Chapter 5
Preferred Integrated Course Model for Grades Six Through Eight

*Grade 8 ONLY

2016 Science Framework

FOR CALIFORNIA PUBLIC SCHOOLS
Kindergarten Through Grade Twelve

Adopted by the California State Board of Education November 2016

Published by the California Department of Education Sacramento, June 2018

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.

Grades Six Through Eight Preferred Integrated Course Model

CHAPTER 5

Introduction to Grades Six Through Eight

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

The two models differ only in the sequence; every student is expected to meet each middle grades' performance expectation (PE) by the end of the grade. "Sequence" here refers to in which course (grade six, seven, or eight) a particular performance expectation is mastered; this framework makes no requirements about the order in which performance expectations are taught within a given year. The example course sequences in this framework describe possible storylines but are not the only way.

Table 5.1 compares **disciplinary core ideas (DCIs)** that are emphasized in the performance expectations required at each grade level in the two models. For both models, all eight **science and engineering practices (SEPs)** are developed and all seven **crosscutting concepts (CCCs)** are highlighted at all grade levels (although each lesson may focus on only one or two, and each year may emphasize a particular subset).

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

Historical Background

The CA NGSS are aligned to the nationally developed NGSS. This nationwide effort specified performance expectations for each year: kindergarten through grade five. However, in the middle grades, the performance expectations were presented for the entire grade span: grade six through grade eight. Because California adopts instructional materials for kindergarten through grade eight on a statewide basis, performance expectations had to be placed at specific grade levels—sixth, seventh, and eighth. Therefore, the State Superintendent of Public Instruction (SSPI) recommended that the State Board of Education (SBE) adopt specific placement of the performance expectations for the middle grades at each grade level.

The SSPI convened the Science Expert Panel comprised of kindergarten through grade twelve teachers, scientists, educators, business and industry representatives, and informal science educators. This panel evaluated a range of options for the appropriate organization and sequence of the performance expectations. The public provided feedback to the Science Expert Panel via three open forums and a webinar. The Science Expert Panel concluded that an integrated model for grades six through eight would be the most effective model for optimizing student learning of the CA NGSS; the panel subsequently reviewed the national model developed by Achieve (2010), and adapted it to better align with California's needs and recommended only the Integrated Course Model to the SBE. The full list of events that led to the adoption of the Preferred Integrated Course Model is described at the California Department of Education (CDE) Web site: https://www.cde.ca.gov/ci/sc/cf/ch5.asp#link1. On November 6, 2013, the SBE unanimously passed the following motion: "To adopt the CDE staff recommendation that the SBE adopt the proposed integrated model as the preferred model for middle grades (6, 7, and 8) science instruction, and requested that the CDE reconvene the Science Expert Panel to develop as an alternative model a discipline specific model based upon the domain specific model outlined by Achieve in the NGSS appendix K." In December 2014, the Science Expert Panel reconvened to develop the Discipline Specific Model of the CA NGSS.

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

Table 5.1. Comparison of When DCIs are Primarily Addressed in the Two Middle Grades Models

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

Learning from Other Successful Countries

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

Matching University Training with Middle Grades Teaching

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

Sequencing in a Developmentally Based Learning Progression

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

Introduction to the Preferred Integrated Course Model for Grades Six through Eight

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

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

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

Table 5.2. Integrated Versus Coordinated Science

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

Source: Sherriff 2015

Purpose and Limitations of this Example Course

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

In this chapter's examples, each year is divided into instructional segments (IS) centered on questions about observations of a specific phenomenon. Different phenomena require different amounts of investigation to explore and understand, so each instructional segment should take a different fraction of the school year. As students achieve the performance expectations within each instructional segment, they uncover **disciplinary core ideas (DCIs)** from the different fields of science (physical science, life science, and Earth and space science) and engineering. Students engage in multiple practices in each instructional segment, not only those explicitly indicated in the performance expectations. Students also focus on one or two CCCs as tools to make sense of their observations and investigations; the CCCs are recurring themes in all disciplines of science and engineering and help tie these seemingly disparate fields together. The SEPs, DCIs, and CCCs grow in sophistication and complexity throughout the K–12 sequence. While this chapter calls out examples of the three dimensions in the text using color-coding, each element should be interpreted with this grade-appropriate complexity in mind (appendix 1 of this framework clarifies the expectations at each grade span in the developmental progression). Engineering, technology, and application of science (ETS1) are a fundamental part of each course. As students explore their environment during this grade span, they develop their growing understanding of the interconnections and interdependence of Earth's natural systems and human social systems as outlined in California's Environmental Principles and Concepts (EP&Cs). All three of the CA NGSS dimensions and the EP&Cs will prepare students to make decisions about California's future and become sources of innovative solutions to the problems the state may face in the future.

Essential Shifts in the CA NGSS

The 1998 *Science Content Standards for California Public Schools: Kindergarten Through Grade Twelve* (1998 CA Science Standards) were written at a low cognitive level ("Students know … "), with some attention paid to the process of science as a separate set of Investigation and Inquiry standards. In the CA NGSS, every performance expectation is "three-dimensional," meaning that it requires proficiency in SEPs alongside a deep understanding of DCIs and the ability to relate these ideas to CCCs that are common across the domains. As a result, instructional materials and strategies must shift.

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

Grade Eight Preferred Integrated Course Model

This section is meant to be a guide for educators on how to approach the teaching of the California Next Generation Science Standards (CA NGSS) in grade eight according to the Integrated Model (see the introduction to this chapter for further details regarding different models for grades six, seven, and eight). It is not meant to be an exhaustive list of what can be taught or how it should be taught.

A primary goal of this section is to provide an example of how to bundle the performance expectations into integrated groups that can effectively guide instruction in four sequential instructional segments (IS). There is no prescription regarding the relative amount of time to be spent on each instructional segment. As shown in figure 5.38, the overarching guiding concept for the entire year is “The processes that change Earth’s systems at different spatial scales today also caused changes in the past.”

Figure 5.38. Grade Eight Integrated Storyline

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

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

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

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

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

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

INTEGRATED GRADE EIGHT INSTRUCTIONAL SEGMENT 1: OBJECTS MOVE AND COLLIDE

Guiding Questions

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

Performance Expectations

Students who demonstrate understanding can do the following:

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

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

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

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

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

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

INTEGRATED GRADE EIGHT INSTRUCTIONAL SEGMENT 1: OBJECTS MOVE AND COLLIDE

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

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

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

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

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

Highlighted California Environmental Principles and Concepts:

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

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

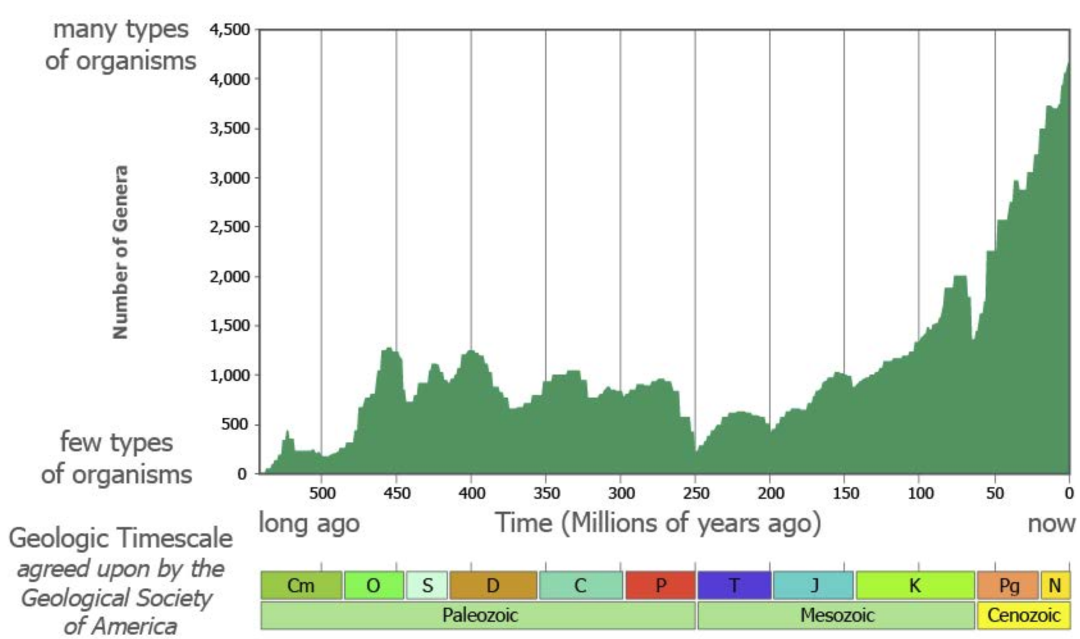
CA CCSS Math Connections: 6.EE.2, 6, 6.NS.5, 6.RP.1, 2, 7.EE.3,4, 7.RP.2, 7.SP.7, 8.EE.1,2, MP.2

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

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

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

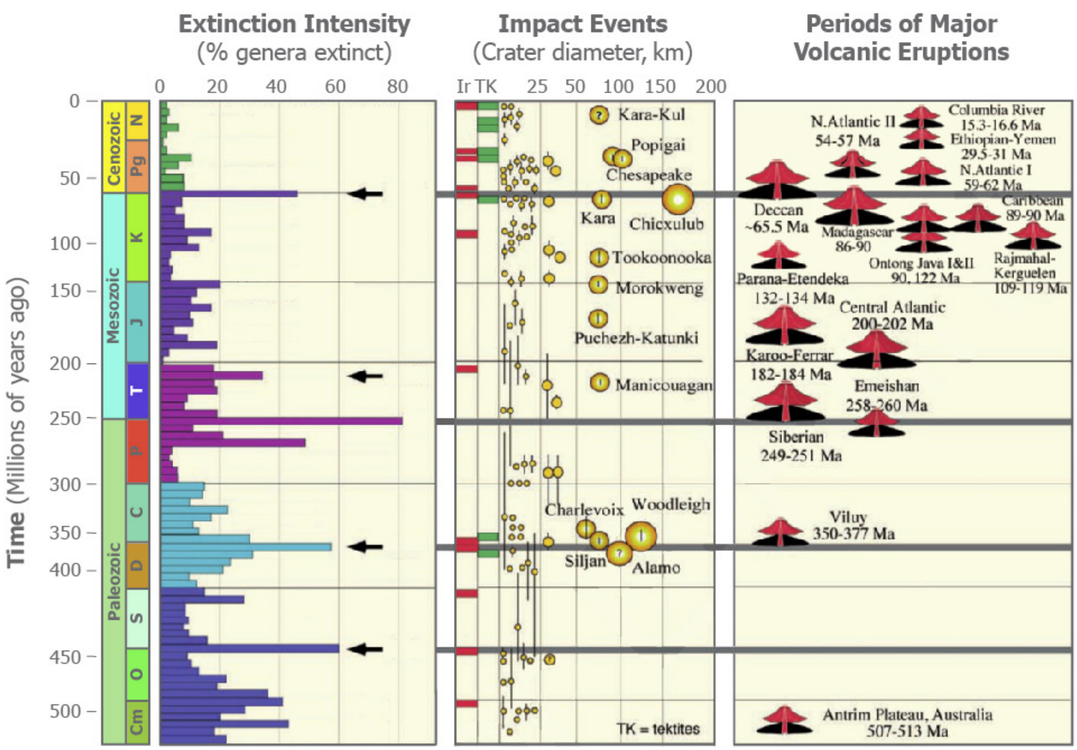
Figure 5.39. Number of Types of Marine Animals from the Last 542 Million Years



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

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

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



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

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

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

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

Integrated Grade Eight Snapshot 5.6: Learning About Motion

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

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

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

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

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

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

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

Resources:

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

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

Speed is a ratio of distance divided by time. Students can **investigate [SEP-3]** speed by conducting experiments in which they measure both distance and time. Manual measurements of time in tabletop experiments using stopwatches are prone to large error, so there are several alternatives: students can pool multiple measurements using collaborative online spreadsheets and take the average, use an app to calculate speed from video clips (such as Tracker at https://www.cde.ca.gov/ci/sc/cf/ch5.asp#link17), use a motion sensor probe, or use computer simulations.

