They will need to interpret aerial and satellite imagery, which is a unique skill (i.e., can they distinguish a small home from a commercial building in a satellite image?). While this vignette provides opportunities to develop those skills, they are not specifically addressed in this lesson outline.

Teacher background: Urban scientists use the term "built" environment to describe landscapes that have been constructed and altered by humans (i.e., "man-made"). Urban heat islands are well-known phenomena found where materials of the built environment absorb and retain energy more readily than surrounding natural landscapes. Urban areas that use these materials surrounded by more rural landscapes with more natural materials are like islands of warm temperatures. There are three main ways that urban land use alters the local energy balance: 1) natural materials tend to reflect more light than artificial materials; 2) natural landscapes retain water but most urban surfaces are designed to drain water very efficiently. Since water has a high heat capacity, natural landscapes that retain it heat up more slowly than built ones. The water that gets retained can also evaporate, which takes thermal energy with it and leaves the surface cooler; and 3) human activities generate excess heat locally. Heating and cooling buildings, combusting fuels in vehicles, using electrical appliances, and industrial processes are all examples that generate heat.

Urban settings: The urban geoscience unit is focused on issues facing the local community, and this vignette introduces a range of local data available freely on the Internet. Despite the use of the word "urban," heat islands can be found in most places where humans modify landscapes. Small towns, farmhouses, and even different species of crops have different thermal properties and affect local temperatures. As such, this vignette should have broad application in most California communities, urban and rural.

5E Learning: This sequence is based on an iterative 5E model where each activity has a role in the 5Es, but each activity also needs to include each of the 5Es along the way. The 5E model parallels the science and engineering practices of the CA NGSS in many ways, but are applied in the perspective of lesson design. While SEPs should be shared explicitly with students, the 5Es are only for the benefit of the teacher.

EARTH AND SPACE SCIENCE VIGNETTE 8.4: KEEPING IT COOL: ENGINEERING SOLUTIONS TO URBAN HEAT ISLANDS

Day 1: Built and Natural Environments

Students explore the differences between the natural and built environment and begin to consider the interactions between these environments and the Sun.

Days 2–3: Neighborhood Temperature from Satellite

Students use satellite images displayed in Google Earth to investigate temperature differences in their neighborhood.

Days 4–5: X-factor Temperature Investigation in the Schoolyard

Students use digital thermometers to investigate different factors that affect the local temperature in their school.

Day 6: Historical Land-Use Changes from Online Aerial Photos

Students analyze land-use changes in their neighborhood over the last several decades using online historical air photos.

Days 7–9: Urban Design Engineering Challenge

Students design and evaluate a city plan based on principles that will reduce the urban heat island effect.

Day 10: Systems Within Systems

Students consider implications for other Earth systems (most notably, the water cycle and relationships to global climate change).

Day 1: Interactions Between the Built and Natural Environment (Engage)

Everyday phenomenon: Some locations like parking lots are hotter than surrounding areas while parks can be cooler than their surroundings.

Dr. D had written a short skit that activated students' prior everyday experiences involving temperature variations at different locations in their own community. She assigned different students roles in the skit, and they acted out their parts, pretending to be hanging out after school and discussing the hot weather. In the skit, Andrea suggested that they all go to the beach, but Raul does not like to leave his car in the hot parking lot and his feet always get burned on the hot sand. Sara knew this one bench at the local park that always seemed much cooler than everywhere else. The skit finished with the students agreeing that wherever they go, they need to leave the hot concrete steps of the school. Dr. D told students that over the next two weeks, they would understand many details about the processes that affect temperatures in their community.

With these ideas in mind, Dr. D had an activity she hoped would motivate students to think about their community as a system with interacting components. She placed students in their standard groups of four and gave each student a different card with a picture of an object from their community on it. She asked students to identify their objects as either natural (like a plant, a rock, or an animal) or an object from the built environment (like a building, a

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parking lot, or a fountain). She had students brainstorm about how the four different objects in their group might interact. Casey was the class clown and comes up with a crazy story that related the fire engine, grass, apartment building, and butterfly in his group: a butterfly sitting on the grass narrowly escaped a lawnmower and flew up to land on the apartment balcony, distracting the resident from her cooking, which led to a disastrous fire that needed to be put out using the fire hydrant. Dr. D loved the story and invited Casey to relate the story to the whole class. She used the opportunity to emphasize that some interactions were simple and plausible and some were not. She asked students to tape their cards to the poster board and decide on plausible interactions between the objects that they thought were the most important to the functioning of the community. After a few minutes, she had each group pair up with a group that received a different set of objects. Students from one group **communicated [SEP-8]** their **models [SEP-2]** to the other group and then switched cards. Students needed to extend their model by adding the new objects. Dr. D then added the final and most important object. She handed each group a card showing the Sun and asked students to draw interactions between their object and the Sun (figure 8.62). The Sun is at the heart of Earth's energy balance and has an effect on every object in our community. She asked them to consider if there are differences between the way natural objects and built objects interact with the Sun.

Figure 8.62. Example System Model Linking Objects in the Built and Natural Environment

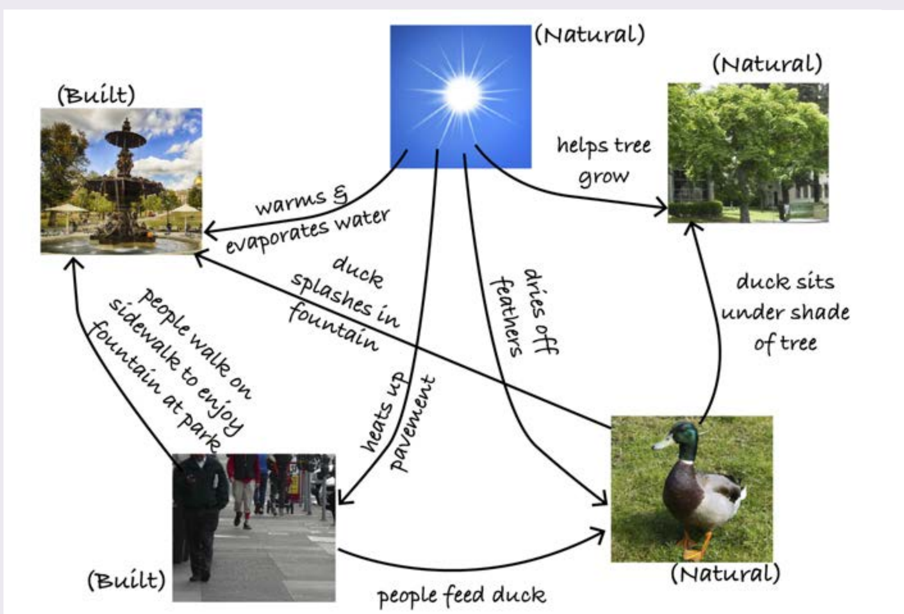

Figure by M. d'Alessio with images from Jordan 2012; Kilby 2013; radcliffe dacanay 2008; JGKlein 2010; nbcorp 2012
Long description of Figure 8.62.

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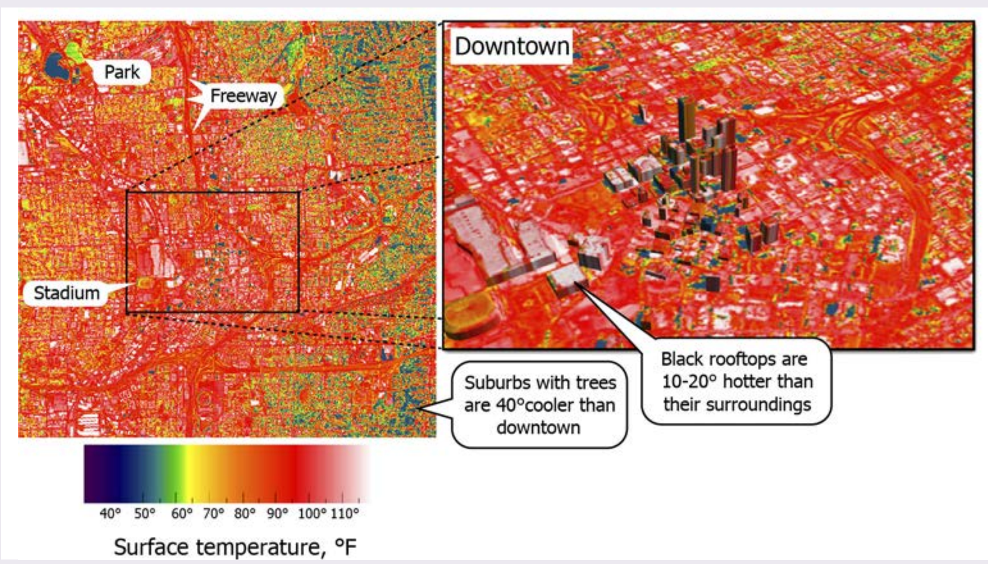
Days 2–3: Neighborhood Temperature from Satellite (Explore)

Anchoring phenomenon: An infrared camera can "see" the difference between a cup of hot water and a cup of cold water.

Earth scientists depend heavily on images collected by satellites to study what is happening on Earth. Dr. D's class next **analyzed [SEP-4]** two different types of satellite pictures, one that students were already familiar with and one that they were not. She began by engaging students with an Internet video clip of a building inspector demonstrating applications of thermal infrared cameras. The inspector held up a mug with cold water and one with hot coffee and showed how the camera distinguished between the two. Dr. D used this to motivate a brief introduction to the physics of black body radiation. She knew that the students would be using this idea again in the study of stars, so she gave a brief lecture about how objects at different temperatures emit energy at different wavelengths. She explained that some satellites have cameras that record the temperature of the land surface by the radiation the land emits in infrared. The students compared these thermal maps with the standard aerial photographs available in Google Earth, looking for **patterns [CCC-1]** in the relationship between the temperature and the type of landscape and land use (different types of natural and built environments) (figure 8.63).

Figure 8.63. Satellite Images Reveal Temperature Differences in Urban Areas



Satellite images in infrared reveal that different land uses cause dramatically different temperatures in urban areas. *Source*: NASA n.d.; NASA/Goddard Space Flight Center Scientific Visualization Studio 1997

Long description of Figure 8.63.

