Grade Eight – Preferred Integrated Learning Progression Course Model

Introduction to the Grade 8 Integrated Science Course

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

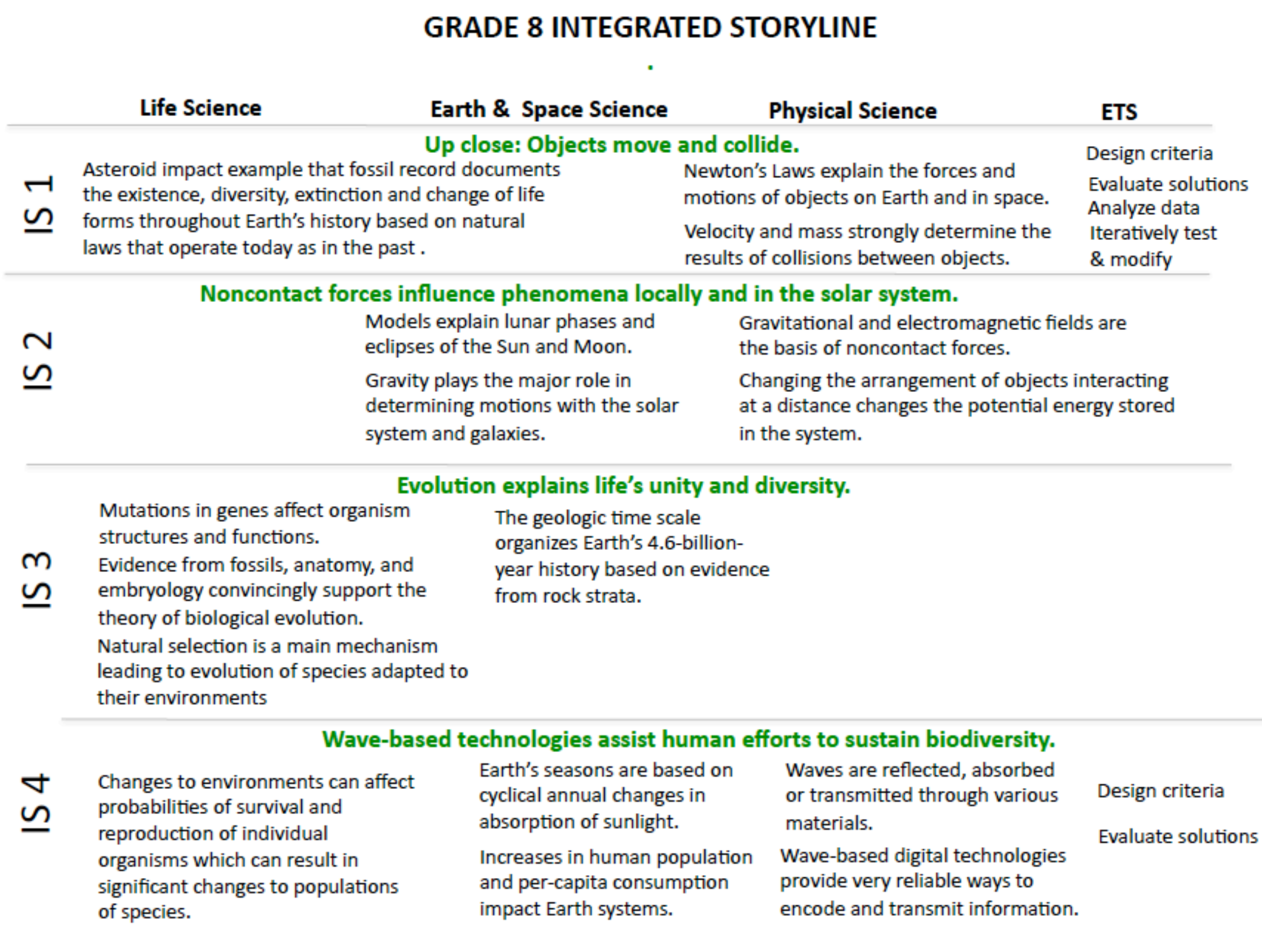

Figure 1: Overview of storyline for Integrated Grade 8.

A primary goal of this section is to provide an example of how to bundle the Performance Expectations into four sequential Instructional Segments. There is no prescription regarding the relative amount of time to be spent on each Instructional Segment (IS).

Integration within each IS and sequentially across the year flows most naturally with the science concepts in Integrated Grade 7. Integrated Grade 6 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 7 Instructional Segments.

Grade 8 presents the greatest challenge within the three middle school grades with respect to integrating the content throughout the year. The major physical science concepts of Newton's Laws and noncontact forces do not readily integrate with the major life science concepts of evolution, natural selection, and human impacts on Earth systems. As shown in Figure 1, each Grade 8 Instructional Segment tells a coherent story that generally includes two or more science disciplines that meaningfully connect with each other within that IS. 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). IS 1 and IS 4 also feature engineering design intimately connected with the IS science concepts.

Perhaps the most important perspective with respect to Integrated Grade 8 is that it serves as a capstone for the middle school grade span. The vignette in IS 4 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 and unifying concepts that students experience and apply in NGSS middle school science.

Table 1: Summary table for Integrated Grade 8

<table>
<tr><td rowspan="6">Instructional Segment 1
Up Close: Objects Move and Collide</td><th colspan="3">Instructional Segment 1: Performance Expectations Addressed</th></tr>
<tr><td colspan="3">PS2-1, PS2-2, PS2-4, PS3-1
LS4-1 (introduce), ETS-1-1 ETS1-2, ETS1-3, ETS1-4</td></tr>
<tr><th>Highlighted SEP</th><th>Highlighted DCI</th><th>Highlighted CCC</th></tr>
<tr><td>• Developing and Using Models
• Using Mathematics and Computational Thinking
• Constructing Explanations and Designing Solutions</td><td>LS4.A Evidence of Common Ancestry and Diversity
PS2.A Forces and Motion
PS2.B Types of Interactions
PS3.A Definitions of Energy
ETS1.A Defining and Delimiting Engineering Problems.
ETS1.B Developing Possible Solutions
ETS1.C Optimizing the Design Solution</td><td>• Systems and System Models
• Cause and Effect: Mechanism and Prediction
• Matter and Energy: Flows, Cycles and Conservation</td></tr>
<tr><th colspan="3">Summary of DCI</th></tr>
<tr><td colspan="3">The motion of an object is determined by the sum of the forces acting on it; if the total force on the object is zero, its motion will not change. [Newton's first law)
The greater the mass of the object, the greater the force needed to achieve the same change in motion. For any given object, a larger force causes a larger change in motion. [Newton's second law]
For any pair of interacting objects, the force exerted by the first object on the second object is equal in strength to the force that the second object exerts on the first, but in the opposite direction. (Newton's third law)
Gravitational forces are always attractive.
The kinetic energy of a moving object is proportional to the mass of the moving object and grows with the square of its speed.
The more precisely a design task's criteria and constraints can be defined, the more likely it is that the designed solution will be successful. There are systematic processes for evaluating solutions with respect to how well they meet the criteria and constraints of a problem. A design solution needs to be tested, and then modified on the basis of the test results, in order to improve it.
Patterns in the fossil record document the existence, diversity, extinction, and change of life forms throughout the history of life on Earth.</td></tr>
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<table>
<tr><td rowspan="6">Instructional Segment 2
Noncontact Forces Influence Phenomena</td><td colspan="3">Instructional Segment 2: Performance Expectations Addressed</td></tr>
<tr><td colspan="3">ESS1-1 (moon phases), ESS1-2, ESS1-3
PS2-3, PS2-4, PS2-5, PS 3-2</td></tr>
<tr><td>Highlighted SEP</td><td>Highlighted DCI</td><td>Highlighted CCC</td></tr>
<tr><td>• Developing and Using Models
• Analyzing and Interpreting data
• Constructing Explanations and Designing Solutions</td><td>ESS1.A The Universe and Its Stars
ESS1.B Earth and the Solar System
PS2.B Types of Interactions</td><td>• Patterns
• Systems and System Models
• Scale, Proportion and Quantity
• Cause and Effect</td></tr>
<tr><td colspan="3">Summary of DCI</td></tr>
<tr><td colspan="3">Patterns of the apparent motion of the sun, the moon, and stars in the sky can be observed, described, predicted, and explained with models.
The solar system consists of the sun and a collection of objects, including planets, their moons, and asteroids that are held in orbit around the sun by its gravitational pull on them. The solar system is part of the Milky Way galaxy, which is one of many galaxies in the universe.
Modeling the Sun-Earth-Moon system can help explain phases of the Moon and eclipses of the sun and the Moon.
Electric and magnetic (electromagnetic) forces can be attractive or repulsive,and their sizes depend on the magnitudes of the charges, currents, or magnetic strengths involved and on the distances between the interacting objects.
Gravitational forces are always attractive. There is a gravitational force between any two masses, but it is very small except when one or both of the objects have large mass—e.g., Earth and the sun.
Forces that act at a distance (electric, magnetic, and gravitational) can be explained by fields that extend through space and can be mapped by their effect on a test object (a charged object, or a ball, respectively).</td></tr>
</table>