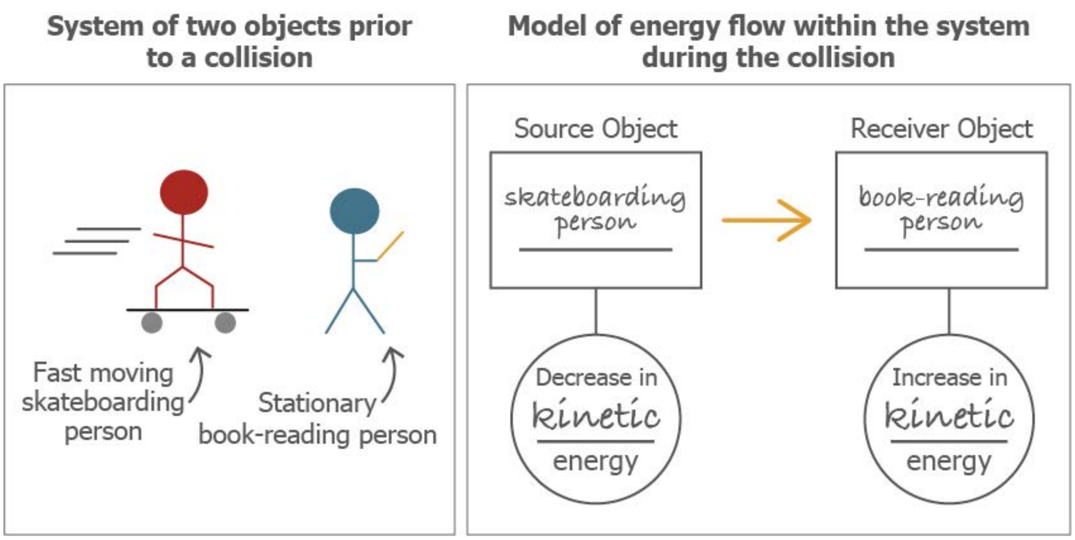
From a mathematical point of view, speed is the ratio of two very disparate quantities (distance such as meters and time such as seconds). Speed itself, the ratio, is also qualitatively different from the distance component and from the time component. This situation is typical in science where ratios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

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

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

Students can create a diagrammatic **model [SEP-2]** of the **flow of energy [CCC-5]** within **systems [CCC-4]** as shown in figure 5.41. This simple diagram of a collision is a model because it includes components (an energy source and receiver), an understanding of the way these objects will interact based on the laws of physics (energy is conserved, with one object decreasing in energy that is transferred to the other object), and it can be used to predict the behavior of the **system [CCC-4]** (the object that decreases in kinetic energy slows down while the object that increases in kinetic energy should speed up). Students can use these types of diagrammatic models to illustrate transfers of energy.

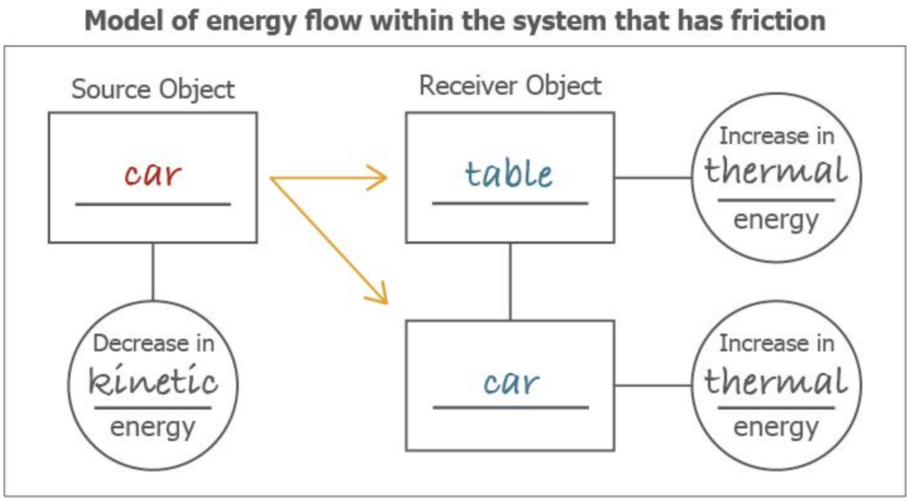
Figure 5.41. Energy Transfer in a Collision



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

The force of friction is an interaction in which **energy [CCC-5]** is transferred. Students must **plan investigations [SEP-3]** to explore the **effects [CCC-2]** of balanced and unbalanced forces on the motion of objects (MS-PS2-2). One such investigation could involve measuring the velocity of model cars with different amounts of friction by attaching sticky notes to the front and sides of the car to vary the amount of friction. Students should notice that when they push the car, they apply a force in one direction (figure 5.42) while friction is a force working in the opposite direction. The overall change in motion (and therefore change in energy) depends on the total sum of these forces. Using an energy source/receiver diagram to model the situation helps draw attention to the fact that all of the energy must be accounted for. The car clearly decreases in energy but that means another component of the system [CCC-4] must increase in energy.

Figure 5.42. Energy Transfer with Friction



Model of energy flow including friction within an experimental system of a tabletop car. Diagram by M. d'Alessio.
Long description of Figure 5.42.

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

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

When the source and target objects have equal masses and collisions transfer all of the **energy [CCC-5]** from source to receiver, the speed of the target object should be similar to the speed of the source object. This phenomenon can be seen clearly in billiards when the cue ball comes to a complete stop after hitting another ball. Observations such as these provide evidence to make the **argument [SEP-7]** that as one object loses kinetic energy during the collision, another object must gain energy, and vice-versa (revisiting MS-PS3-5 from Integrated Grade Six).

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

Engineering Connection: Landslide Early-Warning System

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

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

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

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

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

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

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

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

IS2 Integrated Grade Eight Instructional Segment 2: Noncontact Forces Influence Phenomena

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

INTEGRATED GRADE EIGHT INSTRUCTIONAL SEGMENT 2: NONCONTACT FORCES INFLUENCE PHENOMENA

Guiding Questions

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

Performance Expectations

Students who demonstrate understanding can do the following:

MS-ESS1-1. Develop and use a model of the Earth-Sun-Moon system to describe the cyclic patterns of lunar phases, eclipses of the Sun and Moon, and seasons. [Clarification Statement: Examples of models can be physical, graphical, or conceptual.] (Introduced, but seasons are not assessed until IS4)

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

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

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

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

INTEGRATED GRADE EIGHT INSTRUCTIONAL SEGMENT 2: NONCONTACT FORCES INFLUENCE PHENOMENA

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

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

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

Highlighted Science and Engineering Practices	Highlighted Disciplinary Core Ideas	Highlighted Crosscutting Concepts
[SEP-1] Asking Questions and Defining Problems [SEP-2] Developing and Using Models [SEP-3] Planning and Carrying Out Investigations [SEP-4] Analyzing and Interpreting Data [SEP-7] Engaging in Argument from Evidence	ESS1.A: The Universe and Its Stars ESS1.B: Earth and the Solar System PS2.B: Types of Interactions PS3.A: Definitions of Energy PS3.C: Relationship Between Energy and Forces	[CCC-1] Patterns [CCC-2] Cause and Effect [CCC-3] Scale, Proportion, and Quantity [CCC-4] Systems and System Models

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

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

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

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

Figure 5.43. Interacting Galaxies Demonstrate Attraction

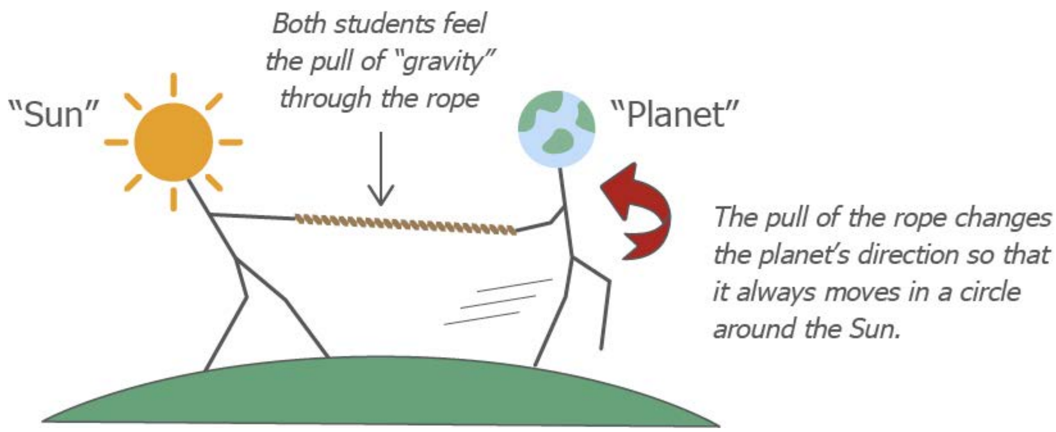
Galaxy pair Ar271. *Source:* Gemini Observatory 2008

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

Students can illustrate the forces in these circular motions with a rope (figure 5.44). One person stands in the center and holds the rope while the other starts moving away.

Once the rope is taut, both people feel the rope tugging them together. The pull of the rope changes the moving person's direction, constantly pulling that person back on course so that they move only in a circular motion around the other person. A significant limitation of this **model [SEP-2]** is that it gives the impression that the central mass must rotate as part of the motion.

Figure 5.44. Kinesthetic Model of an Orbit



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

Isaac Newton was the first person to develop and **mathematically [SEP-5]** prove the idea of gravity as the **cause [CCC-2]** of orbital motions in the solar system. As part of his thinking process, Newton **developed a conceptual model [SEP-2]** of orbits based on shooting cannon balls at different speeds from a very tall mountain. Gravity always pulls the cannon ball down, but the direction of "down" changes constantly (just like the direction of pull from the rope changes constantly as the student runs around the circle). Online interactive simulations of Newton's cannon can help students visualize and enjoy Newton's cannonball model (see https://www.cde.ca.gov/ci/sc/cf/ch5.asp#link18).