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Investigative phenomenon: The temperature of the ground surface at different locations in a city depends on the land use.

Before walking over to the computer lab, Dr. D used her classroom computer to demonstrate how students would obtain the data and how it could be viewed in Google Earth. She demonstrated map navigation and explained the color scale on the thermal map. She emphasized that there is a big range of temperatures and tests students' basic ability to identify the relative temperature of different regions from the color by asking a few clicker questions that the students answered using a smartphone app. She also showed students the data entry form on the course Web site where all student observations would be collected and analyzed together.

Once they walked over to the computer lab, she helped students log into the computers and download the satellite data file she had preloaded on her Web site under today's agenda and opened up the data collection online form. Knowing this is an exciting tool, she encouraged students to explore freely in Google Earth for about three minutes after everyone was logged in. She eventually called the students to attention and instructed them to begin their data collection. They worked diligently, exploring different locations on the map and recording map location, temperature, and land-use category. The class period ended and Dr. D ensured that students had all hit submit on their data collection forms.

When students arrived the next day, submissions from the whole class were combined in an online spreadsheet so that everyone could **analyze the large data set [SEP-4]**. The students all found that the airport runway was among the hottest places on the entire map, and that most of the large shopping centers were very hot as well. "That makes sense because you can feel the heat when you walk across the parking lot," offered Micah. Many people found that parks in the city were cooler than average, but there were a few discrepancies. Since each student had submitted the latitude and longitude of their observation, Dr. D zoomed in on one of these outliers. The location was much hotter than average, but it was clear that this location was a parking lot and not a park, so the submitter made an error. Casey admitted that the submission was his and apologized to the class, saying "It was big like a park."

Investigative phenomenon: Schools tend to be hotter than average, but there is variation between them.

The students were surprised to see that many of the schools in the city were hotter than average, but not all of them. The students were skeptical of the data and insisted that Dr. D zoom in to check the observations. They were satisfied after the data quality was confirmed for the first few submissions. They **asked questions [SEP-1]** about what made one school different from another.

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After the whole class discussion, Dr. D had students individually create a one-paragraph summary **communicating [SEP-8]** the overall class findings, with an emphasis on the **patterns [CCC-1]** in the data. She then randomly selected one student from each team to share their paragraph with the others. The team members offered improvements, additions, and edits, which were implemented in real time. At the end of class, Dr. D collected the one edited team submission and gave each team a group grade for the final product. She confirmed that students left class with the general understanding that many natural landscapes are cooler than average while the built environment is often warmer than average. Students had also come up with an appreciation that there are complexities and exceptions to this general pattern.

Days 4–5: X-Factor Temperature Investigation on the Schoolyard (Explain)

Investigative phenomenon: Two schools that look similar in an aerial photo have different temperatures in satellite data.

Dr. D started off class with aerial pictures of two schools from their city and asked the students to predict which one would be warmer. She intentionally selected two schools that appeared similar in the photos but that had fairly different temperature profiles in the satellite temperature data. This motivated students to think about the full range of possibilities that could **explain [SEP-6]** the difference. “The grass looks greener in one. Do you think that makes a difference?” “Maybe, but look at the parking lots. One is on the south side of the school and the other is smaller and is on the north side of the school.” The students asked Dr. D for the answer, and she replied that she honestly did not know. The students had offered up many plausible ideas that would motivate further investigation, but in real science there is no answer key. They had already made some interesting claims about possible influences on the school’s temperature, but today they would need to gather **evidence [SEP-7]** to see if they could support those claims.

Investigative phenomenon: Students investigate a single factor to see how much it affects the temperature around the schoolyard.

Each group had to **plan and carry out an investigation [SEP-3]** into a single factor that could have affected temperature (the “X-factor”). Each group got one digital stick thermometer that read temperatures with a precision of 0.1 degrees (they cost about $25 each and the chemistry teacher at Dr. D’s school let her borrow a class set). Students all agreed on these general protocols: thermometers should always be shaded with a book; they should be held at arm’s length about one meter above the ground; and they should not record the temperature until the thermometer has stabilized to within 0.1 degrees for at least 30 seconds. Beyond that, individual students had to decide their own procedure that would ensure sufficient data to show a repeatable signal.

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Some of the projects the students decided include measuring temperature as a function of

- distance away from a building;
- distance from the center of a grassy field out towards the edges;
- distance from an air conditioning unit attached to the classroom;
- position along the track for the 100 m dash;
- different sides of the building, as measured a fixed distance away;
- type of ground-surface material, as measured at several locations close to one another;
- elevation, as measured from the windows of different floors of the building;
- air speed, as measured while riding a bicycle at different speeds.

Dr. D knew that some of these factors should not affect the temperature.

After collecting their data, students presented their experiment and their findings and proposed an **explanation [SEP-6]** for the **data [SEP-4]**. Unlike a typical controlled laboratory experiment, students could not completely isolate a single variable. As they presented their project reports, they had to account for any unexpected variations and **construct an argument [SEP-7]** that 1) their X-factor was the most important determiner of temperature; 2) their X-factor turned out to be unimportant; or 3) an unintended variable interfered with the ability to conclude either way. Quite often, students discovered a factor that they did not anticipate had become more important than their original idea.

After the project presentations, Dr. D had students summarize all the findings in a two-column table: factors that **caused [CCC-2]** temperature to be warmer and those that caused temperatures to be cooler. She then gave a short lecture defining the framework for a **model [SEP-2]** of energy balances in **systems [CCC-4]**, including the energy input, output, and storage within the system. She referred back to a few examples from students' X-factor analyses during her lecture; then she asked students to sort all the items in their original table into three new rows corresponding to factors that had affected the amount of energy coming into a spot (e.g., shade from trees decreases the input), the energy output (e.g., shiny surfaces reflect light), or the energy retained (e.g., water has a high heat capacity and so a large amount of energy can be absorbed without causing the temperature to change much). Students applied this model to writing a scientific **explanation [SEP-6]** about why built environments appear hotter than natural ones.

Day 6: Historical Land-Use Changes from Online Aerial Photos (Elaborate)

Investigative phenomenon: Many cities look very different today than they did 50 or more years ago.

Cities are not static. Dr. D engaged students by asking them if anything in the city had changed since they were younger. How might those **changes [CCC-7]** have affected the temperature of the city? Students used online archives of aerial photographs to document some of these land-use changes (figure 8.64). Google Earth has archives going back one or

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two decades (see Google Earth Help at https://www.cde.ca.gov/ci/sc/cf/ch8.asp#link66), and other Web sites include photos going back more than 50 years (such as Historic Aerials at https://www.cde.ca.gov/ci/sc/cf/ch8.asp#link67). Students **communicated their information [SEP-8]** with a simple timeline in which they noted changes in land use and indicated whether or not they thought that the changes increased or decreased the local temperature and whether this change had affected the inputs, outputs, or energy retention properties of the system. Students loved seeing how their city had grown. Amara asked, “Didn’t they know that they were heating up the city when they replaced that marshy area with the shopping mall?”

Figure 8.64. Aerial Photographs Around a Local High School Show Changes Over Time

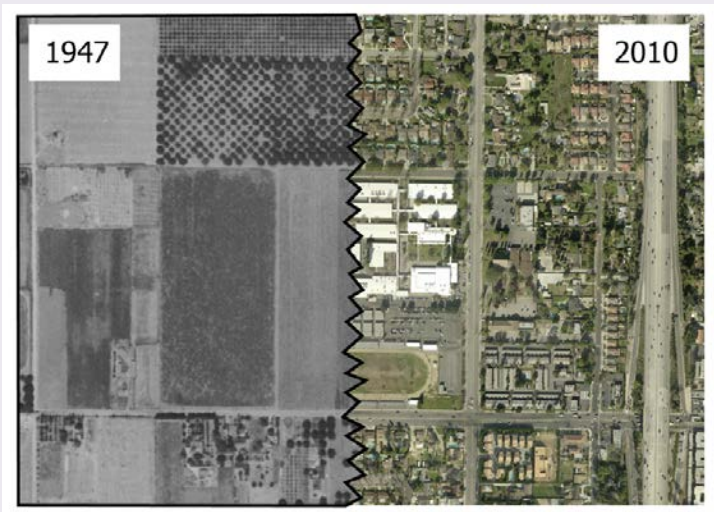

Figure by M. d’Alessio with images from USGS 2015
Long description of Figure 8.64.

Days 7–9: Urban design engineering challenge (Evaluate)

Investigative phenomenon: How can we design a city block so that it stays cool and is comfortable?

Dr. D began the day by showing two different designs by two different people for the same space (figure 8.65). She asked the students to think about the process the designers went through to create the plans. What did they consider? (HS-ETS1-1; EP&C V). She reviewed the engineering design process and explained that it can be applied to a wide range of different types of problems, including some that they may not have even thought of as “engineering” before. For this scenario, the city had recognized the urban heat island problem and was considering solutions. A developer planned to rebuild a large city block and the city council

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would evaluate a range of options. Students played the role of green urban planners presenting their proposal to a city council design review board (HS-ETS1-2). They discussed the constraints (i.e., what materials are available, how many people need to live on the block, the shape and size of the available land, etc.) and the criteria for measuring success (local temperature). They drew up a site plan, visualization sketches, and a bill of materials. As part of their **argument [SEP-7]** to the city council, they had to identify the specific components of the design that reduced urban heat island effects. Audience members evaluated the plan and helped iteratively improve the design by offering specific suggestions for reducing urban heating even further (HS-ETS1-3).

Figure 8.65. Two Competing Designs for a City Block by Professional Design Companies

Source: Cal Srigley Illustration, for Rafii Architects Inc. 2015; Cedeon Design 2015
Long description of Figure 8.65.

Day 10: Systems within Systems (Elaborate/Extend)

Investigative phenomenon: Simulations show that California will feel the effects of global warming, and the change will be more pronounced in urban areas.

Dr. D used this day to explicitly relate urban heating to global climate change. She engaged students by asking them to describe how their behavior changed on really hot days. She then provided students with the results of simulations that indicated that the number of extreme heat days in their city would likely go up significantly as a result of global warming (California Energy Commission 2015), and that this **change [CCC-7]** would be more pronounced in urban areas because of the urban heat island effect (figure 8.66). This **data analysis [SEP-4]** activity could support HS-ESS3-5.