Instructional Segment 3
Evolution Explains Life's Unity and Diversity

<table>
<tr><th colspan="3">Instructional Segment 3: Performance Expectations Addressed</th></tr>
<tr><th colspan="3">ESS1-4, LS3-1, LS4-1, LS4-2, LS4-3, LS4-4, LS4-5 LS4-6</th></tr>
<tr><th>Highlighted SEP</th><th>Highlighted DCI</th><th>Highlighted CCC</th></tr>
<tr><td>• Analyzing and interpreting data
• Constructing Explanations and Designing Solutions
• Arguing from Evidence
• Developing and Using Models
• Using mathematics and computational thinking</td><td>ESS1.C The History of Planet Earth
LS3.A Inheritance of Traits
LS3.A Variation of Traits
LS4.A Evidence of Common Ancestry and Diversity
LS4.B Natural Selection
LS4.C Adaptation</td><td>• Patterns
• Stability and Change
• Cause and Effect: Mechanism and Prediction
• Scale, proportion and quantity</td></tr>
<tr><th colspan="3">Summary of DCI</th></tr>
<tr><td colspan="3">The geologic time scale interpreted from rock strata provides a way to organize Earth's history. The fossil record documents the existence, diversity, extinction, and change of many life forms throughout the history of life on Earth.
Anatomical similarities and differences between various organisms living today and between them and organisms in the fossil record enable the reconstruction of evolutionary history and the inference of lines of evolutionary descent.
Evolution by natural selection explains the unity and diversity of life over the ages and today. Anatomy, embryology and artificial selection provide evidence supporting the theory of evolution by natural selection.
Species change over time in response to changes in environmental conditions. Traits that support successful survival and reproduction in the new environment become more common; those that do not become less common.
Genes are located in the chromosomes of cells, with each chromosome pair containing two variants of each of many distinct genes. Each distinct gene chiefly controls the production of specific proteins, which in turn affects the traits of the individual. Changes (mutations) to genes can result in changes to proteins, which can affect the structures and functions of the organism and thereby change traits.
Life on Earth is bilingual. At the molecular level, all Earth organisms are based on the language of proteins for doing activities and the language of nucleic acids (especially DNA) for storing information (heredity).</td></tr>
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Instructional Segment 4
Sustaining Local and Global Biodiversity

<table>
<tr><th colspan="3">Instructional Segment 4: Performance Expectations Addressed</th></tr>
<tr><td colspan="3">PS4-1, PS4-2, PS4-3, ESS3-4, ESS1-1 (seasons),
LS4-4 (applied), LS4-6 (applied), ETS-1-1, ETS1-2</td></tr>
<tr><th>Highlighted SEP</th><th>Highlighted DCI</th><th>Highlighted CCC</th></tr>
<tr><td>• Obtaining, Evaluating, and Communicating Information
• Constructing Explanations and Designing Solutions
• Engaging in Argument from Evidence</td><td>PS4.A Waves Properties
PS4.B Electromagnetic Radiation
PS4.C Information Technologies and Instrumentation
ESS1.B Earth and the Solar System
ESS3.C Human Impacts on Earth Systems
LS4.C Adaptation
ETS1.A Defining and Delimiting Engineering Problems</td><td>• Systems and System Models
• Cause and Effect: Mechanism and Prediction
• Stability and Change</td></tr>
<tr><th colspan="3">Summary of DCI</th></tr>
<tr><td colspan="3">While waves of water, sound and light appear very different, they also share many common properties. Waves can transfer energy over long distances. Waves can also encode and transmit information. Digitized signals (sent as wave pulses) are a very reliable way to encode and transmit information.
Earth's spin axis is tilted relative to its orbit around the sun. The seasons are a result of tilt and are caused by the differential intensity of sunlight on different areas of Earth across the year.
Increases in human population and per-capita consumption tend to increase negative impacts on Earth unless the activities and technologies involved are engineered otherwise.
Adaptation by natural selection acting over generations is one important process by which species change over time in response to changes in environmental conditions.
The more precisely a design task's criteria and constraints can be defined, the more likely it is that the designed solution will be successful.</td></tr>
</table>

Table 2 – Grade 8 – Instructional Segment 1

Up Close: 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?

Highlighted Scientific and Engineering Practices:

- **Developing and Using Models**
- **Using Mathematics and Computational Thinking**
- **Constructing Explanations and Designing Solutions**

Highlighted Crosscutting concepts:

- ***Systems and System Models***
- ***Cause and Effect: Mechanism and Explanation***
- ***Matter and Energy: Flows, Cycles and Conservation***

Students who demonstrate understanding can:

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

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

MS-PS2-2. **Plan an investigation to provide evidence that the change in an object's motion depends on the sum of the forces on the object and the mass of the object.** [Clarification Statement: Emphasis is on

	balanced (Newton's First Law) and unbalanced forces in a system, qualitative comparisons of forces, mass and changes in motion (Newton's Second Law), frame of reference, and specification of units.] [Assessment Boundary: Assessment is limited to forces and changes in motion in one-dimension in an inertial reference frame and to change in one variable at a time. Assessment does not include the use of trigonometry.]
MS-PS2-4.	**Construct and present arguments using evidence to support the claim that gravitational interactions are attractive and depend on the masses of interacting objects.** [Clarification Statement: Examples of evidence for arguments could include data generated from simulations or digital tools; and charts displaying mass, strength of interaction, distance from the Sun, and orbital periods of objects within the solar system.] [Assessment Boundary: Assessment does not include Newton's Law of Gravitation or Kepler's Laws.]
MS-PS3-1.	**Construct and interpret graphical displays of data to describe the relationships of kinetic energy to the mass of an object and to the speed of an object.** [Clarification Statement: Emphasis is on descriptive relationships between kinetic energy and mass separately from kinetic energy and speed. Examples could include riding a bicycle at different speeds, rolling different sizes of rocks downhill, and getting hit by a wiffle ball versus a tennis ball.]
MS-ETS1-1.	**Define the criteria and constraints of a design problem with sufficient precision to ensure a successful solution, taking into account relevant scientific principles and potential impacts on people and the natural environment that may limit possible solutions.**
MS-ETS1-2.	**Evaluate competing design solutions using a systematic process to determine how well they meet the criteria and constraints of the problem.**
MS-ETS1-3.	**Analyze data from tests to determine similarities and differences among several design solutions to identify the best characteristics of each that can be combined into a new solution to better meet the criteria for success.**
MS-ETS1-4.	**Develop a model to generate data for iterative testing and modification of a proposed object, tool, or process such that an optimal design can be achieved.**
Significant Connections to California's Environmental Principles and Concepts: None	

Instructional Segment 1 Teacher Background and Instructional Suggestions

What happens when two moving objects bang into each other? In part it depends on how much mass each of the two objects has, how fast they are traveling, and the directions in which they are traveling (MS-PS2-1). A particularly interesting example involving planet Earth happened 66 million years ago. You might wonder how we could possibly know with reasonable certainty about something that happened that long ago.