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

Explaining Motion in the Solar System

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

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

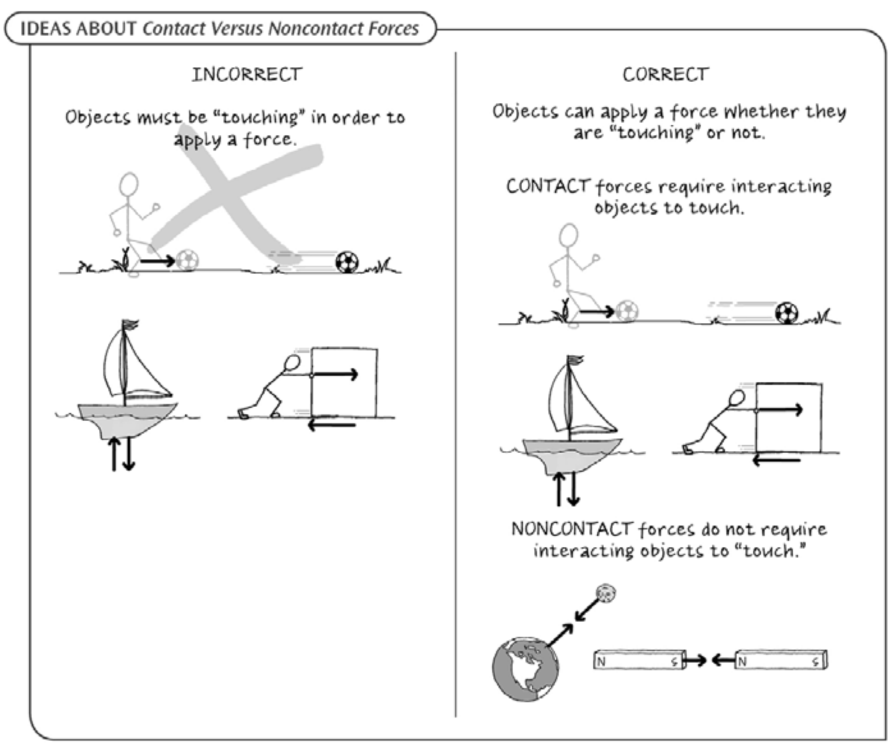
Factors Controlling the Effects of Gravity

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

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

The answer is that the strength of the gravitational force also depends on the relative positions of the interacting objects (i.e., the distance between them). Gravity on Earth is usually thought of as pulling objects toward the center of the planet, but there is nothing particularly special about the mass at the center of the planet or the downward direction. A person gets pulled by every piece of the entire planet, with the ground directly beneath his or her feet exerting the strongest pull and the ground on the opposite side of the planet exerting a much weaker force because of its distance away. Because these secondary forces are so weak, it is difficult to experiment directly with the factors that affect gravity, but students can **investigate [SEP-3]** using free computer simulations that visualize these forces with two bodies (PhET, https://www.cde.ca.gov/ci/sc/cf/ch5.asp#link19). Students can apply their knowledge of gravitational forces to simulations of much more complex planetary systems (Test Tube Games, https://www.cde.ca.gov/ci/sc/cf/ch5.asp#link20) where they get to create different size planets and place them in different positions. They can design experiments, predict how different configurations will end up looking, and be challenged to create their own solar system.

Figure 5.45. Contact Forces and Noncontact Forces



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

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

Opportunities for ELA/ELD Connections

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

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

CA ELD Standards: ELD.PI.6–8.9

Similarities Between Gravity and Magnetism

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

Noncontact Forces and Energy

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

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

Table 5.10. Forms of Energy

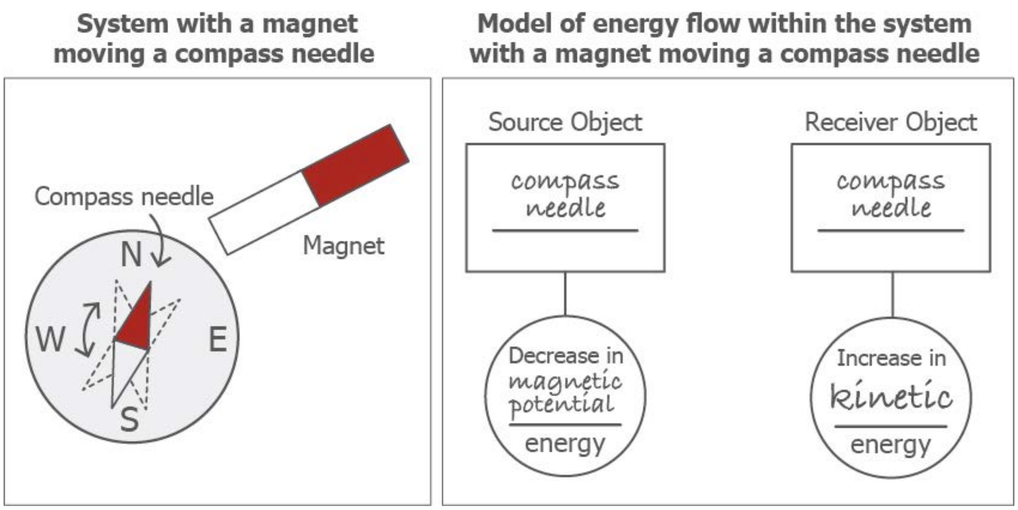
ENERGY OF MOTION **Energy due to the motion of matter**	**ENERGY OF POSITION** **Energy due to the relative positions of matter**
Kinetic Energy	Gravitational Potential Energy
Thermal Energy (often called Heat Energy)	Elastic Potential Energy
Light Energy	Chemical Potential Energy
Sound Energy	Magnetic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

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

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

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

Figure 5.46. A Magnet Moving a Compass Needle



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

Students can also use iron filings to **investigate [SEP-3]** electromagnets and gather evidence about the spatial **patterns [CCC-1]** of the magnetic fields created by electromagnets. Students can try to create the strongest electromagnet, allowing different groups to **ask questions [SEP-1]** about the factors that affect magnetic strength such as the number or arrangement of batteries, number of turns of the coil, or material inside the coil (MS-PS2-3).

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

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

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

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

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

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

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

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

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

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

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

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

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

IS3

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

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

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

Guiding Questions

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

Performance Expectations

Students who demonstrate understanding can do the following:

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

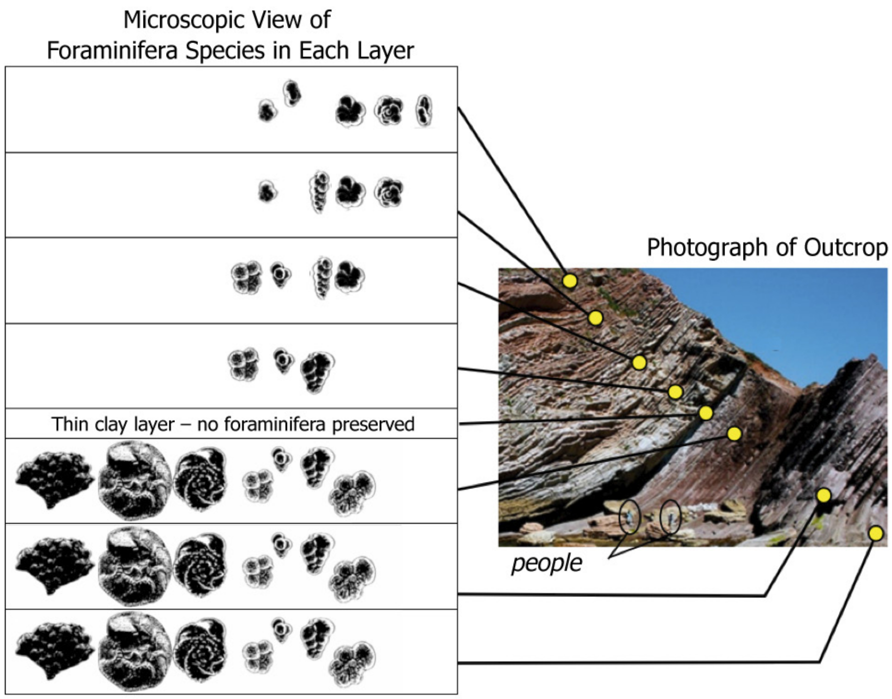
Source: Information from Sussman 2006.

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

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

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

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



Source: M. d’Alessio with foraminifera data from National Research Council 1995 and image from Meléndez and Molina 2008
[Long description of Figure 5.47.](#)

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

Opportunities for ELA/ELD Connections

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

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

CA ELD Standards: ELD.PI.8.6, 7

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

Integrated Grade Eight Snapshot 5.8: Making Sense of Natural Selection

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

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

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

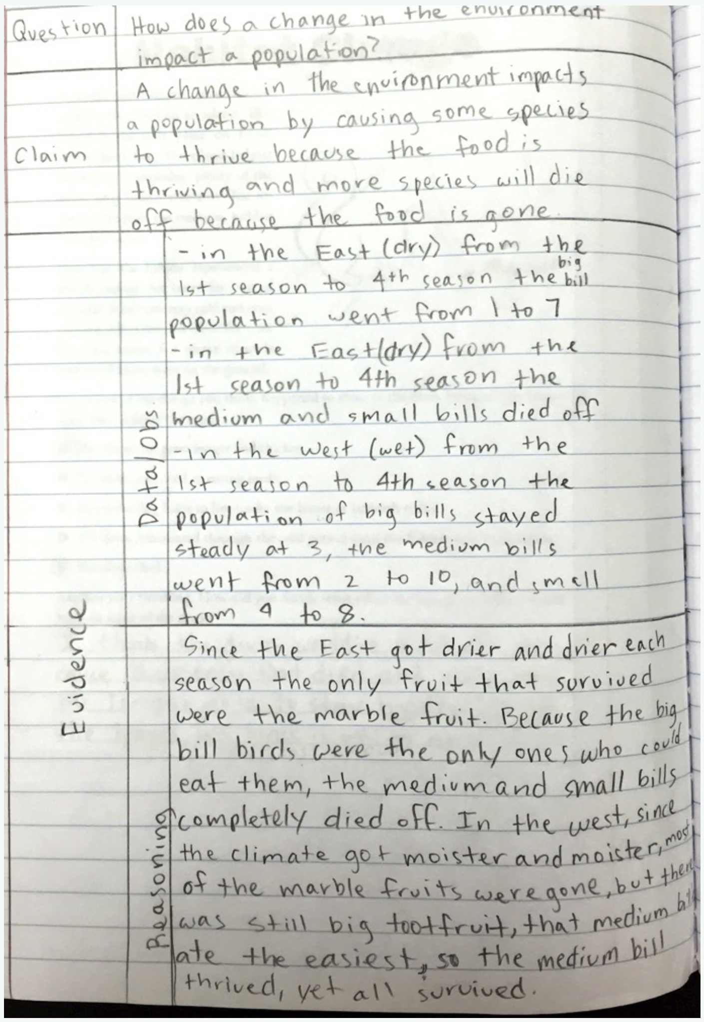
Investigative phenomenon: In a simulation, birds with different size beaks die off when the climate changes and causes a change in food supply.