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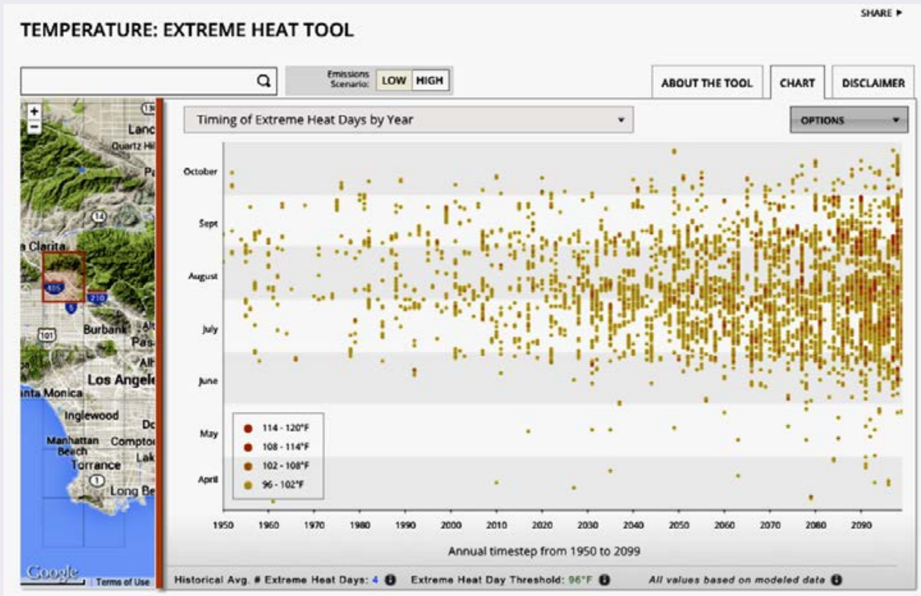
Figure 8.66. Forecasts of Extreme Heat Days for Northridge, CA



Available for all of California on the Cal-Adapt Web site. *Source*: California Energy Commission 2015.

Long description of Figure 8.66.

The class used the article "Climate Change in the Golden State" (https://www.cde.ca.gov/ci/sc/cf/ch8.asp#link68) to gather evidence about the scale and scope of the effects of climate changes in California. The class discussed three key questions: Can the recent changes in California's climate be explained by natural causes? If natural causes cannot explain the rising temperatures, what anthropogenic factors have produced these changes? If temperatures in California's climate continue to rise, what effects will this have on humans and the state's natural systems? Dr. D prompted students to articulate the connections between human society and natural systems (EP&Cs I, II).

The urban heat island effect is very similar to what is going on at a global **scale [CCC-3]** with the greenhouse effect. Students compared the **models [SEP-2]** of the energy balance of the Earth as a whole and the energy balance of a city. So far, students had primarily focused on the interactions between the anthrosphere and the geosphere, but now Dr. D asked students to draw a concept map relating urban heat island effects to other Earth **systems [CCC-4]**. Their maps include the biosphere (that **causes [CCC-2]** cooling by evapotranspiration but is also stressed by increased evaporation from elevated urban temperatures stress plants and animals), the atmosphere (increased temperatures cause increased evaporation), and the hydrosphere (water runs off artificial materials instead of infiltrating into the ground). The connections to the hydrosphere offered an excellent transition into the next topic of study, urban hydrology and water resources.

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Vignette Debrief

Most students had personally experienced the phenomenon of heat islands in the built environment, but few had thought about it as deeply as in this vignette. Having data to measure and being able to visualize the effect (both using satellite imagery and temperature probes) allowed students to dive into understanding the situation using all three CA NGSS dimensions.

SEPs. After students performed two **investigations [SEP-3]** of temperature variations at a range of **scales [CCC-3]**, they **ask questions [SEP-1]** about what was causing the dramatic heat island effects. They **analyzed their data [SEP-4]** to help figure out the relationship between different components in the **system [CCC-4]** they studied. They used these relationships to **develop a model [SEP-2]** of the system. They used the data from their investigations along with the reasoning of their model to **construct an explanation [SEP-6]** about what **caused [CCC-2]** urban heat islands. In the engineering design challenge, they employed engineering practice by **defining the parameters of the problem [SEP-1]** and **designing solutions [SEP-6]**. They then created a compelling **argument [SEP-7]** that their design was an effective way to mitigate human impacts on local temperature. On day 10, students briefly explored the results of **computational [SEP-5]** simulations that forecast how urban heat islands will cause an even greater impact in the future.

DCIs. Urban heat islands are a tangible example of human impacts on Earth systems (ESS3.C) and a microcosm of the entire energy balance in the global climate system (ESS2.D). Students began to characterize variations in Earth materials and the impact of these variations (ESS2.A), acknowledging that the built environment is a key part of Earth's systems.

CCCs. Students applied the crosscutting concept of **systems and systems models [CCC-4]** to represent the **flow of energy [CCC-5]** and the interactions between energy and matter. Students looked for **patterns [CCC-1]** in temperature **data [SEP-4]** to test for **cause and effect [CCC-2]** relationships between land use and heat islands. The **model [SEP-2]** that they developed was valid at a range of **scales [CCC-3]** from a single city block to a whole city or the entire planet.

EP&Cs. Urban heat islands affect the welfare of humans in their everyday lives, and students discovered that many of the best solutions to the problem involved the successful integration of natural ecosystems within the urban core (EP&C I). At the same time, the effect of urban heat islands extended to natural **systems [CCC-4]** within and beyond the urban core. For example, excess heat from urban areas can drive evaporation that stresses ecosystems (EP&C II). Day 10 emphasized these relationships. The engineering design challenge was a realistic scenario in which students had to support the needs of the people living in an urban city block while reducing urban heat island effects. Their design had to consider a range of factors (EP&C V).

CA CCSS Connections to English Language Arts and Mathematics. Throughout the vignette students were asked to participate in small group and whole class discussions (SL.9–10.1a–d). They analyzed data sets online and also created their own data sets by measuring temperatures around their school looking for patterns (S-ID 3, 5, 9). Students were asked

PHYSICS IN THE UNIVERSE VIGNETTE 7.3: SEISMIC WAVES

to summarize their findings and also write scientific explanations (W.9–10.a–f; WHST.9–10.1a–e, 6, 7, 9). Finally, students participated in a mock city council where they presented proposals to reduce the effects of heat islands (SL.9-12.6).

Resources

Several of the activities described in this vignette were adapted from other sources and are cited within. Please refer to them for more detail.

The introductory lesson on the built environment and the historical aerial photo analysis are two lessons in a much broader series of activities by Arizona State University's Ecology Explorers. They offer additional activities that could extend ideas in day 10 of this vignette to investigate impacts on human heat illness, an investigation into evapotranspiration, and more. https://www.cde.ca.gov/ci/sc/cf/ch8.asp#link69

The X-factor urban temperature analysis is a published activity: https://www.cde.ca.gov/ci/sc/cf/ch8.asp#link70

Temperature data from day 2 come from the ASTER GED 100 m data set, which can be downloaded at https://www.cde.ca.gov/ci/sc/cf/ch8.asp#link71. At this point, viewing images downloaded at that site requires specialized tools, but a service by Google called "Earth Engine" provides convenient and user-friendly access to the ASTER GED surface temperature data (https://www.cde.ca.gov/ci/sc/cf/ch8.asp#link72). There are plans to create a simple educational interface for the entire state of California specifically for this activity.

Cal Srigley Illustration, for Rafii Architects Inc. 2015. 2010 Marine Drive / 1633 Capilano Road (Grouse Inn), Plaza Artist Rendering. https://www.cde.ca.gov/ci/sc/cf/ch8.asp#link73 California Energy Commission. 2015. Cal-Adapt, Temperature: Extreme Heat Tool. https://www.cde.ca.gov/ci/sc/cf/ch8.asp#link74

Cedeon Design. 2015. Proposed Commercial Square in Cambridge, UK. https://www.cde.ca.gov/ci/sc/cf/ch8.asp#link75

JGKlein. 2010. "West Valley Regional Branch Library, Reseda, CA." Posted at *Wikimedia Commons*, https://www.cde.ca.gov/ci/sc/cf/ch8.asp#link76

Jordan, Jonathan. 2012. "Mallard Duck on Grass." Posted at *Flickr*, https://www.cde.ca.gov/ci/sc/cf/ch8.asp#link77

Kilby, Eric. 2013. "Boston Common Fountain (HDR)." Posted at *Flickr*, https://www.cde.ca.gov/ci/sc/cf/ch8.asp#link78

NASA. N.d. https://www.cde.ca.gov/ci/sc/cf/ch8.asp#link79

NASA/Goddard Space Flight Center Scientific Visualization Studio. 1997. "Beating the Heat in the World's Big Cities." https://www.cde.ca.gov/ci/sc/cf/ch8.asp#link80

nbcorp. 2012. "Sun." Posted at *Openclipart.org*, https://www.cde.ca.gov/ci/sc/cf/ch8.asp#link81

radcliffe dacanay. 2008. "People Walking on City Street San Francisco 01." Posted at *Flickr*, https://www.cde.ca.gov/ci/sc/cf/ch8.asp#link82

USGS. 2015. Earth Explorer. https://www.cde.ca.gov/ci/sc/cf/ch8.asp#link83

Cities are **systems [CCC-4]** with interacting components that meet a wide range of human needs. Like the broader Earth system, a city is also an example of a system of systems: transportation, utilities, commerce, education, and other sectors of society are all systems of their own that interact with one another. Game-based learning opportunities allow students to explore some of these complexities and the impact that city policies can have on the long-term sustainability of the natural environment (see ElectroCity at https://www.cde.ca.gov/ci/sc/cf/ch8.asp#link84 and SimCityEDU at https://www.cde.ca.gov/ci/sc/cf/ch8.asp#link85). These computer simulations allow students to explore complex real-world problems with numerous constraints and criteria (HS-ETS1-4).