Five Periods of Major Extinctions

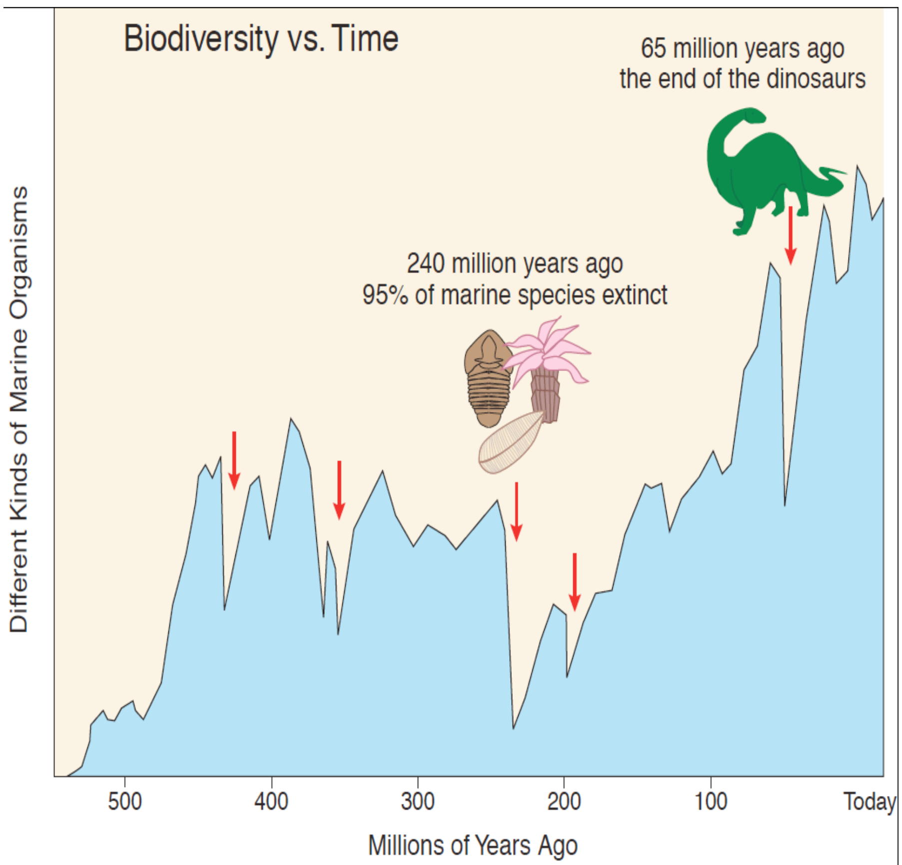

Figure 2: The fossil record of marine organisms indicates five major periods when Earth's biodiversity dramatically decreased. (Illustration from *Dr. Art's Guide to Science*, courtesy of WestEd)

As shown in Figure 2, Earth's fossil record provided the first major ***evidence*** that something changed life on Earth (MS-LS4-1) 66 million years ago. The fossil record of marine species indicates that there have been five periods (indicated by arrows) when Earth's biodiversity dramatically decreased. The most famous in this ***pattern*** of great

extinctions included the extinction of all the approximately one thousand different dinosaur species that existed at that time.
In the case of this major extinction event, scientists have amassed huge amounts of **evidence** that reinforce each other and indicate that an asteroid about 10 kilometers in diameter speeding at about 100,000 kilometers per hour crashed into the Yucatan region of Mexico. This collision released thousands of times more energy than exploding all the nuclear weapons currently on this planet. Global fires, dust and ash circling the globe and blocking sunlight, acidity changing the chemistry of the ocean, and drastic climate changes all combined to kill most of the multicellular organisms living on the planet at that time. Many species recovered but a high percentage of species became extinct.

Students can work in teams to **research** the different periods when these great extinctions happened and the **evidence** supporting those theories. Alternatively, the class could focus on the period of the dinosaur extinction and have different teams explore different kinds of evidence that integrate across the disciplines to convincingly support this ***cause and effect*** theory. The Howard Hughes Medical Institute BioInteractive website has many resources related to Earth's history and mass extinctions including a free App called EarthViewer that illustrates key features of Earth's 4.6 billion year ***time scale*** including fossil information.[10]

In addition to introducing one of the year's major topics (the history of life on Earth), the asteroid impact also leads into many key concepts related to forces, motion and gravity. How does science **describe, model and explain** the motions of objects such as an asteroid or our planet? How can we investigate phenomena related to motions and collisions?

Fortunately for teachers and students of physical science, motions and collisions provide many engaging ways for learners to **design experiments, manipulate**

[10] Howard Hughes Medical Institure (HHMI) BioInteractive Earth History resources can be accessed at: http://www.hhmi.org/biointeractive/earthviewer

variables, and collect useful data 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. On the other hand, few topics in science provide as many challenges with respect to a) using familiar words in ways that have different meanings than their common usages, and b) encountering concepts that seem to be the opposite of a person's everyday experiences.

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*** 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 vignette below, students need to **investigate, model and analyze** many phenomena in order to use common words about motion in scientifically accurate ways, and to correctly use motion concepts to ***explain the cause and effect relationships*** that result in observed phenomena.

Vignette: Learning About Motion[11]

This Vignette presents an example of how teaching and learning may look like in the classroom when the *CA NGSS* are implemented. The purpose is to illustrate how a teacher engages students in three-dimensional learning by providing them with experiences and opportunities to develop and use the Science and Engineering Practices and the Crosscutting Concepts to understand the Disciplinary Core Ideas associated with the topic in the Instructional Segment.

Introduction: From Position to Velocity

Figure 3 is an example that shows three types of models applied to the scenario of a dog going 2 meters from a tree to a fire hydrant, and then returning more quickly past the tree to a dog house that was 1 meter behind the tree. She especially liked students to begin with Difference Tables such as the one at the top of the figure. The middle is an

[11] In addition to cited illustrations, the physical science narrative in this Vignette and Instructional Segment uses material from Making Sense of Science *Forces and Motion* course, courtesy of WestEd

example of a Number Line model and the bottom shows two Line Graph models (position v time and distance v time). Next to the middle diagram, there is a prompt that she used to show that motions can also be represented using arrows of different lengths and pointing in different directions