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

Integrated Grade Eight Snapshot 5.8: Making Sense of Natural Selection

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

Figure 5.48. Preliminary Student Explanation of the Clipbird Scenario



Question		How does a change in the environment impact a population?
Claim		A change in the environment impacts a population by causing some species to thrive because the food is thriving and more species will die off because the food is gone.
Evidence	Data/Obs	- in the East (dry) from the 1st season to 4th season the big bill population went from 1 to 7 - in the East (dry) from the 1st season to 4th season the medium and small bills died off - in the west (wet) from the 1st season to 4th season the population of big bills stayed steady at 3, the medium bills went from 2 to 10, and smell from 4 to 8.
	Reasoning	Since the East got drier and drier each season the only fruit that survived were the marble fruit. Because the big bill birds were the only ones who could eat them, the medium and small bills completely died off. In the west, since the climate got moister and moister, most of the marble fruits were gone, but there was still big tootfruit, that medium bill ate the easiest, so the medium bill thrived, yet all survived.

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

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

Integrated Grade Eight Snapshot 5.8: Making Sense of Natural Selection

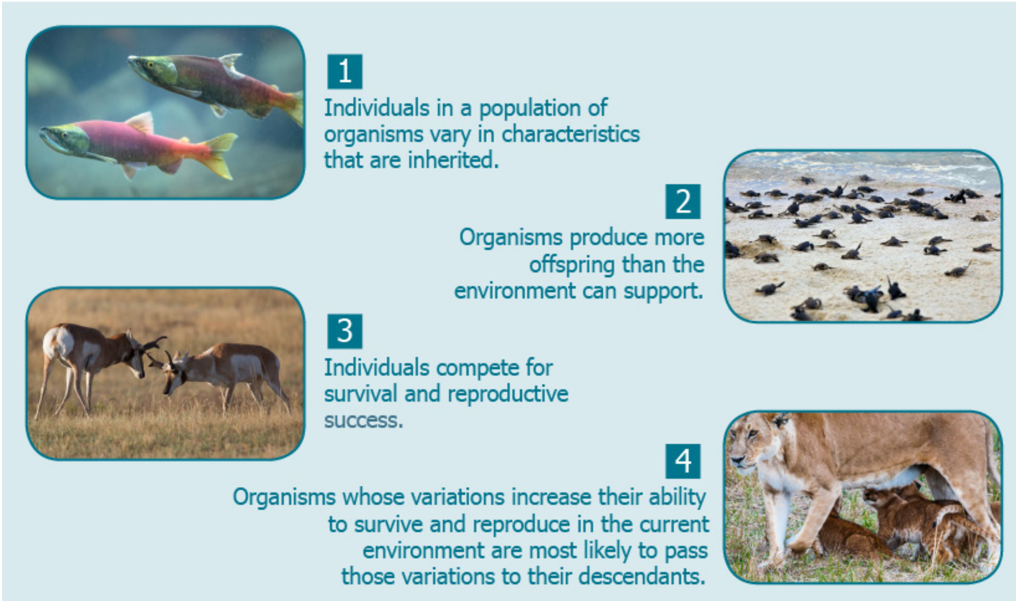
to better understand it, and students agreed they should combine and then graph the data. **Organizing and presenting the data [SEP-4]** in a visual form (graph) helped students make sense of the information and enabled them to discuss and work with their team to **review and revise their explanations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

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

Natural Selection Based on Four Scientific Concepts

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

Figure 5.49. Four Key Ideas in Natural Selection



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

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

Linking Natural Selection and Evolution

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

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

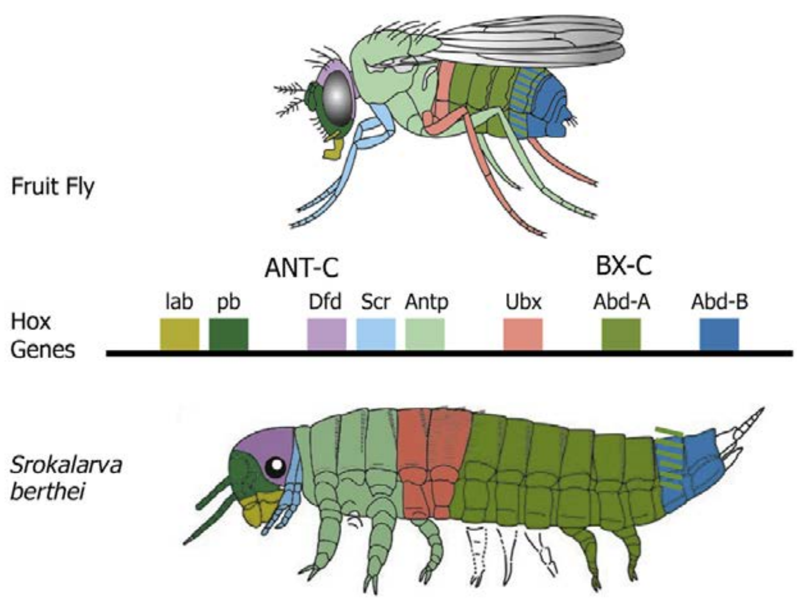
Students can compare and contrast the processes of artificial selection and natural selection. By selecting for specific characteristics over many generations, humans consciously take advantage of naturally occurring variations, and they keep increasing the quantity and quality of a particular trait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

What Causes Variation?

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

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

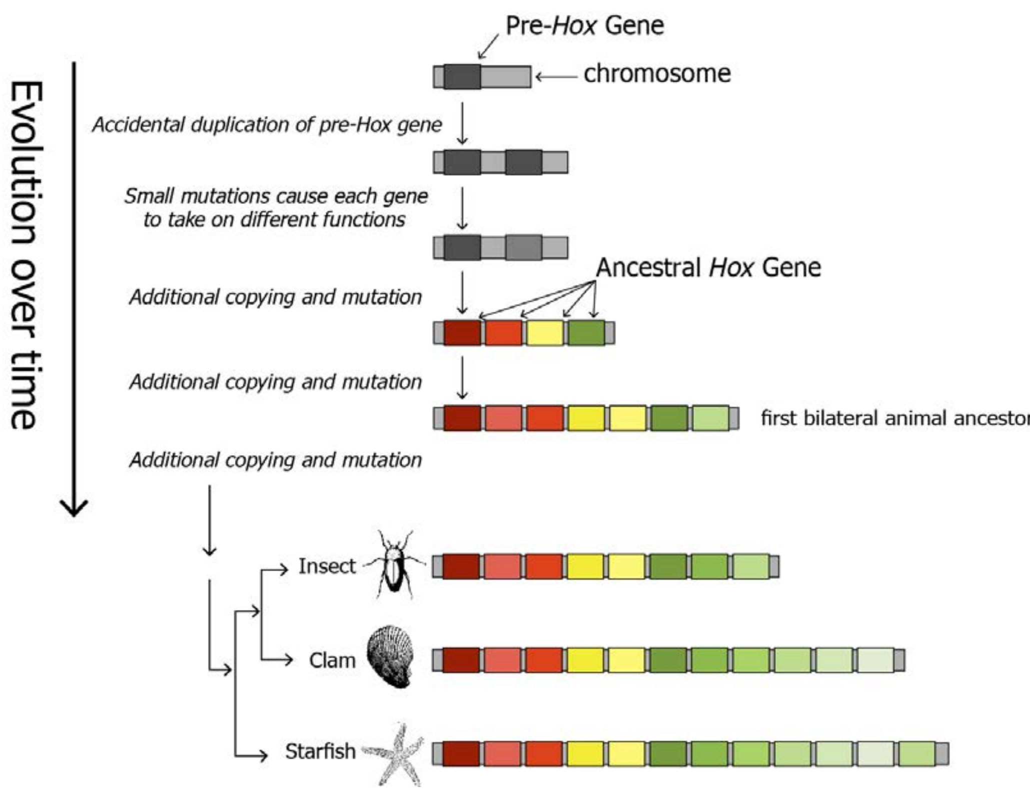
Figure 5.50. Arthropod Bodies Have Similar Structures



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

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

Figure 5.51. Animals Share Similar Genetic Code for Body Segments



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

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

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

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

Table 5.12. Possible Results of a Mutation

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

Source: Dr. Art Sussman, courtesy of WestEd

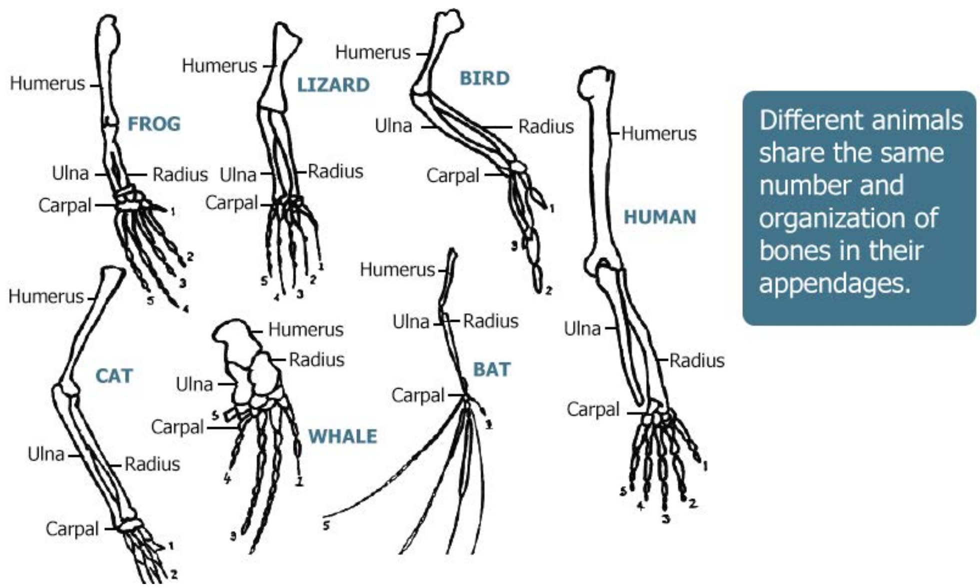
Just like artificial selection parallels natural selection, humans have developed technology to artificially introduce mutations. Students can return to their case study of corn and maize and **obtain information [SEP-8]** about how seed manufacturers have genetically modified some maize traits by inserting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

Unity and Diversity of Life

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

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

Figure 5.52. Comparing Limb Bone Structures in Different Animals



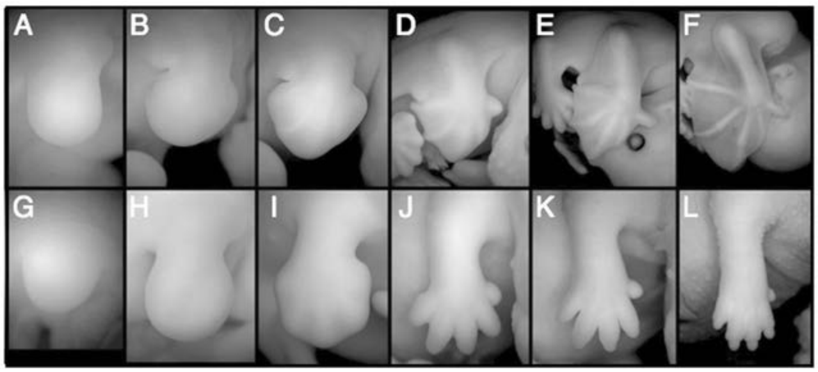
Anatomy reveals both the unity of basic bone structures and the diversity of organisms. *Source:* Lawson 2007

Long description of Figure 5.52.