Engineering Connection: Reducing Urban Runoff

One of the biggest **changes [CCC-7]** an urban landscape makes upon the world is covering soil with impermeable concrete and structures. These **changes [CCC-7]** disrupt the natural hydrologic cycle, preventing water from soaking in and becoming groundwater and instead sending it into river channels where it can cause flooding, increased erosion, or both. As water moves across the surface in the built environment, it carries contaminants into these waterways contaminating the water. Students can apply their knowledge of Earth materials to explore solutions to the urban runoff problem by designing systems to catch and filter runoff before it enters waterways (see Engineering is Elementary *Don't Runoff* at https://www.cde.ca.gov/ci/sc/cf/ch8.asp#link86) (HS-ESS3-4; HS-ETS1-2). Harmful pollutants are just one of the many ways that urban areas have significant impact on plant and animal life in a region (anthrosphere-biosphere interactions, LS4.D; EP&C II).

IS7

Earth and Space Sciences Instructional Segment 7: Star Stuff

Once students have a firm grasp of what goes on here on Earth, the CA NGSS asks them to ponder how Earth fits into the broader universe. The previous instructional segments were ultimately focused on the practical ways in which Earth's **systems [CCC-4]** affect humanity today (always building towards ESS3.A, B, C, and D). However, science does not always need to be practical. The very first page of chapter 1 of the *NRC Framework* states, "Understanding science and the extraordinary insights it has produced can be meaningful and relevant on a personal level, opening new worlds to explore and offering lifelong opportunities for enriching people's lives" (National Research Council 2012, 7). This human dimension of science is codified in the science and engineering practices of the CA NGSS, which identify **asking questions [SEP-1]** and curiosity as a fundamental part of doing science. For this reason, IS7 and IS8 focus in on big picture questions about our origins and place in the universe (ESS1.A). To transition into these instructional segments, teachers might want to emphasize the different purpose of the science in the previous instructional segments from these final instructional segments.

EARTH AND SPACE SCIENCES INSTRUCTIONAL SEGMENT 7: STAR STUFF

Guiding Questions

- How do we know what are stars made out of?
- What fuels our Sun? Will it ever run out of that fuel?
- Do other stars work the same way as our Sun?

Performance Expectations

Students who demonstrate understanding can do the following:

HS-ESS1-1. Develop a model based on evidence to illustrate the life span of the sun and the role of nuclear fusion in the sun's core to release energy in the form of radiation. [Clarification Statement: Emphasis is on the energy transfer mechanisms that allow energy from nuclear fusion in the sun's core to reach Earth. Examples of evidence for the model include observations of the masses and lifetimes of other stars, as well as the ways that the sun's radiation varies due to sudden solar flares ("space weather"), the 11-year sunspot cycle, and non-cyclic variations over centuries.] [*Assessment Boundary: Assessment does not include details of the atomic and sub-atomic processes involved with the sun's nuclear fusion.*]

HS-ESS1-3. Communicate scientific ideas about the way stars, over their life cycle, produce elements. [Clarification Statement: Emphasis is on the way nucleosynthesis, and therefore the different elements created, varies as a function of the mass of a star and the stage of its lifetime.] [*Assessment Boundary: Details of the many different nucleosynthesis pathways for stars of differing masses are not assessed.*]

EARTH AND SPACE SCIENCES INSTRUCTIONAL SEGMENT 7: STAR STUFF

HS-ESS1-6. Apply scientific reasoning and evidence from ancient Earth materials, meteorites, and other planetary surfaces to construct an account of Earth's formation and early history. [Clarification Statement: Emphasis is on using available evidence within the solar system to reconstruct the early history of Earth, which formed along with the rest of the solar system 4.6 billion years ago. Examples of evidence include the absolute ages of ancient materials (obtained by radiometric dating of meteorites, Moon rocks, and Earth's oldest minerals), the sizes and compositions of solar system objects, and the impact cratering record of planetary surfaces.] (Repeated in IS8)

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

Highlighted Science and Engineering Practices	Highlighted Disciplinary Core Ideas	Highlighted Crosscutting Concepts
[SEP-2] Developing and Using Models [SEP-6] Constructing Explanations (for science) and Designing Solutions (for engineering) [SEP-8] Obtaining, Evaluating, and Communicating Information	ESS1.A: The Universe and Its Stars ESS1.C: The History of Planet Earth PS1.C: Nuclear Processes PS3.D: Energy in Chemical Processes and Everyday Life	[CCC-1] Patterns [CCC-2] Cause and Effect: Mechanism and Explanation [CCC-3] Scale, Proportion, and Quantity [CCC-5] Energy and Matter: Flows, Cycles, and Conservation [CCC-7] Stability and Change

Highlighted California Environmental Principles and Concepts:

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

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

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

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

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

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

CA CCSS for ELA/Literacy Connections: SL.11–12.4; RST.11–12.1, 2, 7, 8, 9; WHST.9–12.1a–e, 2a–e, 7

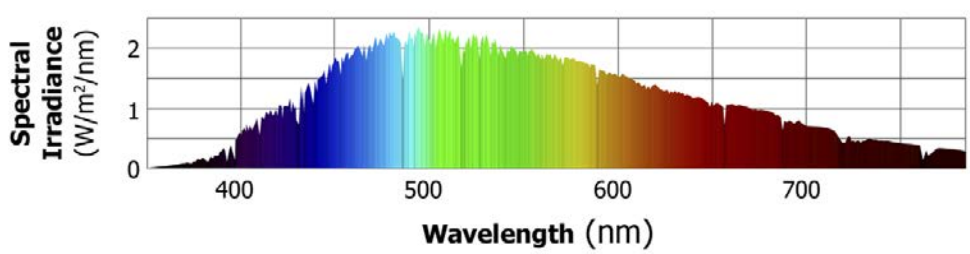
CA ELD Connections: ELD.PI.11–12.1, 5, 6a–b, 9, 10, 11a

The title of IS7 derives from a quote by Carl Sagan: “Some part of our being knows this is where we came from. We long to return. And we can. Because the cosmos is also within us. We're made of star-stuff.” This rather philosophical statement may resonate well with students, as distant objects in the universe are made familiar to them and they become able to understand that the universe can indeed be explored and studied.

The Colors of Stars

Looking carefully, students notice different stars have slightly different colors—those differences reveal a huge amount about what stars are and the way they work. When viewing the rainbow of light from our Sun through a prism, some colors appear brighter than others (figure 8.67). What causes these variations? Are they the result of errors in the equipment, something peculiar about our Sun, or a common feature of stars? Like all good science, this general observation with the naked eye can be refined with detailed measurement of specific **quantities [CCC-3]** such as the intensity of light at each wavelength (a color spectrum). Students can **obtain [SEP-8]** color spectra from many different stars using an online tool (such as the Sloan Digital Sky Survey/Sky Server, *What is Color* at https://www.cde.ca.gov/ci/sc/cf/ch8.asp#link87) and **compare them [SEP-4]**, noting several important **patterns [CCC-1]**. These patterns give clues about the **cause [CCC-2]** of different phenomena.

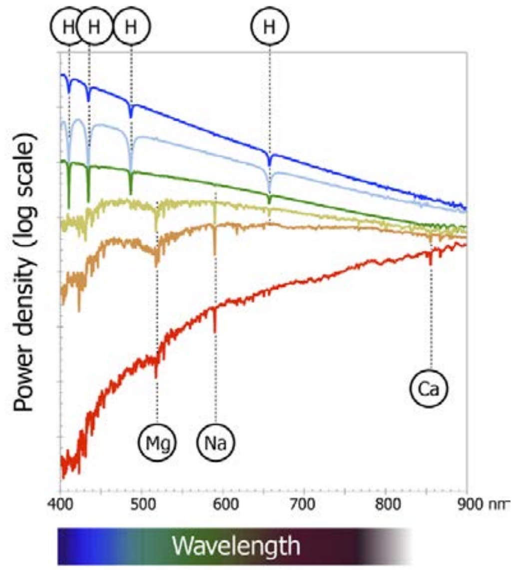
Figure 8.67. Color Spectrum of Our Sun



Color spectrum of our Sun. The rainbow image and the height of the graph depict the same information. The rainbow image is created by splitting the light from a telescope with a prism. The values of the graph are measurements of the relative intensity of each color. The graph dips lower where the rainbow image is dimmer. Graph by M. d’Alessio
Long description of Figure 8.67.

Students notice that many stars have bands of low intensity at exactly the same wavelength (fig. 8.68). Understanding this observation requires additional background in physical science. The *NRC Framework* lays out strong connections between the DCIs in this instructional segment and physical science: “The history of the universe, and of the **structures [CCC-6]** and objects within it, can be deciphered using observations of their present condition together with knowledge of physics and chemistry” (National Research Council 2012, 173).

Figure 8.68. Spectra of Six Different Stars

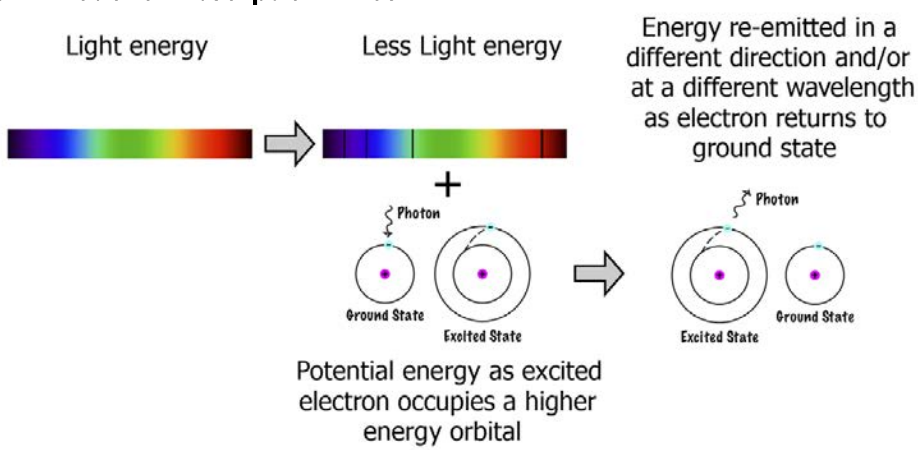


Circles indicate spectral lines from different elements on the periodic table. Graph by M. d’Alessio with data from Sloan Digital Sky Survey/SkyServer n.d.a
Long description of Figure 8.68.