Some Different Models of Motion

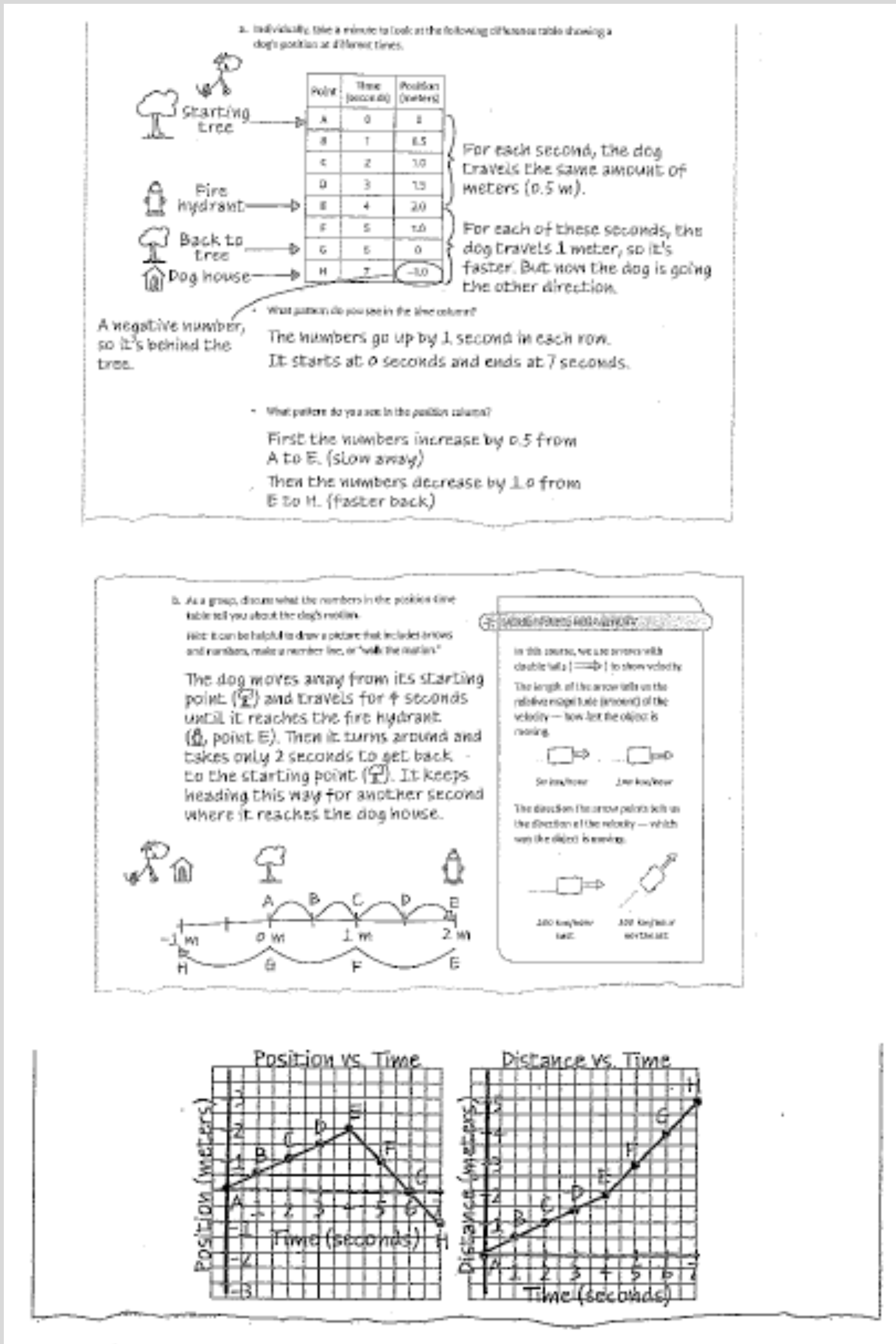

Figure 3: Different kinds of models can be used to analyze motion. (Illustrations from Making Sense of Science *Force & Motion* course, courtesy of WestEd)

Over the entire course of lessons involving motions, Ms. Z encourages students to **compare different models** of the same phenomenon, and **communicate** which model features help them understand the phenomenon better and which model features are not so helpful. Since this entire grade level involves many examples of ***systems thinking and system models***, students will often experience that "models are limited in that they only represent certain aspects of the system under study."[12] By comparing and expressing how particular model types do or do not help them understand a specific phenomenon, students gain insights into how the limitations of a model sometimes help them focus on a key concept and sometimes do not provide enough information.

In the case of the dog's journey, several students said that the line graphs confused them while other students said that they liked how the directions and slopes of the lines summarized key aspects of the motion scenario. Kanesha said that at first she did not like the line graphs, but after she figured out what the different vertical and horizontal axes represented, she liked them a lot better, and could use the line graphs to **explain** the scenario. Ms. Z took this opportunity to discuss common misconceptions about line graphs and introduce a way that the class as a whole could **communicate** about incorrect and correct conceptions (Figure 4).

Student teams and then the whole class discussed the correct conception that a graph is not a literal picture of motion. Kanesha pointed out that the correct conception statements all mentioned the reference point, but each of the three graphs actually started at a different x value for that reference point. She said that it would be better if they all started from the same point on the vertical axis at time zero. Other students said that in their math class, the x value was always on the horizontal axis, not the vertical axis. After this discussion, the students formed teams to make new versions of this incorrect/correct diagram, and compared their diagrams with each other.

[12] NGSS Crosscutting Concepts Middle School third bullet for "Systems and System Models."

Incorrect and Correct Ideas About Line Graph Shapes

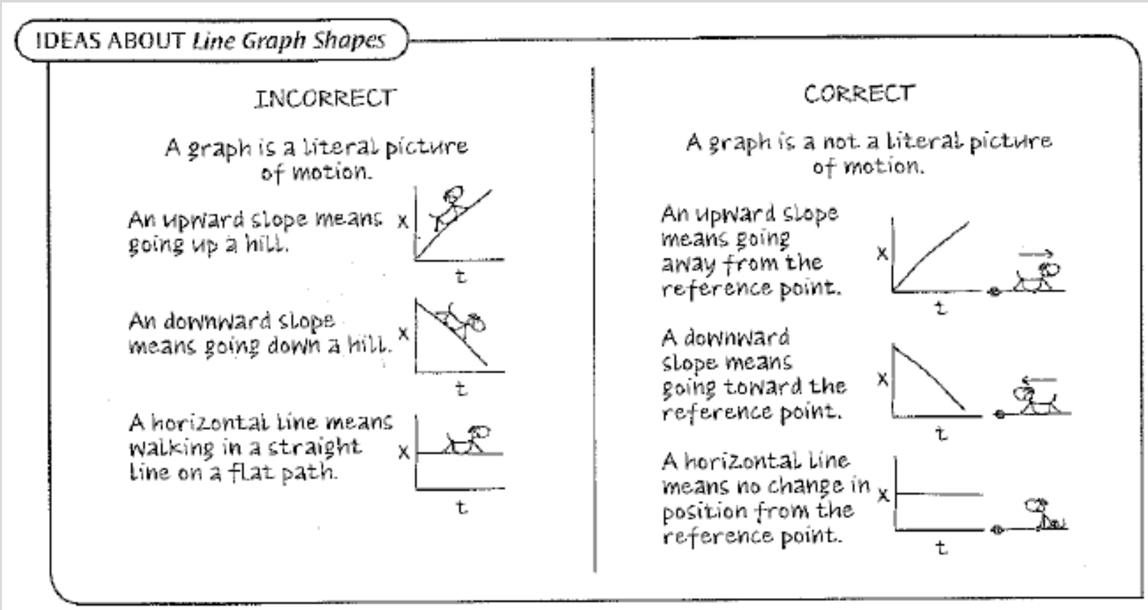

Figure 4: Comparing incorrect and correct ideas about a concept or a cognitive tool, in this case the shapes of line graphs. (Illustration from Making Sense of Science *Force & Motion* course, courtesy of WestEd)

This unexpected development perfectly supported Ms. Z's plan to have the students use this incorrect/correct diagramming as a way to solidify and summarize key motion concepts. She congratulated the students for effectively **developing and using models**, and then provided videos and animations that illustrated a wide variety of motions that included changes in position, speed and velocity. In each case students used multiple types of models to **describe, model and begin to explain** these motions.

This variety of experiences helped reveal key concepts as well as common misconceptions. Students used the incorrect/correct diagram format to **explain** the differences to themselves and each other. By the end of the investigations, students had decorated the class walls with many of these charts. In particular, there had been considerable discussions and revisions with respect to the concepts of speed and velocity, especially negative velocity (Figure 5). Students also developed diagrams that contrasted the incorrect conception that speed and velocity are identical with the correct conception that velocity includes direction as well as speed (Figure 6).