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

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

Figure 5.53. View of Embryo Development in Bats and Mice



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

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

Integrated Grade Eight Snapshot 5.9: Simulating Mutant Hands

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

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

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

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

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

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

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

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

Bringing the Unit Together

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

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

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

IS4

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

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

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

Guiding Questions

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

Performance Expectations

Students who demonstrate understanding can do the following:

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

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

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

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

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

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

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

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

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

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

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

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

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

Highlighted Science and Engineering Practices	Highlighted Disciplinary Core Ideas	Highlighted Crosscutting Concepts
[SEP-1] Asking Questions and Defining Problems [SEP-2] Developing and Using Models [SEP-4] Analyzing and Interpreting Data [SEP-5] Using Mathematics and Computational Thinking [SEP-6] Constructing Explanations (for science) and Designing Solutions (for engineering) [SEP-7] Engaging in Argument from Evidence [SEP-8] Obtaining, Evaluating, and Communicating Information	LS4.B: Natural Selection LS4.C: Adaptation ESS1.A: The Universe and Its Stars ESS1.B: Earth and the Solar System ESS3.C: Human Impacts on Earth Systems PS4.A: Waves Properties PS4.B: Electromagnetic Radiation PS4.C: Information Technologies and Instrumentation ETS1.A: Defining and Delimiting Engineering Problems ETS1.B: Developing Possible Solutions	[CCC-1] Patterns [CCC-2] Cause and Effect [CCC-6] Structure and Function [CCC-7] Stability and Change

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

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

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

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

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

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

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

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

Performance Expectations

Students who demonstrate understanding can do the following:

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

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

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

MS-PS4-2. Develop and use a model of the Earth-Sun-Moon system to describe the cyclic patterns of lunar phases, eclipses of the Sun and Moon, and seasons. [Clarification Statement: Emphasis is on both light and mechanical waves. Examples of models could include drawings, simulations, and written descriptions.] [*Assessment Boundary: Assessment is limited to qualitative applications pertaining to light and mechanical waves*.]

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

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

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

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

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

CA CCSS Math Connections: 7.SP.1-3, 8.SP.4

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

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

Introduction

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

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

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

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

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

Day 1: Questioning Claims about Shark Encounters

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

Day 2: Data with More Questions than Answers

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

Day 3: Locating with Sound

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

Day 4: Obtaining Information about Tags

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

Days 5–6: Light and Sound

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

Days 7–8: Interpreting Shark Data

Students explored new understandings from this technology.

Days 9–10: Applying Understanding to a Different Population

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

Days 11–12: Educating Different Audiences

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

Day 1: Questioning Claims about Shark Encounters (Engage)

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

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

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

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

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

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

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

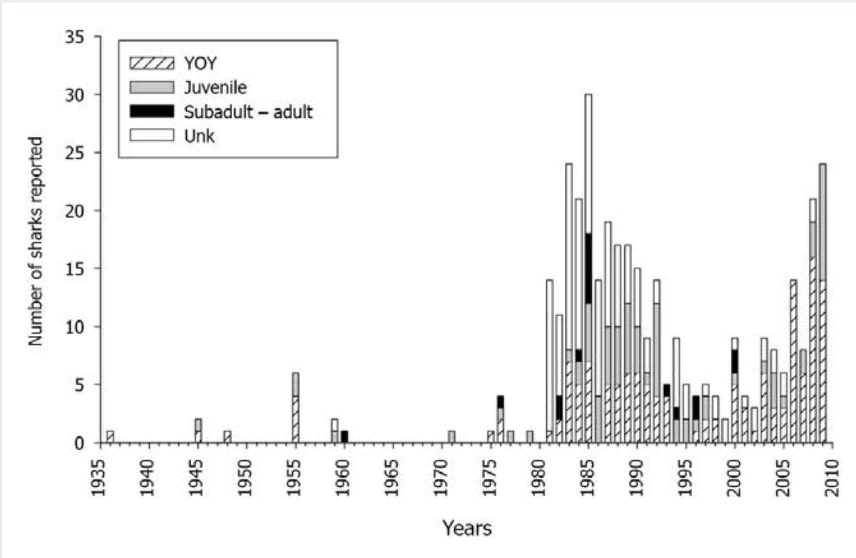
Anchoring phenomenon: The number of shark sightings increased dramatically in 1980 and goes up and down over time.

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

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

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

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



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

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

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

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

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

Possible causes:

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

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

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

Day 3: Locating with Sound (Explain)

Investigative problem: Sharks are hard to track and identify.

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

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

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

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

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

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

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

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

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

Day 4: Obtaining Information about Tags (Explore)

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

Days 11–12: Educating Different Audiences (Evaluate)

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

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

Vignette Debrief

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

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

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

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

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

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

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

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

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

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

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

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

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

Reference:
Developed by Jill Grace.

Resources:

Dulaney, Josh. 2013. "CSULB Shark Lab Study: Young Great Whites Surviving Fishing Nets." *Long Beach Press Telegram*. https://www.cde.ca.gov/ci/sc/cf/ch5.asp#link29.

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

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

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

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

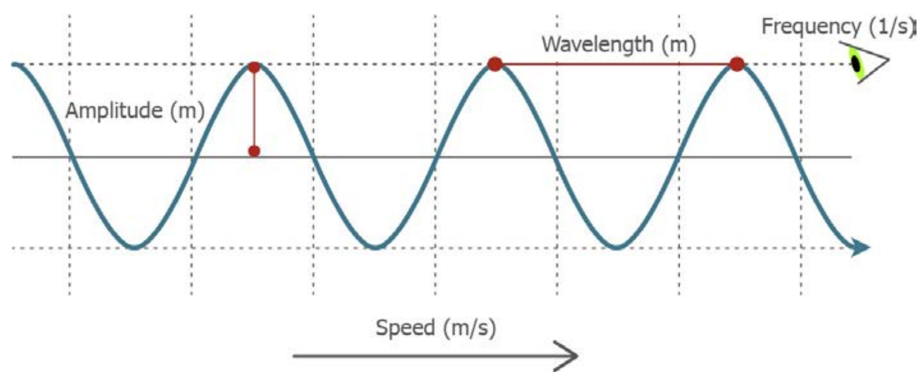
Water Waves

Over the course of this instructional segment, modeling activities should begin with mechanical waves propagating in a matter medium that is visible (such as water waves), then waves that propagate through a matter medium that is invisible (such as sound waves moving through air), and finally wave models of light. **Investigations [SEP-3]** with real-world objects can be complemented with technology. Computer or smartphone apps provide interactive simulations of simple waves (see https://www.cde.ca.gov/ci/sc/cf/ch5.asp#link32), ripple tanks (Falstad n.d.) or even display the waveforms of sound recorded by microphones so that students can use their personal technology as an oscilloscope to visualize waveforms of noises in the room.

Students **investigate [SEP-3]** a variety of waves they can generate and observe in a flat-bottomed water container (ripple tank). Students observe and discuss general wave properties that they observe including absorption, reflection, transmission of one wave through another, and even make observations that prepare them for the high school understanding of waves by observing how the simultaneous production of multiple waves produces complex waveforms. Placing floating objects at the surface and drops of colored dye below the surface allows students to track the motion of particles within the tank. These observations of phenomena should provoke students to **ask questions [SEP-1]** about wave behaviors. Each group of students could use a digital camera to create a short video clip of a surprising or exciting observation that they would like to understand further. These questions can form the organizing **structure [CCC-6]** for the instructional segment, and teachers can revisit these questions and the emerging explanations.

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

Figure 5.55. Model of a Typical Wave



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

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

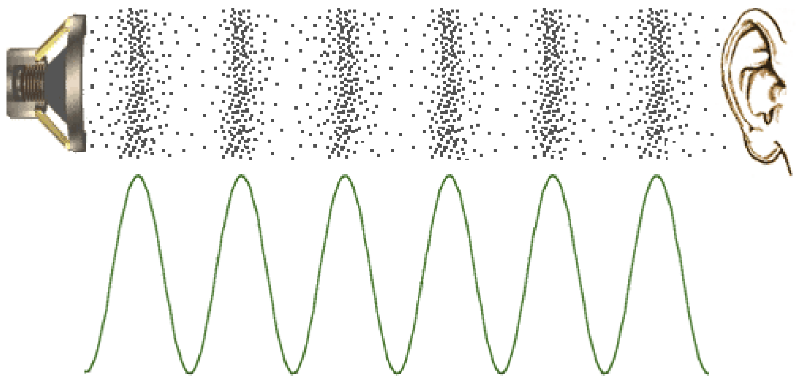
Students' **models [SEP-2]** of wave motion, amplitude, and **energy [CCC-5]** can help them **explain [SEP-6]** why waves break at the beach (enabling California's famous surfing and other beach play). Surfers know that the water in a breaking wave is moving toward the beach (which pushes their surfboard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

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

Sound Waves

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

Figure 5.56. Model of a Sound Wave in Air



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

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

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

A surprising phenomenon related to the transmission of **energy [CCC-5]** by sound waves is the event in which a singer is able to break a glass using the sound of his/her voice. In order to **explain [SEP-6]** how the glass breaks, students will **model [SEP-2]** the transformation of energy and its propagation as a wave through the air to the glass. First, they will include the vibration of the vocal cords and how that vibration is transferred to the molecules of air. Then, they will model how that vibration travels through space by compression and expansion of air molecule density that reaches the glass. Finally, the students' models will represent the transfer of energy from the vibrating air molecules to the molecules in the glass.

Light Waves

The idea that light is also a wave phenomenon can best be developed by the fact that it shows all the behaviors of waves (reflection, absorption, transmission through a medium such as glass, and carrying **energy [CCC-5]** from place to place; MS-PS4-2). The obvious question, What is the moving medium in a wave pattern for light? is difficult to answer at this grade level. In light, the "movement" is actually the changing pattern of electric and magnetic fields travelling across space or through some forms of matter. Students know that these fields are related to energy after their investigations in IS2, but the assessment boundaries for the middle grades MS-PS4-1 and MS-PS4-2 explicitly state that electromagnetic radiation (including a discussion of the electromagnetic spectrum) is not assessed in the middle grades. For grade eight students, visible light serves as a familiar form of energy and an example of how electromagnetic radiation can transfer energy very quickly across huge distances.

Light travels in straight lines, until it encounters an object where its energy can be absorbed, reflected back, or be transmitted through the material. Students can perform **investigations [SEP-3]** to compare the different effect of mirrors and different color paper on the path of light. Students can draw diagrams to **model [SEP-2]** each situation, tracing the path of light and how **energy [CCC-5]** is transferred to different objects based upon the interaction between the light and the materials (MS PS4 2). In fourth grade, students already began developing a model of how light allows objects to be seen (4-PS4-2), and teachers should connect to that earlier learning experience to emphasize that reflection is crucial because we only see objects after they reflect light back to our eyes. Eyes perceive waves with different frequencies as different colors, and each wave's amplitude is observed as light's brightness.