The concept of absorption lines in spectra from stars unites the study of matter and the study of waves. Students must build upon their understanding of matter too small to see (5-PS1-1) by developing a model of the internal structure of atoms (HS-PS1-8). They must understand that atoms are made of nuclei of protons and neutrons and that the number of protons and neutrons helps determine the physical properties of the diverse materials that make up the universe, and that atoms have electrons that can move closer or farther away from the nucleus. If students take this ESS course before the physics or chemistry course, teachers must develop that model here since it is not included in the performance expectations for the middle grades. Understanding the **evidence [SEP-7]** about light spectra requires building on the idea that light is part of the broader electromagnetic spectrum (PS4.B: HS-PS4-1 in the high school physics course). The dark bands common in star spectra occur because atoms of different elements absorb specific colors of light. Students have studied **energy [CCC-5]** conversion as early as fourth grade and throughout the grade spans (PS3.B: 4-PS3-4, MS-PS3-3, 4, 5, HS-PS3-3), and now they must consider a very sophisticated example of individual atoms working as tiny energy conversion devices.

Atoms absorb some of the light energy (or other energy from the electromagnetic spectrum) that hits them, which pushes electrons to higher energy levels than their normal "ground state" and temporarily stores the energy as a potential energy. The atom quickly converts the energy back to light energy to return to its ground state, but that energy may be emitted in a completely different direction than the original energy or may be at a different wavelength. Each element on the periodic table has a unique configuration of electron orbitals, so different elements absorb light energy at very specific colors (wavelengths). Students can therefore use the absorption bands as fingerprints to identify the types and relative quantity of elements in a given star. Figure 8.68 shows that common star spectra include fingerprints of a number of elements, and more detailed analysis allows scientists to determine the full range of elements and even their relative abundance to construct the complete chemical composition of a star's atmosphere. For students to be able to **explain [SEP-6]** this multi-step process, the class could act out the process using their bodies to represent different components of the **system [CCC-4]** in a physical **model [SEP-2**. Using the language of **systems [CCC-4]** helps focus student attention on the energy inputs (light), the internal workings of the system (electrons in different energy-level orbitals), and the energy outputs (light emitted in a different direction or at a different frequency than the energy input) (figure 8.69).

Figure 8.69. A Model of Absorption Lines



Absorption spectra occur because individual atoms can temporarily convert light energy into potential energy. Diagram by M. d'Alessio with images from Wereon 2006 and NASA 2010
Long description of Figure 8.69.

The absorption of specific wavelengths of electromagnetic waves occurs in stars, but also all around on Earth, including in greenhouse gases in Earth's atmosphere. Materials like CO_2 and water vapor absorb infrared energy leaving the planet and re-emit it back toward

Earth so that energy that would otherwise have left the system is retained. This process is fundamental to Earth's **energy [CCC-5]** balance as discussed in the high school Chemistry in the Earth System course (HS-ESS2-4).

Evidence for Fusion

For ages, scientists have pondered what has caused the Sun to shine. In 1854 William Thomson (who later became so well known as a scientist that he was knighted and now is known as Lord Kelvin) published a paper calculating that the Sun would run out of fuel completely in just 8,000 years if it were made entirely of gunpowder, which was the most energy-dense self-contained fuel he could think of at the time (Kelvin 1854). Even in the 1850s, geologists had evidence that the Earth is considerably older than that, so controversy ensued over what causes the Sun to shine.

Lord Kelvin correctly determined that no chemical reaction would yield enough energy to power the Sun, but he incorrectly concluded that the Sun must be getting a constant replenishment of energy from meteors that collide with it. He died in 1907, more than a decade before scientists discovered a process that could release previously inconceivable amounts of energy, nuclear fusion (IS4). Under most conditions, when two atoms collide they bounce off one another because of the repulsive forces between their nuclei. If the atoms are moving fast enough, their nuclei may get close enough together so that when they collide, they fuse, releasing more than a million times more energy per unit of mass than any chemical reaction.

Students can repeat Lord Kelvin's **calculation [SEP-5]** about how long the Sun can last if it continues to emit energy at its current rate, but this time using information he did not have about the composition of the Sun from spectral lines (not gunpowder, but 75 percent hydrogen) and the energy release of hydrogen fusion (instead of chemical reactions). This approximate calculation of the **scale [CCC-3]** of energy release shows that the Sun's lifetime will be on the order of several billion years. Students can **support or refute the claim [SEP-7]** that this result is reasonable using evidence of the age of the Earth from IS4.

A Model of Fusion in Stars Over Their Lifecycle

For fusion to occur, atoms must reach a high enough temperature that they move quickly enough to fuse together, typically millions of degrees. Such temperatures do not occur naturally anywhere on Earth—they only happen in the interiors of stars where temperatures and pressures are so high due to gravity and the kinetic energy of in-falling matter. But even at the center of a star, conditions can **change [CCC-7]** that cause fusion to start and stop. As a result, we say that stars are born and die.

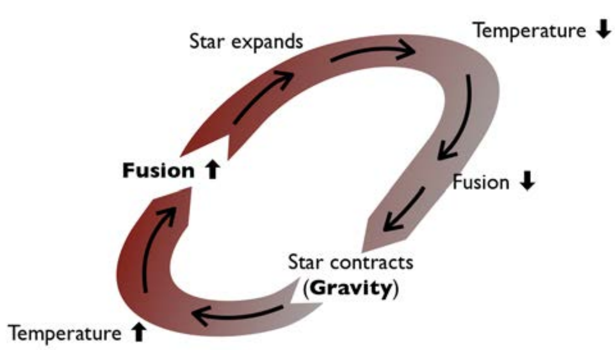
Stellar Birth and Activating Fusion

A star begins its life as a cold cloud of dust and gas. Gravity attracts the individual dust and gas particles and they fall towards one another, decreasing the gravitational potential **energy [CCC-5]** of the **system [CCC-4]**. Since energy must be conserved in the system, the particles gain kinetic energy (much like a ball falling downward speeds up as it gets lower). The temperature of an object is a measure of the average kinetic energy of its molecules, so we say that the star warms as it contracts. At some point, the particles may be moving fast enough that they undergo nuclear fusion when they collide. Within the same cloud of dust and gas, many objects can form simultaneously. Objects that accumulate enough mass to start fusion are called stars. Planets are made of the exact same material as stars and accumulate by the exact same gravitational processes, but their mass is not sufficient to begin fusion.

Mid-life as a Star: A Balance

Once fusion begins, the **energy [CCC-5]** it releases causes particles to push one another apart and the star begins to expand again. This is the opposite situation as the original star formation and involves an increase in gravitational potential energy that must be balanced by the particles slowing down (much like a ball thrown upward slows down as it gets higher). At slower speeds, fusion is less likely to occur and the star stops expanding. This counterbalancing feedback between the explosive force of fusion and the attraction due to gravity keeps stars **stable [CCC-7]** during most of their lifespan. This stable period of a star's life is referred to as the main sequence and it means that hydrogen is fusing in the star's core (figure 8.70). This stable period of a star's life is referred to as the main sequence and it means that hydrogen is fusing in the star's core.

Figure 8.70. Counterbalancing Feedback in Stars



The explosive force of fusion balances the attractive force of gravity keeping stars **stable [CCC-7]** during most of their lives. Diagram by M. d'Alessio
Long description of Figure 8.70.

Growing Older

Even the core of a young star is not typically hot enough to fuse anything except hydrogen. Larger stars burn it more quickly because they are hotter, and all stars eventually fuse all the hydrogen in their core to form helium. At that time, fusion stops, marking the end of the period called the main sequence. Without fusion pushing the star outward, the counterbalancing feedback shown in figure 8.70 becomes unbalanced, and then gravity acts alone to contract the star.

Contraction causes temperature increases in both the core and the surrounding envelope. If the star has enough mass, it may heat enough for helium atoms to begin fusing together. If that helium gets used up, the same processes will create, in sequence, large elements up to the size of iron. Only stars that start off their lives with a large enough mass are able to generate elements larger than helium during their lifetimes. Contraction of the star's envelope triggers hydrogen to begin fusing there. The outer envelope (surrounding gaseous material) is less dense, so gravity does not act as effectively to hold the star together and fusion in the envelope causes the star to expand to a massive size, which is why some stars are called *giants* and *supergiants*.

Our Sun is currently in its main sequence, so it has not yet become a giant and still only fuses hydrogen in its core. So how does it get all the more massive elements than helium that show up in its spectra? Where did they come from?

The End of Stars

Once hydrogen fusion stops in the Sun's core, hydrogen fusion in its envelope will cause it to grow to be a giant star. Eventually its envelope will expand, leaving behind a core made primarily of carbon and oxygen. That core will still be incredibly hot and it will continue to glow for a long time even without fusion. Some of the stars we see in the night sky are actually the hot, dying cores of stars that have finished fusion.

Larger stars continue fusing atoms until they end up with only iron in their cores and spontaneous fusion stops. The core is already very dense and gravity can cause the entire core to collapse within a few seconds. This rapid core collapse leads to such high temperatures and pressures that there is finally enough extra **energy [CCC-5]** to fuse elements larger than iron. Practically all of the atoms in the universe heavier than iron formed during the cataclysmic collapse of these large stars. The collapsing core rebounds in a dramatic explosion called a supernova, ejecting all of its material out into space where it can eventually coalesce into new stars. The carbon in our bodies came from carbon made in a star that exploded and was ejected into a region of space where our solar system was born. As Carl Sagan once said, "We are made of star stuff."

Students combine their model of fusion (HS-PS1-8) with the counterbalancing feedback in figure 8.70 to construct a **model [SEP-2]** of how fusion relates to a star's lifecycle (HS-ESS1-1). They apply this model to a product that communicates how material got from the random hydrogen atoms inside a young star to the complex range of elements inside their own bodies (HS-ESS1-3). They create a diagram, storyboard, movie, or other product that illustrates this step-by-step sequence. At each stage of their diagram, they should be able to answer the question, "What is the evidence that this particular stage happens?"

Earth and Space Science Snapshot 8.10: Asking Questions About Patterns in Stars

Investigative phenomenon: Bright stars can be located near or far from Earth, but they are typically hotter.