Incorrect and Correct Ideas About Negative Velocity

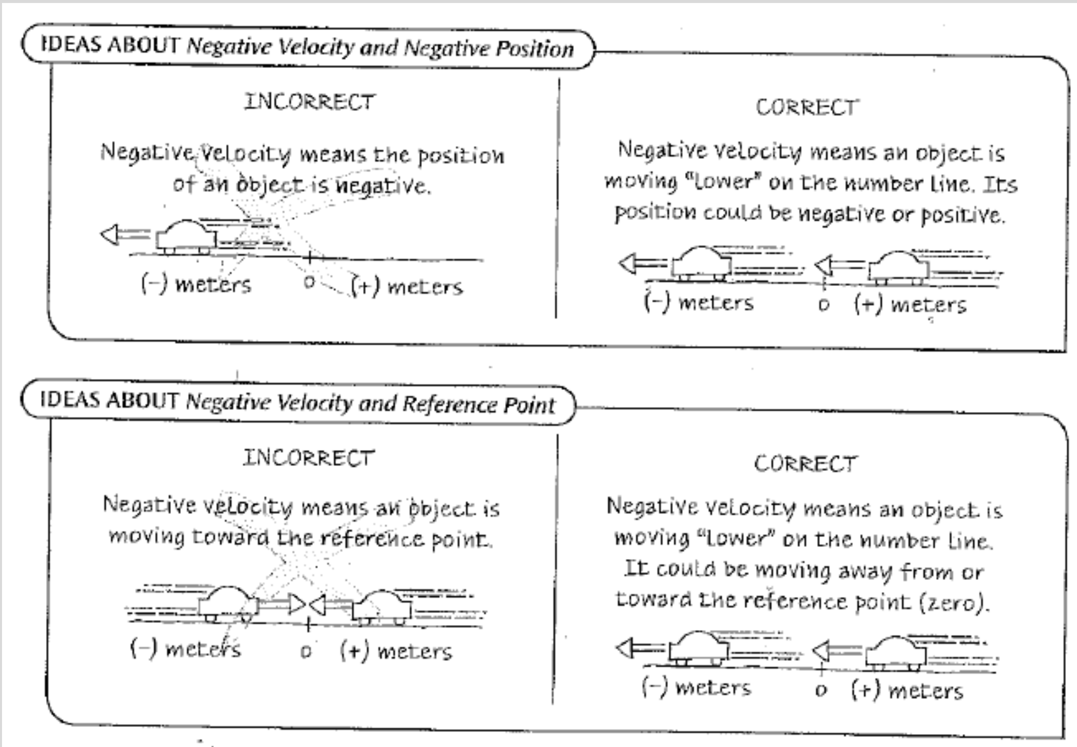

Figure 5: Comparing incorrect and correct ideas about negative velocity. (Illustration from Making Sense of Science *Force & Motion* course, courtesy of WestEd)

Constant Speed May Not Be Constant Velocity

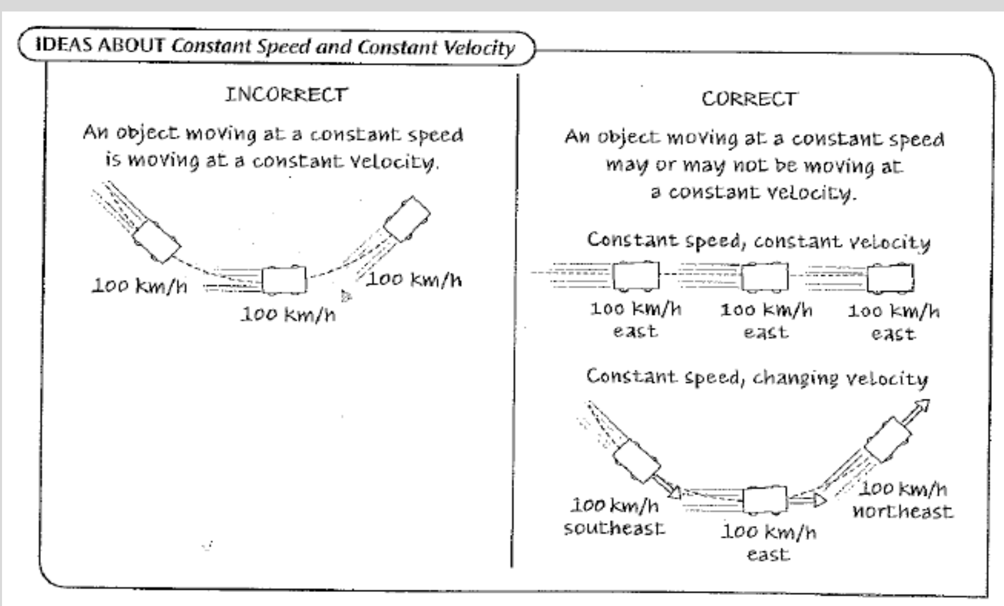

Figure 6: Object moving at constant speed may not be moving at constant velocity. (Illustration from Making Sense of Science *Force & Motion* course, courtesy of WestEd)

In the next series of lessons, students had many opportunities to **design and carry out investigations** on how the motion of an object varies depending on the amount of friction experienced by the moving object. Student teams could **design and do new experiments** only after they used their notebooks to show Ms. Z that they had accurately described their experimental procedures and results, and that they had used models to help **communicate their explanations and predictions**. Periodically student teams had opportunities to share and critique each other's work, and Ms Z also organized whole class discussions to help guide the investigations and explanations in the most productive directions.

Building on the preliminary conclusions from these investigations, Ms. Z began a class session by demonstrating the motion of a puck on an air hockey table under three conditions: table covered with a layer of paper towels, uncovered table with air off, and uncovered table with air on. She then asked what would happen if the table were very long and had zero friction. Students individually wrote their predictions, and then shared in dyads, larger groups, and finally as a whole class.

Ms. Z then had students work in teams to safely investigate the motion of a small chunk of dry ice. She told them that they could exert a force on the dry ice only by lightly pushing it with a pencil, and absolutely not letting it touch bare skin. Students immediately observed that dry ice seems to experience very little friction. This relatively quick and highly supervised activity helped support the prediction that an object in motion that experienced zero friction would indefinitely continue at the same speed. Ms. Z concluded the lesson with a homework reading about Newton's First Law and an introduction to the concept of forces. The reading showed how to illustrate different forces as arrows of different lengths that could also point in different directions. The students needed to use at least one of three different literacy strategies referenced in the handout.

Based on the homework, Ms. Z lead a class discussion that helped summarize that a force is a push or pull interaction among two or more objects. Student teams then had to use their notebooks to pick one of their motion investigations involving a push or a pull in the horizontal direction. For their selected investigation, the teams had to use arrows to **model the forces** that were acting in the horizontal direction at four different times:

A) before they pushed or pulled the object to initiate the motion;
B) at the instant that the object was pushed or pulled;
C) at an instant where the object was slowing down but had not stopped; and
D) at a time after the object had stopped moving.

Team sharing and whole class discussion then led to a consensus that there were no horizontal forces acting at instants A (before) and D (after). It took a little more time to get everyone to agree that at time C the only horizontal force was friction acting opposite to the direction of motion. By comparing C and D, some students **explained** that the force of friction was decreasing from the beginning of the motion to the end of the motion. The most extended and controversial discussion regarded instant B, the moment the object was pushed or pulled.