Opportunities for ELA/ELD Connections

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

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

CA ELD Standards: ELD.PI.6–8.6

A Model of Seasons

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

Figure 5.57. Earth–Sun System Scale

A scale illustration of the Earth–Sun system (top). The Sun is 5 pixels wide and the Earth is 1075 pixels away, but is only 0.05 pixels wide, which is too small to display. At this scale, it is easier to recognize that rays of sunlight arrive at Earth as parallel rays at all latitudes (bottom). Diagram by M. d'Alessio. Long description of Figure 5.57.

Students can make these connections using a physical model where their own body represents the motion of the planet (Space Science Institute, Kinesthetic Astronomy at https://www.cde.ca.gov/ci/sc/cf/ch5.asp#link33). They tilt their bodies toward or away from the Sun at the same 23.5° tilt as the Earth and move around Earth's orbit, making sure that their tilt axes always point towards the North Star. As they move from one side of the Sun to the other, they see how the angle of the Sun's rays **changes [CCC-7]** in the different hemispheres: in the northern hemisphere summer, the tilt brings the angle of the Sun's rays closer to 90° while it makes the angle smaller in the Southern Hemisphere. Computer simulations allow students another way to visualize these changes (NOAA, Seasons and Ecliptic Simulator, https://www.cde.ca.gov/ci/sc/cf/ch5.asp#link34).

Learning a scientifically accurate model for the seasons is often impeded by students' incoming preconceptions (documented vividly in the short documentary *Private Universe*, Harvard-Smithsonian Center for Astrophysics, at https://www.cde.ca.gov/ci/sc/cf/ch5.asp#link35 and in review articles at https://www.cde.ca.gov/ci/sc/cf/ch5.asp#link36). Most notably, students often incorrectly believe that the Earth is closer to the Sun in summer and farther in winter. In this example course sequence, seasons are deliberately placed in a separate instructional segment from the discussion of orbits in order to increase the association between seasons and Sun angle instead of reinforcing an incorrect connection between seasons and orbital distance. Nonetheless, many students will still harbor this preconception and it must be addressed. Interactive 3-D simulations have been shown to help students confront this preconception.[2] In these virtual worlds, students view the Sun–Moon–Earth **system [CCC-4]** from various viewpoints and control different aspects, including rotation and revolution rates, and inclination of Earth's spin axis. The story of seasons is mostly a story of light and energy absorption. Emphasis should be placed on the intensity and duration that sunlight shines on a particular patch of Earth's surface. Because Earth's tilt causes the Sun to appear to travel across the sky along a different path during summer versus winter, the Sun shines for more hours during the day (causing longer duration sunlight) and from higher angles in the sky (causing more sunlight to appear more intense in a given patch of the surface). Together, these give rise to warmer summers and cooler winters.

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

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

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

Integrated Grade Eight Snapshot 5.10: School Solar Energy Project

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

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

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

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

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

Waves Can Encode and Transmit Information

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

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

Table 5.13. Characteristics of Waves

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

Table by Dr. Art Sussman, courtesy of WestEd.

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

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

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

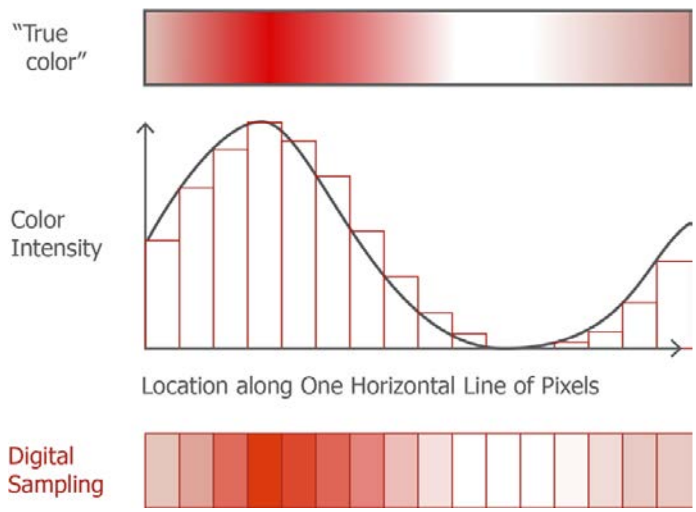
Students can compare the advantages and disadvantages of the earliest mechanisms of transmitting information to the beginning ages of radio to today's wireless cell phones and tablets. Historical examples of encoded information in wave pulses (e.g., drum or smoke signals, the invention of Morse code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

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

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

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

Figure 5.58. Digitizing a Screen Picture



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

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

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

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Performance Expectations

Students who demonstrate understanding can do the following:

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

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

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

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

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

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

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

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Highlighted California Environmental Principles and Concepts:

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

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

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

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

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

CA CCSS Math Connections: 8.SP.2, 4

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

CA ELD Connections: ELD.PI.6–8.1, 9

INTEGRATED GRADE EIGHT VIGNETTE 5.4: STUDENT CAPSTONE PROJECTS

Introduction

By the end of grade eight, students can approach new phenomena, recognize how different parts of the Earth system are interacting in the situation, draw on DCIs from all disciplines of science and engineering to explain the mechanisms driving these interactions, and design solutions to problems that they identify and constrain. This capstone project puts them to work at using all their understanding from grades K–8.

Day 1: Analyzing Per-Capita Consumption

Students calculate per-capita consumption of different countries, develop and critique different ways of communicating these data, and ask questions about trends they see.

Day 2: Introducing Capstone Projects

Ms. D provides the background about the capstone project and students read and discuss five environmental case studies.

Day 3: Focus on Solutions

Students read about five case studies of communities that have developed solutions to environmental problems. Students brainstorm ideas for their capstone projects.

Days 4–8: Collaborative Work Sessions

Teams work collaboratively and the teacher helps focus and guide students.

Day 9: Project Presentations

Students prepare final presentations for a school science night.

Day 10: Synthesis

Students from different project groups combine together to identify common elements in the projects and identify how the projects relate to the EP&Cs.

Day 1: Analyzing Per-Capita Consumption

Anchoring phenomenon: Different countries consume radically different amounts of energy per capita.

How many people live on planet Earth? Where in the world do they live? Ms. D facilitated the discussions and appropriately guided them towards information about specific countries (e.g., the United States, China, Mexico) and also about parts of the world (e.g., Africa, Pacific Islands, Europe). She charted their comments, and then asked students if they had any ideas about which areas consumed the most resources and why. After a while, students concluded that for each country or continental area, they should probably get **quantitative [CCC-3]** data about total consumption and per-capita consumption.

Ms. D provided each group of students with information about world populations (available at Data from the Population Reference Bureau report accessed at https://www.cde.ca.gov/ci/sc/cf/ch5.asp#link37) and about consumption of natural resources in the year 2013. In both

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cases, the datasets included information at the country level (e.g., Brazil) and at a regional level (e.g., South America). The consumption data were reported as the number of millions of metric tons of carbon dioxide emitted from the consumption of energy resources (see Data from the U.S. Energy Information Administration accessed at https://www.cde.ca.gov/ci/sc/cf/ch5.asp#link38). Because the total amount of data from the sources was somewhat overwhelming and also not 100 percent consistent with respect to country/region designations, Ms. D had compiled the data to cover seven distinct regions, and had highlighted within each region significant representative countries.

Student groups **analyzed the data [SEP-4]** that Ms. D had provided, **calculated [SEP-5]** per-capita consumption as the ratio of the emissions and population, and then developed a poster to **communicate [SEP-8]** the differences to their classmates. Some student groups chose color-coding maps to compare per-capita consumption. Other groups superimposed on global maps pictorial ways to represent total consumption by a country or region. This representation helped them compare geographic size with consumption total. A less visually oriented group created a summary table (table 5.14).

Table 5.14. Per-Capita Consumption

Region, *[An example country]*	Population in 2013 *(number of people)*	Total CO_2 Emitted in 2013 *(tons)*	Per-Capita Emission of CO_2 *(tons/person/year)*
Africa *[Nigeria]*	1,100 million *(174 million)*	1,268 million *(96 million)*	1 *(0.5)*
Asia *[China]*	4,302 million *(1,357 million)*	18,909 million *(10,246 million)*	4 *(8)*
East Europe *[Russia]*	295 million *(144 million)*	2,713 million *(1,789 million)*	9 *(12)*
West Europe *[Germany]*	190 million *(81 million)*	1,466 million *(759 million)*	8 *(9)*
South America *[Brazil]*	401 million *(196 million)*	1,188 million *(502 million)*	3 *(3)*
Middle East *[Saudi Arabia]*	251 million *(30 million)*	1,716 million *(543 million)*	7 *(18)*
North America *[USA]*	352 million *(316 million)*	5,660 million *(5,184 million)*	16 *(16)*

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

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The whole class then did a gallery walk where they examined each of the posters and listened to the group's presentation about their chart. The students discussed the benefits and disadvantages of each representation of the data. Students asked questions, and wrote down notes about specific pieces of the data that they noticed in each representation. After the gallery walk and while the charts were still visible, the whole class discussed the most important **patterns [CCC-1]** of per-capita consumption, and Ms. D invited students to propose **evidence-based claims [SEP-7]**. Some students noticed a **pattern [CCC-1]** that some small countries, particularly in the Middle East, had the highest levels of per-capita emission. For example, Kuwait had a per-capita emission rate of 37 tons of CO_2 per person per year. They made a claim that this extremely high rate resulted from Kuwait's large role as a producer, refiner and exporter of fossil fuel resources, and cited as **evidence [SEP-7]** correlations with other countries that produce and export large amounts of fossil fuels.

Throughout the year, Ms. D had posters along her wall with illustrations of California's Environmental Principles and Concepts and she asked students to refer to them now. She asked her students which EP&Cs might apply to the data set they analyzed. One student suggested EP&C II (*The long-term functioning and health of terrestrial, freshwater, coastal and marine ecosystems are influenced by their relationships with human societies*). She facilitated a brief class discussion about the concepts associated with that principle. Several students observed that their data seemed to support the idea that the growth of human populations is directly related to the amount of resources humans consume (EP&C II, concept a).

Day 2: Introducing Capstone Projects

Motivated by these observations about human consumption and questions about the possible impacts this consumption has on the rest of Earth systems, Ms. D introduced student group projects that concluded their immersion in the middle grades science. Student teams chose a specific human activity that has an environmental impact and explored it using all three dimensions of the CA NGSS as they experienced them throughout all three middle grades. She organized her expectations around the SEPs:

- **obtain and evaluate information [SEP-8]** about a specific phenomenon in which human activities are impacting one or more Earth systems;
- **analyze data [SEP-4]** related to the impacts on Earth systems, and identify how they demonstrate the California EP&Cs;
- **construct explanations and design solutions [SEP-6]** related to those human activities and impacts;
- **analyze design solutions [SEP-4]** with respect to their criteria and constraints associated with successful implementation;
- **model [SEP-2]** how digital technologies can assist with gathering data, implementing solutions, and/or communicating results;
- **argue using evidence [SEP-7]** to evaluate and refine their solutions; and
- **communicate the scientific and/or technical information [SEP-8]** related to their project and their proposed solution.