Students reviewed a table of a number of properties of the 100 nearest stars and the 100 brightest stars using a spreadsheet (figure 8.71). They constructed graphs of different properties looking for **patterns [CCC-1]** in the data. They found that many of the factors were uncorrelated. For example, they probably noticed that bright stars are located both near and far from Earth, but they should have seen a definite pattern between brightness and temperature—hotter stars are brighter and colder stars are dimmer. They may have begun with a linear **scale [CCC-3]**, but with such a large range in the brightness of stars (less than 1 percent as bright up to 100 times brighter than the Sun), they discovered the need to adjust to a logarithmic **scale [CCC-3]**.

Figure 8.71: How Does Star Brightness Depend on Temperature?

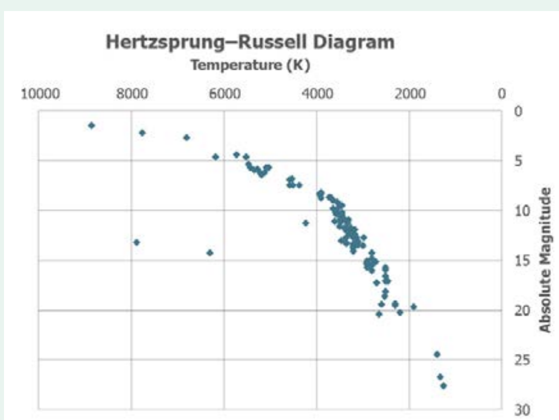


Diagram by M. d'Alessio

Long description of Figure 8.71.

Earth and Space Science Snapshot 8.10: Asking Questions About Patterns in Stars

Anaya: Not all the bright stars are hot, though. Are those outliers?

Cole: And not all the dim stars are cold.

Ms. M: Why do you think that is? Should we graph more data?

Jordan: Maybe those dim ones are farther away.

Diego: I don't think so. We graphed distance versus brightness and there wasn't any trend. But I'll look specifically at the data for those stars to make sure.

Jordan: Well maybe they're smaller then. If they're small, maybe they wouldn't be very bright even if they were hot.

Anaya: And maybe those cold ones would be bright if they were really big.

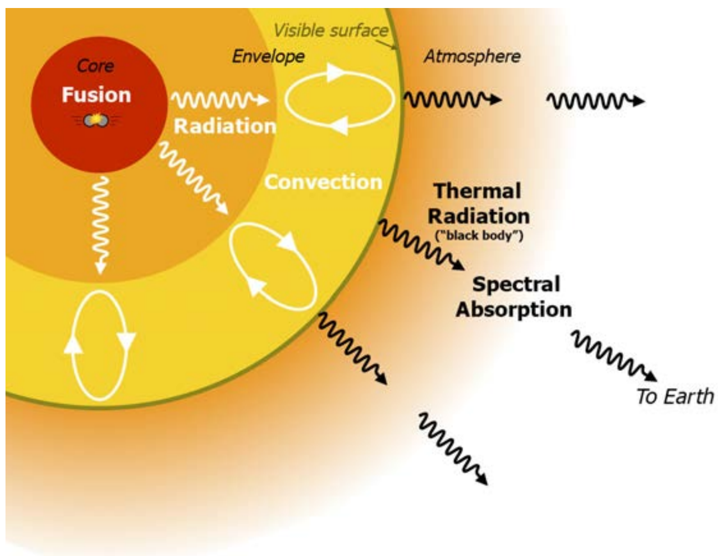
Students **asked questions [SEP-1]** that led them to further investigation. The example student dialog is idealized, but effective talk moves can help structure conversations so that students move towards this ideal (as outlined in the "Instructional Strategies" chapter of this framework).

This **pattern [CCC-1]** in the data was discovered by Ejnar Hertzsprung and Henry Russell around 1910 and is commonly referred to as a Hertzsprung-Russell (H-R) Diagram. It appears in several different forms including color (spectral type) instead of temperature. Like the coals in a fire, cooler stars are red and hotter stars are orange, yellow, or even blue. (Several online simulations are available to allow students to explore this relationship between temperature and color.) Students can add this relationship to their model of the Sun's **energy [CCC-5]** emissions (HS-ESS1-1) because it helps explain the overall broad range of colors emitted by the Sun in figure 7.62. It relates to the star's lifecycle because most of the stars plot along the central diagonal line in the H-R diagram, which is referred to as the *main sequence*. As each star moves through its life cycle and stops fusing elements in its core, it plots in a different section of the H-R diagram than it did during its main sequence.

Getting Energy to Earth

As early as grade five in the CA NGSS, students generated a model showing that most of the energy that we see on Earth originated in the Sun (5-PS3-1). Now students will expand their system **model [SEP-2]** to trace the **flow of energy [CCC-5]** back to fusion in the Sun's hot core (HS-ESS1-1). Students will need to use models of heat transfer within a system such as radiation and convection from physical science (HS-PS3-4). They develop a model of convection at Earth's surface in the middle grades (MS-ESS2-6) and in Earth's interior in the high school Chemistry in the Earth System course. Now they can apply that model to the interior of the Sun. Convection occurs in a large section of the Sun's outer envelope, moving heat from the interior out to the visible surface (figure 8.72). Students can directly observe evidence of this convection in high-resolution optical images of the Sun's surface that resemble a bubbling cauldron. This convection plays a role in the eruption of solar flares and other variations in solar intensity, which have been recorded for centuries (NASA 2003b). Some of these variations are periodic (the Sun's magnetic field flips about every 11 years, **causing changes [CCC-7]** in the amount of radiation of about 0.1 percent) while slightly larger variations are less well understood but can make a big difference in Earth's climate over much longer **timescales [CCC-3]** (from decades to millions of years). The existence of these variations is further evidence for convection, which constantly bubbles up new high-temperature material that emits more **energy [CCC-5]** than the cooler and denser material that sinks down. Even though no fusion occurs on the visible surface, it still shines via a process known as thermal radiation (or *black body* radiation). Most of this radiation travels directly towards earth, but a small fraction of it is absorbed, creating the absorption spectra of figure 8.69.

Figure 8.72. Energy Transfer from the Sun to Earth



Energy transfer by radiation and convection moves energy from the Sun's core to Earth. There are a number of steps along the way. Diagram by M. d'Alessio
[Long description of Figure 8.72.](#)

Opportunities for ELA/ELD Connections

Students select, read, and report out on biographies about or autobiographies/memoirs by famous or influential scientists known for their work about the stars, Sun, planets, or universe. (Note: The teacher may provide a list of names to select from to ensure certain concepts are highlighted.) The report should include the critical concept, knowledge, or discovery by the scientist; identify relevant or key symbols, key terms, or other words/phrases relevant to the topic; and incorporate a visual presentation. A checklist may help students keep track of all the features the teacher expects in the reports.

CA CCSS for ELA/Literacy Standards: RST.9–12.2, 4, 8; SL. 9–12.4, 5
CA ELD Standards: ELD.PI. 9–12.6, 10

IS8 Earth and Space Sciences Instructional Segment 8: Motion in the Universe

According to the NGSS storyline:

> High school students can examine the processes governing the formation, evolution, and workings of the solar system and universe. Some concepts studied are fundamental to science, such as understanding how the matter of our world formed during the Big Bang and within the cores of stars. Others concepts are practical, such as understanding how short-term **changes [CCC-7]** in the behavior of our [S]un directly affect humans. Engineering and technology play a large role here in obtaining and analyzing the data that support the theories of the formation of the solar system and universe. (NGSS Lead States 2013c)

EARTH AND SPACE SCIENCES INSTRUCTIONAL SEGMENT 8: MOTION IN THE UNIVERSE

Guiding Questions

- What are the predictable patterns of movement in our solar system and beyond?
- What can those motions tell us about the origin of the universe and our planet?

Performance Expectations

Students who demonstrate understanding can do the following:

HS-ESS1-2. Construct an explanation of the Big Bang theory based on astronomical evidence of light spectra, motion of distant galaxies, and composition of matter in the universe. [Clarification Statement: Emphasis is on the astronomical evidence of the red shift of light from galaxies as an indication that the universe is currently expanding, the cosmic microwave background as the remnant radiation from the Big Bang, and the observed composition of ordinary matter of the universe, primarily found in stars and interstellar gases (from the spectra of electromagnetic radiation from stars), which matches that predicted by the Big Bang theory (3/4 hydrogen and 1/4 helium).]

HS-ESS1-4. Use mathematical or computational representations to predict the motion of orbiting objects in the solar system. [Clarification Statement: Emphasis is on Newtonian gravitational laws governing orbital motions, which apply to human-made satellites as well as planets and moons.] [*Assessment Boundary: Mathematical representations for the gravitational attraction of bodies and Kepler's Laws of orbital motions should not deal with more than two bodies, nor involve calculus.*]

HS-ESS1-6. Apply scientific reasoning and evidence from ancient Earth materials, meteorites, and other planetary surfaces to construct an account of Earth's formation and early history. [Clarification Statement: Emphasis is on using available evidence within the solar system to reconstruct the early history of Earth, which formed along with the rest of the solar system 4.6 billion years ago. Examples of evidence include the absolute ages of ancient materials (obtained by radiometric dating of meteorites, Moon rocks, and Earth's oldest minerals), the sizes and compositions of solar system objects, and the impact cratering record of planetary surfaces.] (Revisited from IS 7)

EARTH AND SPACE SCIENCES INSTRUCTIONAL SEGMENT 8: MOTION IN THE UNIVERSE

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-5] Using Mathematics and Computational Thinking [SEP-6] Constructing Explanations (for science) and Designing Solutions (for engineering)	ESS1.A: The Universe and Its Stars ESS1.B: Earth and the Solar System ESS1.C: The History of Planet Earth PS4.B: Electromagnetic Radiation	[CCC-3] Scale, Proportion, and Quantity [CCC-5] Energy and Matter: Flows, Cycles, and Conservation [CCC-6] Structure and Function [CCC-7] Stability and Change Connections to Engineering, Technology, and Applications of Science Interdependence of Science, Engineering, and Technology Connections to Nature of Science Scientific Knowledge Assumes an Order and Consistency in Natural Systems

Highlighted California Environmental Principles and Concepts:

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

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

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

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

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

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

CA CCSS for ELA/Literacy Connections: RST.11–12.1, 2, 7, 9; WHST.9–12.2a–e, 7

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

In earlier grades, students observed and described **patterns [CCC-1]** of motion in the sky (1-ESS1-1, 5-ESS1-2). In this instructional segment, students will explore motion at a range of **scales [CCC-3]** that help **explain [SEP-6]** where Earth's materials came from, how they came together, and how they have been modified since then.