Ms. Z did not push or pull for a resolution of the Instant B discussion. Instead she asked the students to individually consider motion in a frictionless system such as outer space or an astronaut training facility. Their challenge was to **model** how an astronaut could maintain a constant velocity in the up direction while exerting one or more forces. The astronaut has two air guns, each of which can exert either 20 or 40 newtons of force. Ms. Z used this challenge to help solidify the notion that constant velocity can ***result from*** an absence of forces or from perfectly balanced forces.

From Constant Velocity to Acceleration

Ms. Z decided to use free Forces and Motion education animations[13] in transitioning the instructional focus from constant velocity to acceleration, from balanced forces/Newton's First Law to unbalanced forces/Newton's Second Law. She began by summarizing Newton's First Law, "When the total force on an object is zero its motion does not change at that instant." She solicited responses to why she had emphasized "at that instant."

[13] https://phet.colorado.edu/en/simulation/forces-and-motion-basics

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

In the succeeding days, class sessions focused on the animations in the order of Motion then Friction then Acceleration. As the students presented, they or Ms. V used the projector to manipulate the animation to support and extend what the students had recorded in their notebooks. After having reviewed the three animations as a whole class, the students collaboratively with each other and with Ms. Z agreed on specific questions or concepts to explore further within the animations, such as **obtaining and analyzing data** about the ***effects*** of mass and velocity on acceleration. These investigations and subsequent **analyses** 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 had been surprised that the scientific meaning of the term “acceleration” includes speeding up, slowing down or changing direction. Some of the students enjoyed telling people that vehicles actually have three accelerators: the gas pedal, the brake and the steering wheel.

Ms. Z completed this acceleration section of her instructional plan by challenging student teams to develop “incorrect/correct diagrams” related to the connections among forces, mass and acceleration. She wanted to help ensure that their take-away understandings remained deeper than repeating the F = ma equation. Students enjoyed returning to that diagram format, sharing their diagram models, and improving them. The most complex consensus diagram combined ideas about acceleration, motion and net force (Figure 7). The horizontal wavy lines represent air blowing from fans located on the top left and top right of each cart.

Acceleration, Motion and Net Force

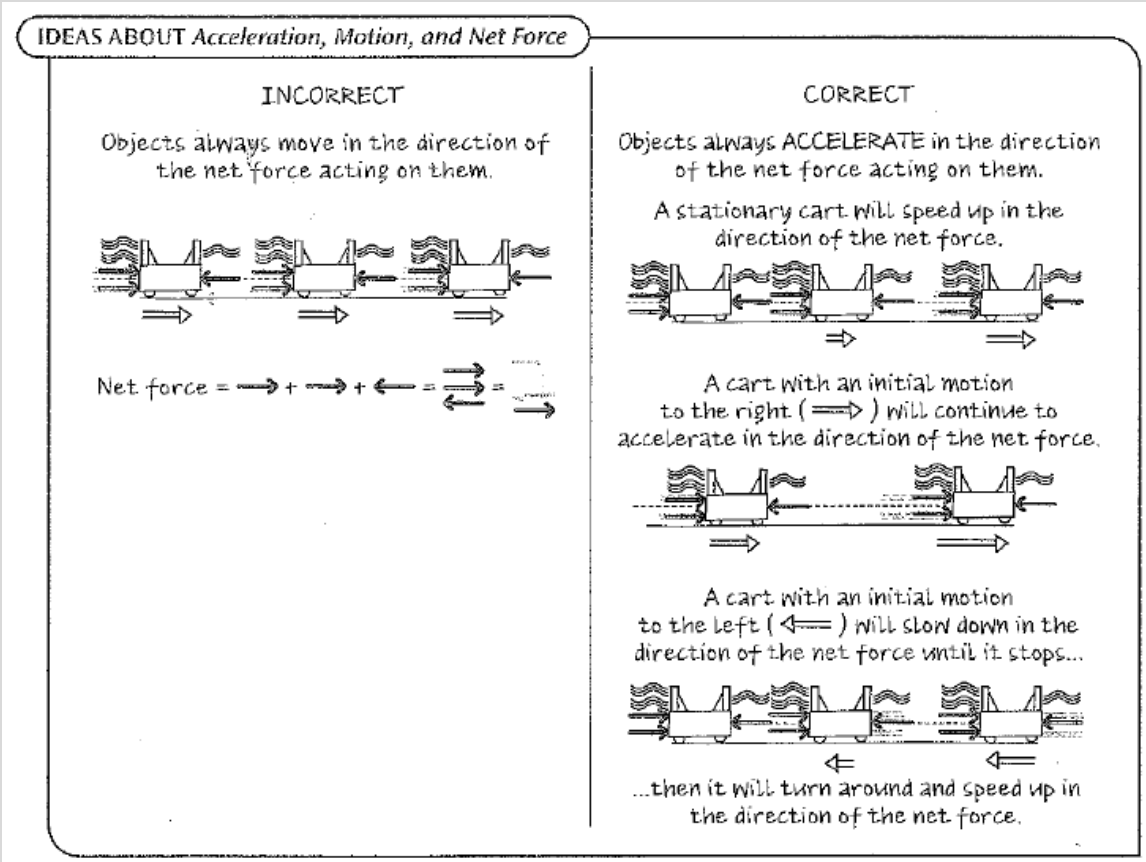

Figure 7: Objects always accelerate in the direction of the net force acting on them, but they do not always move in that direction. (Illustration from Making Sense of Science *Force & Motion* course, courtesy of WestEd)

Forces: Equal and Opposite

Ms. Z prominently displayed the incorrect/correct diagram about acceleration, motion and net force as a way to initiate a deeper discussion about forces. She asked students to talk about what they may have noticed about forces that is confusing to them, and scaffolded the discussion so it highlighted the “equal and opposite” nature of forces, a question about whether friction is pushing or pulling, and the role of gravity in their motion investigations. For example, she focused their attention on the carts with fans in Figure 7. What did they think about the force arrows that push in a direction that is opposite to the direction that the fan blows? The amount of force of those opposite pushing arrows seems to be directly related to the amount of force of the blowing fan.

This more theory-driven analysis of force and motion required more reading, modeling and discussing than hands-on investigating. Ms. Z provided different illustrated handouts that analyzed specific phenomena from the point of view of equal and opposite forces. She encountered three major conceptual issues for students: (1) the notion that only living beings or powered machines exert forces; (2) the rationale for why the forces have to be equal and opposite; and (3) the idea that objects can push and pull each other without actually touching.

For the purposes of Grade 8 students, Ms. Z honored the questions that the students raised but tried to keep the focus on the observable phenomena and how to explain these phenomena at the macroscopic level rather than theorizing about what could be happening at the invisible levels to cause the attractions and repulsions. She told students that physicists are still investigating and learning about the ultimate nature of gravity and electromagnetism.

Her main pedagogical goal for these discussions was to help students understand that a force is more than a push or a pull. A force is an interaction between objects that can result in a change in motion. When a person pushes on a wall, the wall pushes back with an equal and opposite force. When a balloon blows air behind it, the air pushes the balloon forward with an equal and opposite force. When a book presses down on a table top because of the force of gravity attracting it, the tabletop pushes up on the book with an equal and opposite force. If the tabletop did not push up, the book would go through the tabletop and fall to the ground. If the tabletop pushed back stronger than gravity, then the book would rise into the air.

Ms. Z reminded the students of the systems they had studied in grades 6 and 7. Forces provide yet another example of ***systems and system properties***. She concluded this part of the learning by having students revisit their investigations that involved objects sliding down ramps. Ms. Z handed out a paragraph about gravity to help guide their modeling:

"At the surface of Earth all objects experience a force due to gravity at every instant. This force, the weight of the object, is directed down towards the center of Earth. At the same time that an object's weight presses down on a horizontal surface, the surface

pushes straight up with an equal and opposite force that is called the "normal force." On a slanted surface, this normal force pushes upward, perpendicular to the surface."