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To help establish a shared background within and across the student groups, Ms. D provided five different illustrated readings that she had made based on the *Living Planet Report 2014* from the World Wildlife Fund (World Wildlife Fund 2014). Students worked in teams of two to initially process the information in one of the readings and then combined into larger groups focused on that reading. These groups then made presentations to the whole class, followed by discussions about the individual topics and how those topics connected with each other around the theme of human impacts on Earth systems. The five readings focused on **cause and effect [CCC-2]** and **stability and change [CCC-7]** as they related to

- an overall decline in biodiversity of 52 percent between 1970 and 2010 resulting from habitat modification, over-exploitation, pollution, and invasive species;
- the ways that climate change can magnify the negative impacts on biodiversity;
- how humans are currently converting more nitrogen from the atmosphere into "reactive forms" than all terrestrial processes combined;
- the claim that humanity's demand for natural resources currently exceeds the capacity of land and sea areas to regenerate those resources; and
- **analyzing data [SEP-4]** comparing the "ecological footprints" of high-income countries and low-income countries.

Day 3: Focus on Solutions

Ms. D transitioned to a focus on solutions by sharing seven brief readings from the *Living Planet Report 2014*. Each reading described positive strategies that a specific community had implemented to preserve natural resources, have more efficient production, and consume more wisely. While they **evaluated information [SEP-8]** in these readings in teams and as a whole class, students began brainstorming potential solutions related to the impacts in the first set of readings. Student facilitators helped summarize and display notes on these potential solutions.

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

Days 4–8: Collaborative Work Sessions

The schedule for the work on student projects included designated dates when groups shared their current status with each other. This sharing greatly broadened the learning from the projects about the topics and expanded the feedback to the student groups. During these

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sessions, each group focused on reporting about their project through the lens of one or two CCCs. The CCCs helped guide student thinking and lead them to ask specific types of questions (see chapter 1 of this framework for examples).

Day 9: Poster Presentations

At the end of the projects, student groups across the different grade eight classes presented posters of their projects at a school science evening program.

Some highlights from the projects included public outreach and monitoring water quality in a local stream to help protect the California freshwater shrimp. Students shared that this organism was an example of the four main HIPPO (**H**abitat loss, **I**nvasive species, **P**ollution, **P**opulation growth, **O**verexploitation) categories of activities that threaten biodiversity. People have altered its habitat by building dams, and also overharvesting timber and gravel along the stream banks. In addition, people have stocked streams with invasive nonnative fish species and polluted the water. The students proposed plans to increase public awareness related to stream overharvesting and pollution practices, and identified constraints that need to be addressed to reduce these practices. (EP&C II; See the EEI unit “Extinction: Past and Present” https://www.cde.ca.gov/ci/sc/cf/ch5.asp#link39 for more information and a lesson on HIPPO.)

The genetic engineering group made an analogy between genetic code and the encoding involved in digital files. They claimed that genetic code is neither analog nor digital, but instead is uniquely biological and provides the evidence that the language of DNA includes four “digits” instead of just the two options in the binary codes of digital communication. In addition, they provided **evidence for claims [SEP-7]** that genetic engineering of food crops does not significantly endanger personal health (e.g., cancer) but a key design constraint in genetic engineering is that solutions must not endanger the health of ecosystems (EP&C V).

The school energy group visited a school in a different district that had been recognized as a green school. They **analyzed and compared energy consumption data [SEP-4]** from their school and the green school, and made recommendations based on those analyses. In addition, they **shared information [SEP-8]** about digital tools that schools use to monitor and reduce energy consumption by improving the efficiency of lighting and heating. The team identified specific reduction goals as their criteria for success as well as detailed plans to achieve those goals. They identified a constraint that energy budgets and decisions are made at the district level rather than the school level (EP&C V).

One of the asteroid-impact teams changed projects. They remembered that the HHMI BioInteractive Web site about the impact crater included remote digital data that originally identified the crater in the Yucatan. While checking other links, they discovered that the HHMI BioInteractive Web site included conservation efforts at the Gorongosa National Park in Mozambique (https://www.cde.ca.gov/ci/sc/cf/ch5.asp#link40). The students explained that this park provided a case study in ecology and conservation science. They were particularly excited when they learned that park scientists used GPS satellite collars and motion-sensitive cameras to gather data about the recovery of the park’s lion population. In addition to sharing pictures and video, the students used educational resources from the Web site to **explain [SEP-6]**

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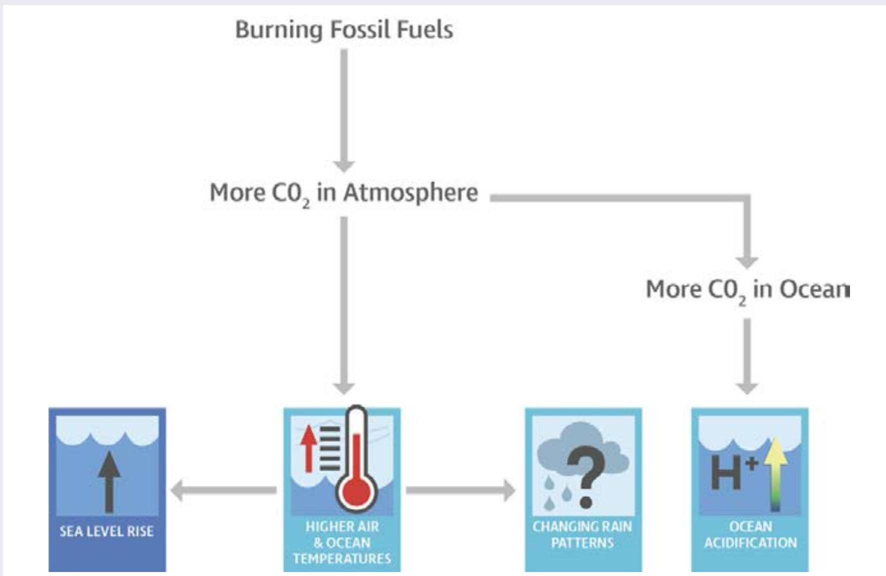
factors that influenced the park ecology, the conservation recovery plans, and significant constraints that need to be addressed to promote successful restoration (EP&C V).

The different student groups working on climate change issues jointly identified as a constraint that many people were confused about global warming and climate change. They consulted with their grade six science teacher who had taught them that global warming is the increase in air and ocean temperatures due to the increased greenhouse effect (MS-ESS3-5). She referred them to a PBS LearningMedia Web site (https://www.cde.ca.gov/ci/sc/cf/ch5.asp#link41) that has a computer interactive explaining four main impacts of climate change (figure 5.59). Higher concentrations of atmospheric CO_2 directly result in global warming and ocean acidification. The increased thermal energy trapped in the Earth system **causes [CCC-2]** other changes such as sea-level rise and changing precipitation patterns (EP&C IV).

Figure 5.59. Effects of Burning Fossil Fuels



Increased emissions of carbon dioxide cause global warming (higher air and ocean temperatures) and three other climate change impacts. *Sources:* Illustration by Dr. Art Sussman, WestEd, and Lisa Rosenthal, WGBH.
Long description of Figure 5.59.

Since their school is located relatively near the major Lake County 2015 Valley Fire that burned 76,000 acres and destroyed almost 2,000 structures, several student groups researched predictions related to climate change and wildfires. They learned that average temperatures in California are projected to generally keep increasing throughout this century (figure 5.60). They noted that reductions in emissions of greenhouse gases could reduce the amount of heating. They also learned that communities could engage in individual and collective actions that would increase the fire safety of homes.

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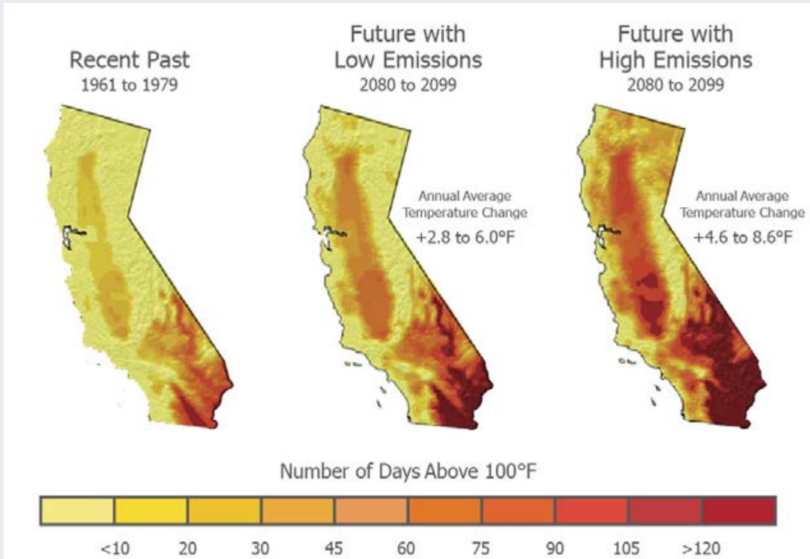
Figure 5.60. Projected Changes to California's Average Temperature



Projected increases in statewide annual temperatures during this century. *Source:* M. d'Alessio with images from U.S. Global Change Research Program 2009 and data from Moser, Ekstrom, and Franco 2012.
Long description of Figure 5.60.

The Pacific Atoll climate change group reported about the Marshall Islands, which had been a territory of the United States. They shared information about its geography and used digital tools to video conference with a school on the island of Majuro. The group explained that the approximately 60,000 Marshall Islanders were severely threatened by sea-level rise. The highest natural points on the islands are generally just 3 meters (10 feet) above sea level. During the period the schools communicated with each other, a King Tide caused serious flooding in the area of the Majuro School. The group presentation included **explanations [SEP-6]** of how climate change **caused [CCC-2]** sea levels to rise, and how scientists remotely measure sea level around the globe via satellites equipped with digital tools. Their engineering design challenge focused on ways communities can protect beaches and homes from rising sea levels. Like the other student groups, they wanted to learn more about ways to reduce the amount of climate change caused by human activities. (EEI Curriculum unit *The Greenhouse Effect on Natural Systems* https://www.cde.ca.gov/ci/sc/cf/ch5.asp#link42 provide additional resource materials on climate change and greenhouse gases.)

Day 10: Synthesis

In each of the three middle grades, students learned about the EP&Cs that were approved by the California State Board of Education. For the final lesson related to the student projects, students formed groups that consisted of students who had worked on at least three of the different projects. Each of these new groups then discussed what they had done or heard

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about that related to each of the EP&Cs. Students then shared their ideas in a whole-class discussion. They were surprised how many of them identified Principle V as something they had seen but not really understood until they had to think about engineering criteria and constraints related to reducing their specific environmental impact. They concluded that decisions affecting resources and natural systems are definitely based on a wide range of considerations and decision-making processes.

Vignette Debrief

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

SEPs. Scientists typically use all SEPs to fully understand new phenomenon, though they may focus on one practice at a time during the course of a project. Typical educational settings mirror this focus by isolating certain tasks to focus on building specific skills. In a capstone project where students confront an entirely new phenomenon and have the time to fully pursue it, students should fully employ all SEPs. For this reason, Ms. D explicitly organized her project criteria around all the SEPs.