Students **analyze [SEP-4]** spectra of stars beyond the Sun by comparing them to a set of known spectral lines of different elements determined in a laboratory. To match the laboratory lines, they find that they need to shift the star spectra. Understanding the significance of this observation requires understanding of the Doppler effect, a process that builds on students' existing models of waves but is not required to meet other CA NGSS performance expectations. When stars move toward or away from a viewer, the wavelength of their light shifts. We can therefore use the Doppler shifts to map out the movements of stars toward or away from us. For example, we find that galaxies rotate, so even if overall the galaxy is moving away from us, stars on one side of it may have a smaller Doppler shift than stars on the other side. When students examine different stars in different parts of the sky, they will make the discovery that almost all galaxies are shifted toward longer wavelengths, revealing that the stars are all moving away from us. This effect is referred to as a *redshift* because all the other colors of visible light are shifted towards red, the longest wavelength of visible light, when their wavelength is lengthened.

Students are now ready to **obtain information [SEP-8]** from media about Edwin Hubble's surprising discovery that the universe is expanding (Sloan Digital Sky Survey/ Sky Server n.d.b.; Kirshner 2004). At the time, scientists wondered if our universe has always looked the way it does today. Einstein assumed a **static [CCC-7]**, "ungrowing" universe in his equations of relativity, but others like Willem de Sitter showed that an expanding universe was also theoretically possible. Meanwhile, observational astronomers like Henrietta Leavitt developed techniques that allowed accurate distance measurements of objects in the universe, and Vesto Slipher cataloged the redshifts of entire galaxies. Hubble entered the debate by combining these techniques and noticing a **pattern [CCC-1]** in the redshifts: the farther away a galaxy is from Earth, the faster it moves away from us. Some of the most distant galaxies have such an extreme redshift that they appear to be receding from us at a speed faster than the speed of light when we calculate their velocity using Doppler shift alone. If they were moving that fast, their light would never reach us and we wouldn't be able to see them. Hubble proposed a bold **model [SEP-2]** that could **explain [SEP-6]** this pattern in which galaxies are not really moving in space, but rather the space between the galaxies is getting bigger (much like a lump of dough expanding and moving mixed-in raisins farther apart from one another). The redshifts must be the combined effect of Doppler shift and the wavelengths getting stretched by the stretching of space itself.

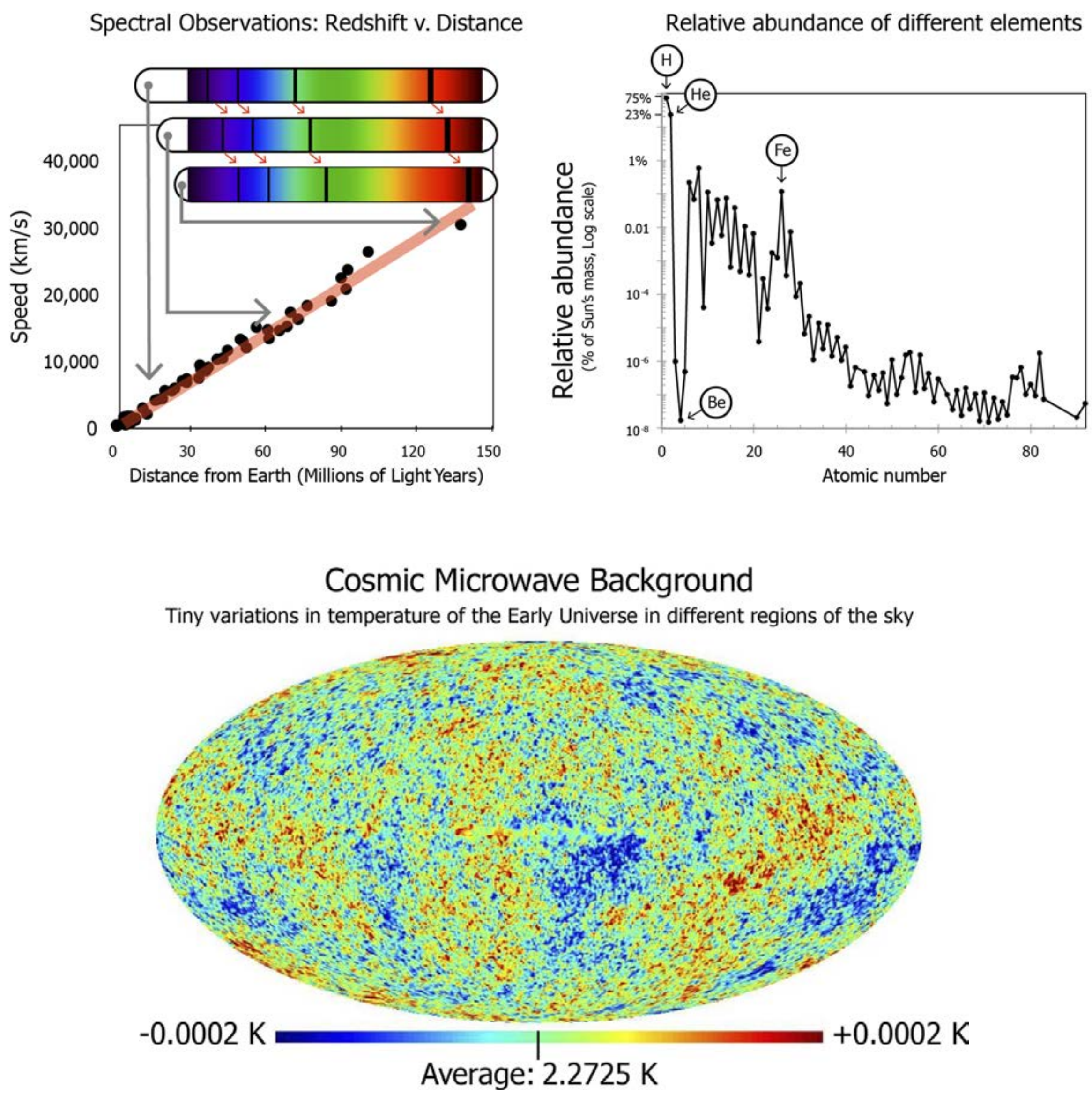
Students can perform their own **investigation [SEP-3]** of redshifts using simulated telescope data from online laboratory exercises. Two older examples include Project CLEA at https://www.cde.ca.gov/ci/sc/cf/ch8.asp#link88 or University of Washington Astronomy Department at https://www.cde.ca.gov/ci/sc/cf/ch8.asp#link89. This investigation requires an understanding of how distances are measured in the universe, which builds on the **argument [SEP-7]** students constructed in fifth grade that the apparent brightness of stars in the sky depends on their distance from Earth (5-ESS1-1). Students can work independently or in small groups to **obtain information [SEP-8]** about one of the methods for determining distance in the universe and then combine their findings with other students' findings to develop a report, a poster, or a presentation that describes the **scale [CCC-3]** of the universe and how it is measured.

Students now have **evidence [SEP-7]** that the universe is expanding, so teachers can invite them to **ask questions [SEP-1]** such as "What is causing this expansion?" and "What would the universe look like if we could 'rewind' this expansion to look back in time?" The inevitable answer is that everything that we can see as far as we can look out into the universe was at one time all contained in a tiny region smaller than the size of an atomic nucleus. This region was extremely hot and dense at this time until everything started rapidly to spread apart in what we call the Big Bang. We can see evidence of this expansion in the **matter and energy [CCC-5]** that exists in the universe today. As the material spread apart, it started to cool enough for atomic nuclei to form, but calculations by scientists show that only specific elements would form and in specific proportions. We can look for that "fingerprint" by using spectral lines and other techniques to determine the relative abundance of different elements in stars like our Sun (graph in the top right in figure 8.73). While the Sun's relatively small proportion of heavier elements was formed in distant supernovas, its overall composition is similar to most other stars and matches the fingerprint predicted by the Big Bang with roughly three-quarters hydrogen and one-quarter helium.

In 1963, a group of scientists detected another piece of evidence of the Big Bang when they observed a constant stream of microwave radiation coming toward Earth in every direction. They were worried something was wrong with their equipment, but it became apparent that the signal they were detecting was also consistent with **models [SEP-2]** of a hot early universe that emitted radiation, which should still be traveling toward Earth today. We now call that **energy [CCC-5]** the Cosmic Microwave Background Radiation and can use it to describe what the universe looked like shortly after the initial Big Bang (image on the bottom in figure 8.73). Like so many scientific discoveries, engineering and technology have had a profound impact on scientists' ability to make measurements. Cosmic Microwave

Background Radiation was not measurable in the days of Hubble because the technology did not exist to observe it. Students should be able to **explain [SEP-6]** each of these pieces of evidence.

Figure 8.73. Evidence for the Big Bang



Evidence of the Big Bang comes from the redshift versus distance of stellar spectra (top left), the relative abundance of elements in the Sun determined from absorption spectra (top right), and the Cosmic Microwave Background Radiation that reveals minute differences in temperature in the early universe (bottom). *Sources*: M. d'Alessio with data from Jha, Riess, and Kirshner 2007; M. d'Alessio with data from Lodders 2003; NASA 2008
Long description of Figure 8.73.

Predicting Motions

In IS7, students develop a model for the birth of the Sun from a cloud of dust and gas. That model also predicts that planets and other bodies in the solar system all formed the same way from the same initial materials. The force of gravity causing particles to coalesce into larger and larger objects is at the heart of this model. This nebular theory provides a framework used to explain many major features in the solar system, such as the compositional difference between the rocky inner planets, the gaseous outer planets, and the asteroid belt where planetesimals and smaller bodies continue to circulate today. A consequence of the gravity-driven motion in the early solar system is that random variations **cause [CCC-2]** all of the bodies in a region to start rotating the same direction as they accumulate more mass. Motion in our solar system shows **evidence [SEP-7]** for this effect, as most objects rotate and revolve in a common direction, rather than randomly. Observations of those consistent motions, including the period of each planet's orbit, can be the driving observation behind the discussion of the use of Kepler's laws to predict those motions (HS-ESS1-4).