Forces Acting on a Sliding Sled

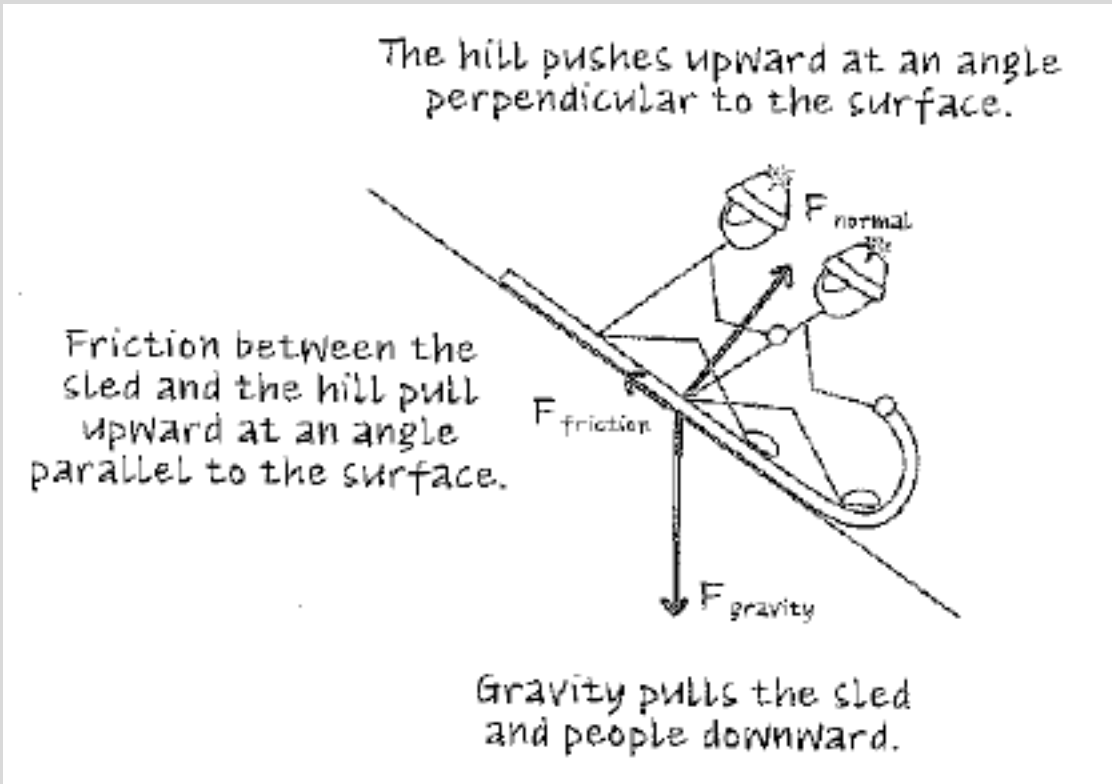

Figure 8: The net force on the sled causes it to slide down the hill. (Illustration from Making Sense of Science *Force & Motion* course, courtesy of WestEd)

This paragraph was accompanied by an illustration of the forces acting on a sled on a hillside (Figure 8). Ms. Z told the students to use this illustration as a guide in modeling their ramp investigation. She also told them that they would not be tested on determining the net force in these two-dimensional situations, but that this modeling was necessary for them to understand the interplay of forces in downward sliding motions. Ms. Z concluded this series of lessons by telling the students that their questions about gravity would be the focus of a later Instructional Segment on spooky forces that can act at a distance. However, before that Instructional Segment, they would have to play with objects that collided with each other. She smilingly apologized for having to make them play with collisions.

3153 **NGSS Connections and Three-Dimensional Learning**

Performance Expectations		
MS-PS2-1 Newton's Laws of Motion *Apply Newton's Third Law to design a solution to a problem involving the motion of two colliding objects.** **MS-PS2-2 Newton's Laws of Motion** *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.*		
Science and engineering practices	**Disciplinary core ideas**	**Crosscutting concepts**
Developing and Using Models *Develop and use a model to describe phenomena.* **Analyzing and Interpreting Data** *Analyze and interpret data to determine similarities and differences in findings.* **Constructing Explanations** *Construct an explanation using models or representations.*	**PS2.A Forces and Motion** *For any pair of interacting objects, the forces exerted by the first object on the second object is equal in strength to the force that the second object exerts on the first, but in the opposite direction. (Newton's 3rd Law)* *The motion of an object is determined by the sum of the forces acting on it; if the total force on the object is not zero, its motion will change. The greater the mass of the object, the greater the force needed to achieve the same change in motion. For any given object, a larger force causes a larger change in motion.* *All positions of objects and the directions of forces and motions must be described in an arbitrarily chosen*	**Systems and System Models** *Models can be used to represent systems and their interactions.* *Models are limited in that they only represent certain aspects of the system under study.* **Cause and Effect: Mechanism and Explanation** *Cause-and-effect relationships may be used to predict phenomena.*

	reference frame and arbitrarily chosen units of size. In order to share information with other people, these choices must also be shared.	
Connections to the CA CCSSM: 8.EE.5–6, 8.F.1–3		
Connections to CA CCSS for ELA/Literacy: RST.6–8.1, 4, 9; WHST.6–8.7, 8; SL.8.1		
Connection to CA ELD Standards:		

Vignette Debrief

The *CA NGSS* require that students engage in science and engineering practices to develop deeper understanding of the disciplinary core ideas and crosscutting concepts. The lessons give students multiple opportunities to engage with core ideas in space science (Moon phases and the solar system), helping them to move towards mastery of the three dimensions described in the *CA NGSS* performance expectations (PE's). Students continue to apply the crosscutting concept of ***Systems and System Models*** as they explore many situations involving the motions of objects. They also apply the crosscutting concept of ***Cause and Effect: Mechanism and Explanation*** to explain and predict the relationships among force, mass and acceleration. In their wide-ranging investigations students conduct the practices of **Developing and Using Models**, A**nalyzing and Interpreting Data**, and **Constructing Explanations**. Just quickly reviewing the figures within the vignette highlights the many models, analyses and explanations that connect the ideas and practices within this connected set of lessons.

Instructional Segment 1 Teacher Background and Instructional Suggestions (continued)

During the vignette, students investigated and measured motions of objects. The word "motion" in the NGSS implies both the object's speed and its direction of travel. While the Vignette included analysis of velocity (speed and direction), the assessment boundaries of PE's for 8th grade state that students will only be required in state/national testing to add forces that are aligned, and deal with changes in speed that occur when the net force is aligned to the motion.

Speed is a ratio of distance divided by time. Students can **investigate** speed by **conducting experiments** where they measure both distance and time. Manual measurements of time in tabletop experiments using stopwatches are prone to large error, so there are several alternatives: students can pool multiple measurements using collaborative online spreadsheets and take the average, use an app to calculate speed from video clips[14], or use a motion sensor probe.

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

As noted in the Vignette, students often harbor the preconception that a moving object will naturally stop rather than keep moving. If I 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.

[14] Tracker: https://www.cabrillo.edu/~dbrown/tracker/

However, even after extended investigations and discussions, students can still retain misconceptions such as that the initiating force somehow remains associated with the moving object and keeps propelling it. As described in the Vignette, modeling the forces at different instants of time (before, during and after motion) can help address this kind of misconception. Another very powerful way to deepen understanding of motion is to provide an ***energy*** perspective in addition to the force perspective.

The ***energy*** 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, it naturally slows down and eventually stops.