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

DCIs. The vignette integrated major concepts in Earth science (human impacts and Earth systems), physical science (information technologies and instrumentation), life science (natural selection), and engineering technology and applications of science (engineering design: defining and delimiting engineering problems). Different project groups focused on problems that were more closely related to DCIs in one or two domains, though the project criteria required that students consider human impacts (ESS3) and include digital technology (PS4.C) and engineering design (ETS).

CA CCSS Connections to English Language Arts and Mathematics. The capstone projects and surrounding structure in the vignette were heavily focused on gathering and synthesizing information from informational texts about environmental problems (RST.6–8.1, 2, 7, 9; RI.8.3). Student groups analyzed data, calculating the per-capita consumption as the ratio of the emissions and population. They looked for patterns in the data and made evidence-based claims about what they observed (8.SP.2, 4). The entire project was structured to promote student discourse in small groups and in formal presentations (SL.8.1, 4, 6). Students then created written and visual communications products that summarized their process and findings (WHST.6–8.2, 7-9).

EP&Cs. By the end of grade eight, students are able to focus on much broader issues than they did back in kindergarten. The entire capstone project was designed to draw together all of the EP&Cs. Even though this framing was intentional, Ms. D still devoted specific time on day 1 and again on day 10 to identifying which EP&Cs apply to the situations.

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Resources:

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

U.S. Global Change Research Program. 2009. "Number of Days Above 100 Degrees Maps." In *Global Climate Change Impacts in the United States*, edited by Thomas R. Karl, Jerry M. Melillo, and Thomas C. Peterson. New York: Cambridge University Press. https://www.cde.ca.gov/ci/sc/cf/ch5.asp#link43

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

References

Achieve. 2010. *International Science Benchmarking Report: Taking the Lead in Science Education: Forging Next-Generation Science Standards*. Washington, D.C.: Achieve.

American Geophysical Union. 2011. "New Paper on Landslide-Dams and Genetic Change in Fish." https://www.cde.ca.gov/ci/sc/cf/ch5.asp#link44

Bakas, Christos, and Tassos A. Mikropoulos. 2003. "Design of Virtual Environments for the Comprehension of Planetary Phenomena Based on Students' Ideas." *International Journal of Science Education* 25 (8).

Beccario, Cameron. 2016. Earth. https://www.cde.ca.gov/ci/sc/cf/ch5.asp#link45

Benda, Lee, and Thomas Dunne. 1997. "Sediment Routing by Debris Flow." *Erosion and Sedimentation in the Pacific Rim* (Proceedings of the Corvallis Symposium, August 1987). IAHS-AISH publication 165: 213–223.

California Department of Water Resources. 2015. California Data Exchange Center. https://www.cde.ca.gov/ci/sc/cf/ch5.asp#link46

California Energy Commission. 2015. California Building Climate Zone Areas. https://www.cde.ca.gov/ci/sc/cf/ch5.asp#link47

Callaham, Robert Z. 1962. "Chapter 20: Geographic Variability in Growth of Forest Trees." In *Tree Growth*, edited by Theodore T. Kozlowski. New York: Ronald Press Company: 311–325. https://www.cde.ca.gov/ci/sc/cf/ch5.asp#link48

Cornwell, Paige. 2014. "State, Tribal Officials Keep Watch on Mudslide's Effect on Fish." *The Seattle Times*. https://www.cde.ca.gov/ci/sc/cf/ch5.asp#link49

Cowan, Richard. 2000. "Tracking the Course of Evolution: The K-T Extinction." In *History of Life*, by Richard Cowan. Boston: Blackwell Science.

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

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

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

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

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

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

Exploratorium Teacher Institute. 2016. Science Snacks: Gas Model. https://www.cde.ca.gov/ci/sc/cf/ch5.asp#link50

Falstad, Paul. N.d. Virtual Ripple Tank. https://www.cde.ca.gov/ci/sc/cf/ch5.asp#link51

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

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

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

Haug, Joachim T., Conrad C. Labandeira, Jorge A. Santiago-Blay, Carolin Haug, and Susan Brown. 2015. "Life Habits, Hox Genes, and Affinities of a 311 Million-Year-Old Holometabolan Larva." *BMC Evolutionary Biology* 15: 208. https://www.cde.ca.gov/ci/sc/cf/ch5.asp#link52

Howard Hughes Medical Institute. 2014. The Origin of Species: The Beak of the Finch. https://www.cde.ca.gov/ci/sc/cf/ch5.asp#link53

InquireBotany. N.d. "Can You See the Difference between Wind Pollinated and Insect Pollinated Flowers?" https://www.cde.ca.gov/ci/sc/cf/ch5.asp#link54

Intergovernmental Panel on Climate Change (IPCC). 2007. *Climate Change 2007: Synthesis Report. Contribution of Working Groups I, II and III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*, Core Writing Team R.K. Pachauri and A. Reisinger, eds. Geneva, Switzerland: Intergovernmental Panel on Climate Change.

———. 2014. *Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*, Core Writing Team R.K. Pachauri and L. Meyer, eds. Geneva, Switzerland: Intergovernmental Panel on Climate Change.

Janulaw, Al, and Judy Scotchmoor. 2011. UCMP Lessons: Clipbirds. https://www.cde.ca.gov/ci/sc/cf/ch5.asp#link55

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

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

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

Lawson, Ruth. 2007. "Anatomy and Physiology of Animals Various Vertebrate Limbs." Posted at *Wikimedia Commons*, https://www.cde.ca.gov/ci/sc/cf/ch5.asp#link56

Mackey, Benjamin H., Joshua J. Roering, and Michael P. Lamb. 2011. "Landslide-Dammed Paleolake

Perturbs Marine Sedimentation and Drives Genetic Change in Anadromous Fish." *Proceedings of the National Academy of Sciences of the United States of America* 108 (47): 18905–18909. https://www.cde.ca.gov/ci/sc/cf/ch5.asp#link57

Meléndez, A. and Molina, E. 2008. "The Cretaceous-Tertiary (KT) boundary." In *Contextos Geológicos Españoles*, edited by Angel García-Cortés, José Águeda Villar, Jaime Palacio Suárez-Valgrande, and Carlos I Salvador González. Madrid: Publicaciones del Instituto Geológico y Minero de España, 107–113. https://www.cde.ca.gov/ci/sc/cf/ch5.asp#link58

Meyer, Walter H. 1938. "Yield of Even-Aged Stands of Ponderosa Pine." U.S. Department of Agriculture Technical Bulletin 630. http://www.cde.ca.gov/ci/sc/cf/ch5.asp#link59

NASA. 2008. Chapter 4. Angle of Light Rays and Surface Distribution: A Structured-Inquiry Activity. https://www.cde.ca.gov/ci/sc/cf/ch5.asp#link60

———. 2014. All Dry on the Western Front. https://www.cde.ca.gov/ci/sc/cf/ch5.asp#link61

———. 2016. GISS Surface Temperature Analysis (GISTEMP). https://www.cde.ca.gov/ci/sc/cf/ch5 asp#link62

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

Netburn, Donna. 2016. "Dinosaurs were in Decline Long before the Chicxulub Asteroid Finished Them off." https://www.cde.ca.gov/ci/sc/cf/ch5.asp#link63

NGSS Lead States. 2013. Appendix F—Science and Engineering Practices in the NGSS. https://www.cde.ca.gov/ci/sc/cf/ch5.asp#link64

Pearce, Andrew J., and Alex John Watson. 1986. "Effects of Earthquake-Induced Landslides on Sediment Budget and Transport over a 50-yr Period." *Geology* 14 (1): 52–55.

PhiLiP. 2007. "Hoxgenesoffruitfly." Posted at *Wikimedia Commons*, https://www.cde.ca.gov/ci/sc/cf/ch5.asp#link65

Pittsburgh City Photographer. 1917. *15 Years of Typhoid*. https://www.cde.ca.gov/ci/sc/cf/ch5 asp#link66

Pluke. 2012. "CPT-Sound-Physical-Manifestation." Posted at *Wikimedia Commons*, https://www.cde ca.gov/ci/sc/cf/ch5.asp#link67

Population Reference Bureau. 2013. World Population Data Sheet. https://www.cde.ca.gov/ci/sc/cf/ch5.asp#link68

———. 2016. World Population Data Sheet. https://www.cde.ca.gov/ci/sc/cf/ch5.asp#link69

Rathbun, J.A., J.R. Spencer, A.G. Davies, R.R. Howell, and Lionel Wilson. 2002. "Loki, Io: A Periodic Volcano." *Geophysical Research Letters* 29. (10): 84-1–84-4.

Rohde, Robert A., and Richard A. Muller. 2005. "Cycles in Fossil Diversity." *Nature* 434 (7030): 208–210.

Roth, Mitchel. 1997. "Cholera, Community, and Public Health in Gold Rush Sacramento and San Francisco". *Pacific Historical Review* 66 (4): 527–551.

Ruggerone, Gregory. 2008. "Evaluation of Salmon and Steelhead Migration after a Landslide on the Sultan River. Phase I: Fish Passage Assessment." Prepared for Snohomish County Public Utility District 1.

Sadler, Philip, Gerhard Sonnert, Harold P. Coyle, Nancy Cook-Smith, Jaimie L. Miller. 2013. "The Influence of Teachers' Knowledge on Student Learning in Middle School Physical Science Classrooms." *American Educational Research Journal*. 50 (5): 1020–1049.

Sherriff, Robert. 2015. "Middle School Madness Part 2: Integrated Science versus Coordinated Science." *California Classroom Science* 28: 10/11.

Summey, Barbara. N.d. The Hadley Effect. Southwest Climate Network. From the NASA Goddard Visualization Analysis Lab. https://www.cde.ca.gov/ci/sc/cf/ch5.asp#link70

Sussman, Art. 2000. *Dr. Art's Guide to Planet Earth*. White River Junction, VT: Chelsea Green Publishing Company.

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

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

Thebiologyprimer. 2015. "Relationship between Latitude vs. Temperature and Precipitation." Posted at *Wikimedia Commons*, https://www.cde.ca.gov/ci/sc/cf/ch5.asp#link71

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

———. 1995. Inventory of Landslides Triggered by the 1994 Northridge, California Earthquake. USGS Open File Report 95-213. https://www.cde.ca.gov/ci/sc/cf/ch5.asp#link72

———. 1999. Snider-Pellegrini Wegener Fossil Map. https://www.cde.ca.gov/ci/sc/cf/ch5.asp#link73

U.S. Energy Information Administration. 2012. International Energy Statistics. https://www.cde.ca.gov/ci/sc/cf/ch5.asp#link74

Viégas, Fernanda, and Martin Wattenberg. 2016. Wind Map. https://www.cde.ca.gov/ci/sc/cf/ch5.asp#link75

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

Zimmer, Carl. 2016. "From Fins into Hands: Scientists Discover a Deep Evolutionary Link." https://www.cde.ca.gov/ci/sc/cf/ch5.asp#link76

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