Science and Engineering Practices and the History of Gravity

Although scientists have studied gravity and electromagnetism intensely for centuries, many mysteries remain concerning the nature of these forces. The CA NGSS learning progression mirrors the historical development of our understanding of gravity and orbital motion. In 1576 Danish scientist Tycho Brahe set up the world's most sophisticated astronomical observatory of its time. He methodically **investigated [SEP-3]** and recorded the motion of celestial objects across the sky. Just before he died, Brahe took on Johannes Kepler as a student who **analyzed the data [SEP-4]** to develop a simple descriptive **model [SEP-2]**. Even though his model did a superb job of predicting the motion of objects in the sky, it was incomplete because it could not explain the fundamental forces driving the motions. In late 1600s Isaac Newton extended Kepler's model by describing the nature of gravitational forces. From his fundamental equations of gravity, Newton was able to derive Kepler's geometric laws and match the observations of Brahe. Newton is known not only for his innovative thinking, but for his ability to **communicate [SEP-8]** clearly; many twenty-first century physics classes still read his book *Principia Mathematica* to learn about his ideas. In the CA NGSS, elementary students mirror the work of Brahe, recognizing **patterns [CCC-1]** in the sky (1-ESS1-1, 5-ESS1-2). At the middle grades level, students mirror the work of Kepler by making simple **models [SEP-2]** that describe how galaxies and the solar system are shaped (MS-ESS1-2). In high school, students add **mathematical thinking [SEP-5]** to their descriptive model (using Kepler's laws, HS-ESS1-4) and then finally extend their model to a full explanation with the equations of the force of gravity from Newton's model (HS-PS2-4).

Even though students quantitatively describe the force of gravity in physical science

(HS-PS2-4), deriving Kepler's Laws for elliptical orbits directly from the gravitational force is beyond the mathematical scope of many students. Instead, focus should be on interpreting the **evidence [SEP-7]** of the orbital period of different bodies in our solar system, including planets and comets. These laws form an excellent illustration of the crosscutting concept of **scale, proportion, and quantity [CCC-3]**. By comparing the distance of objects away from the Sun and the time it takes them to complete one orbit, students recognize a **pattern [CCC-1]**. Table 8.10 shows that the ratio determined by Kepler (orbital period squared divided by orbital distance cubed) is nearly constant for objects in our solar system. Students can calculate this ratio for Earth and other planets and then make measurements of the orbital path of comets to try to estimate how often they will return. The ratio is only true for objects orbiting the same body (illustrated by the dramatically different ratio for the Moon in table 8.10). But students can use measurements of the Moon to predict the height of satellites in geosynchronous orbit, which have an orbital period of exactly one day, allowing them to always be in the same position in the sky. Satellite television receives signals from these satellites. Alternately, students can use the orbital period of the International Space Station from its height above Earth. Students can also use the more complete form of Kepler's laws to calculate the mass of distant stars using only the orbital period of newly discovered planets that orbit them.

Table 8.10. Orbital Period and Distance from the Sun of Objects in our Solar System

PLANET	PERIOD (yr)	AVERAGE DISTANCE (AU)	KEPLER'S RATIO: T^2/R^3 (yr^2/AU^3)
Mercury	0.241	0.39	0.98
Venus	0.615	0.72	1.01
Earth	1	1	1.00
Mars	1.88	1.52	1.01
Jupiter	11.8	5.2	0.99
Saturn	29.5	9.54	1.00
Uranus	84	19.18	1.00
Neptune	165	30.06	1.00
Pluto (dwarf planet)	248	39.44	1.00
Halley's Comet	75.3	17.8	1.00
Comet Hale-Bopp	2,521	186	0.99
Moon (relative to Earth)*	0.0766	0.00257	345667*

*Kepler's ratio only works for objects orbiting around the same body. Since the Moon orbits Earth, its ratio should be much different.

Engineering Connection: Computational Models of Orbit

When a company spends millions of dollars to launch a communications satellite or the government launches a new weather satellite, they employ computer models of orbital motion to make sure these satellites will stay in orbit and the investment is not lost. These **models [SEP-2]** are based on the exact equations introduced in the CA NGSS high school courses. In fact, students can gain a deeper understanding of the orbital relationships and develop **computational thinking [SEP-5]** skills by interacting directly with computer models of simple two-body **systems [CCC-4]**. Even with minimal computer programming background, students could learn to interpret an existing computer program of a two-body gravitational system. They could start by being challenged to identify an error in the implementation of the gravity equations in sample code given to them. Next, students modify the code to correctly reflect the mass of the Earth and a small artificial communications satellite orbiting around it. They can vary different parameters in the code such as the distance from Earth or initial speed and see how those parameters affect the path of the satellite (HS-ESS1-4). At what initial launch speeds will the satellite stay in orbit? What is the tradeoff between the cost of fuel and the payload mass?

(Note: Appendix 3 in this framework provides guidance about teaching computer coding aligned with the CA NGSS.)

While Kepler's laws present a simple view of orbital shapes and periods, the *NRC Framework* pushes teachers to emphasize the importance of **changes [CCC-7]** in orbits, as these **changes [CCC-7]** have large impacts on Earth's internal **systems [CCC-4]**:

> Orbits may change due to the gravitational effects from, or collisions with, other objects in the solar system. Cyclical changes in the shape of Earth's orbit around the [S]un, together with changes in the orientation of the planet's axis of rotation, both occurring over tens to hundreds of thousands of years, have altered the intensity and distribution of sunlight falling on Earth. These phenomena cause cycles of ice ages and other gradual climate changes. (National Research Council 2012, 176)

Using realistic computer simulations of Earth's orbit (HS-ESS1-4), students can **investigate [SEP-3]** the **effects [CCC-2]** collisions (such as the impact that led to the creation of the Moon) or explore the variation in the Earth–Sun distance to look for **evidence [SEP-7]** of cyclic **patterns [CCC-1]**. They would discover some cyclic **patterns [CCC-1]** called Milankovitch cycles, which have a strong influence on Earth's ice age **cycles [CCC-5]**.

The CA NGSS pushes teachers to connect these ideas so that Earth's place in the universe is strongly integrated with our understanding of the complete Earth system.

Concept Map of Earth and Space Science Disciplinary Core Ideas

In meeting the performance expectations selected for this course, instructors must introduce some DCIs as well as build on the DCIs introduced in the middle grades. Figure 8.74 shows a concept map with the relationships between DCIs introduced during the middle grades and high school levels. This concept map is not a conceptual flow with a specific order or sequence, nor is it a comprehensive illustration of all ideas that should be taught in the courses. It may, however, be helpful in identifying how DCIs build from middle grades to high school and relate to one another. This map is explicitly placed at the end of the instructional segment so that readers view them with a full appreciation of how these DCIs must be explored using the other two dimensions of the CA NGSS as outlined in the course above. The concept map is limited only to DCIs, so even if students had a full appreciation of what is in these maps they also need practice in doing SEPs and identifying big picture relationships to other disciplines (CCCs).

Figure 8.74. Relationship of DCIs in Earth and Space Science, Including High School and Middle Grades Content

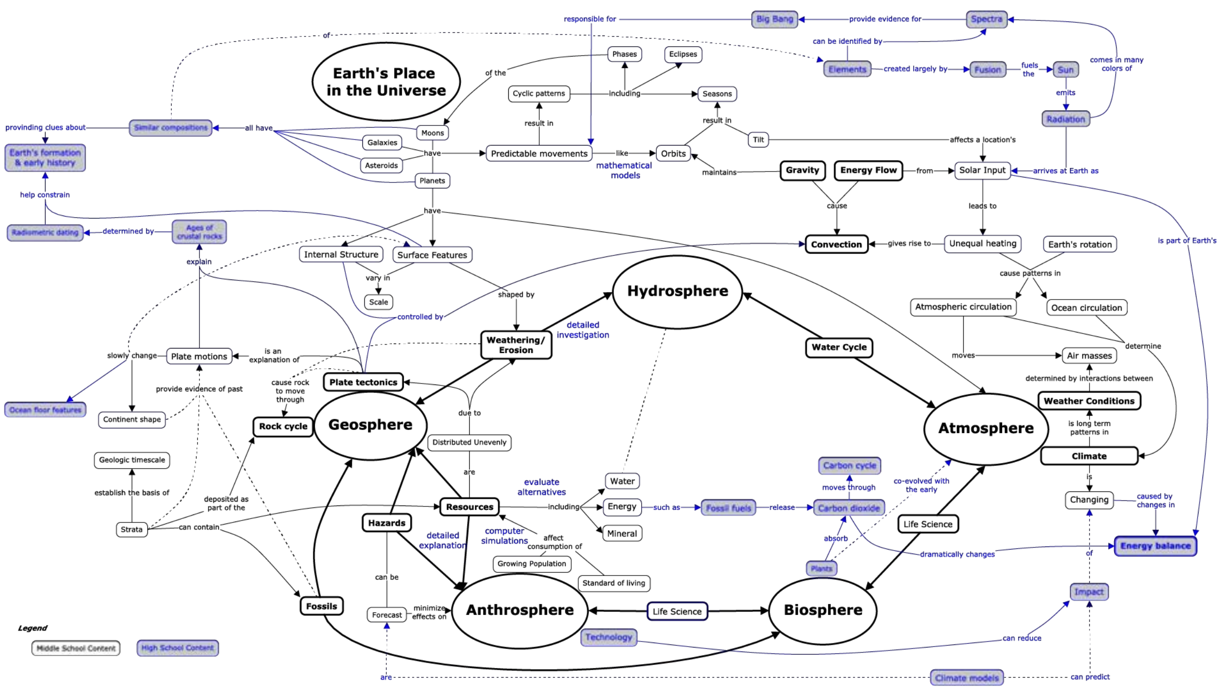


Diagram by M. d'Alessio

Long description of Figure 8.74.

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