Collision of a Moving Person with a Stationary Person

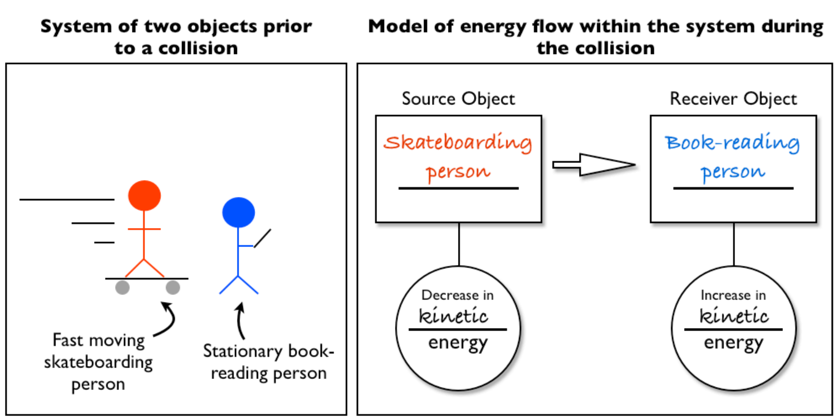

Figure 9. Model of energy flow within a system during a collision. Image credit: M. d'Alessio, released to the public domain.

Students can create a diagrammatic ***model*** of the ***flow of energy*** within ***systems*** as shown in Figure 9. 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*** (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.

Model of energy flow within a system that has friction

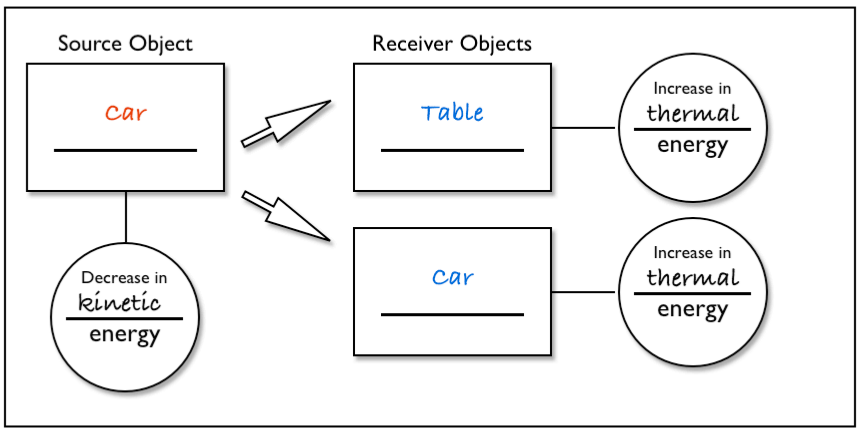

Figure 10. Model of energy flow including friction within an experimental system of a tabletop car. Image credit: M. d'Alessio, released to the public domain.

The force of friction is an interaction in which ***energy*** is transferred. Students must ***plan investigations*** to explore the ***effects*** 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 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 (Figure 10) helps draw attention to the fact that some of the energy must go somewhere. The car clearly decreases in energy but that means another component of the ***system*** must increase in energy.

With some simple analogies such as friction of hands rubbing together, students can conclude that the energy is likely converted into thermal energy. When rubbing hands together, both hands warm up even if one hand remains stationary during the rubbing. This observation gives rise to two related modifications to the previous simpler energy source/receiver diagram: 1) there can be multiple energy receivers in a ***system*** 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** in 4th 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** by colliding the same moving object with target objects of different masses that are otherwise identical in shape (for example glass versus steel marbles of different sizes, cars with or without fishing weights attached, etc). In order to measure consistent ***patterns***, students will need to ***plan their investigation*** (*MS-PS2-2*) such that the source object has a consistent speed (by rolling down a ramp of a fixed distance, for example). This procedure will ensure that the initial kinetic energy is constant and lead to a consistent force initiating the collision interaction, if all other factors remain constant. Students can vary the mass of the target object and see how its speed changes as a result of the impact, plotting the results to look for a consistent pattern. This graphical representation should lead them towards a discovery of Newton's Second Law that relates the change in an object's motion ("acceleration") to the force applied and the mass of the object. *MS-PS2-2* does not require that students have a mathematical understanding of acceleration. Instead this PE focuses on the ***proportional*** relationship of motion changes and force.

When the source and target objects have equal masses and collisions transfer all of the ***energy*** 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** 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 6*).

In each collision so far, the target object always receives the same amount of ***energy*** from the source object. The effect of this energy transfer on the target object's speed depends on its mass. 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 the 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. The animation investigations cited in the Vignette can complement these tabletop investigations very nicely, and the dual perspectives of force and energy can help **explain** the results of changing variables within the animations.

The crosscutting concept of ***energy and matter: flows, cycles and conservation*** is applied in many different contexts throughout the middle school grade span. One of the middle grade bullets used to describe this CCC states that, “the transfer of energy drives the motion and/or cycling of matter.” In Integrated Grades 6 and 7, 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 8 Instructional Segment 1, the emphasis is on the role of energy transfer in driving the motion of matter.

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

Engineering Design Challenge

Performance Expectation MS-PS2-1 provides a capstone project for Instructional Segment 1. Students are challenged to use what they have learned throughout the Instructional Segment to design a solution to a problem involving the motion of two colliding objects. The PE suggests examples of collisions between two cars, between a car and a stationary object, or between a meteor and a space vehicle. In order for this challenge to extend deeper into the design process, the suggestion here is to restrict the projects to situations that students can physically model and obtain data that can be used in iterative testing and refinement of their design solution.

The classic egg drop could be used but many of the solutions to that problem involve slowing the falling egg before the collision. The emphasis for the PE is on applying Newton's Third Law that objects experience equal and opposite forces during a collision. For example, a variation where students attach eggs to model cars and design bumpers will follow naturally from their prior tabletop experiments. At the conclusion of their testing and refinement, students should be able to use their models of ***energy transfer*** and kinetic energy to make an **argument** 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, 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 10. Towards the end of their design challenge, students need to **explain** why certain choices they made actually work, and then use their more detailed ***models of their system*** to further refine their design.

Table 3 – Grade 8 – 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?
Highlighted Scientific and Engineering Practices: • **Developing and Using Models** • **Analyzing and Interpreting data** • **Constructing Explanations and Designing Solutions**
Highlighted Cross-cutting concepts: • ***Patterns*** • ***Systems and System Models*** • ***Scale, Proportion and Quantity*** • ***Cause and Effect: Mechanism and Explanation***
Students who demonstrate understanding can: **MS-ESS1-1. Develop and use a model of the Earth-Sun-Moon system to describe the cyclic patterns of lunar phases, eclipses of the Sun and Moon, and seasons.** [Clarification Statement: Examples of models can be physical, graphical, or conceptual.] **MS-ESS1-2. Develop and use a model to describe the role of gravity in the motions within galaxies and the solar system.** [Clarification Statement: Emphasis for the model is on gravity as the force that holds together the solar system and Milky Way galaxy and controls orbital motions within them. Examples of models can be physical (such as the analogy of distance along a football field or computer visualizations of elliptical orbits) or conceptual (such as mathematical proportions relative to the size of familiar objects such as their school or state).] [Assessment Boundary: Assessment does not include Kepler's Laws of orbital motion or the apparent retrograde motion of the planets as viewed from Earth.] **MS-ESS1-3. Analyze and interpret data to determine scale properties of objects in the solar system.** [Clarification Statement: Emphasis is on the analysis of data from Earth-based instruments, space-based telescopes, and spacecraft to determine similarities and differences among solar system objects. Examples of scale properties include the sizes of an object's layers (such as crust and atmosphere),

	surface features (such as volcanoes), and orbital radius. Examples of data include statistical information, drawings and photographs, and models.] [Assessment Boundary: Assessment does not include recalling facts about properties of the planets and other solar system bodies.]
MS-PS2-3.	**Ask questions about data to determine the factors that affect the strength of electrical and magnetic forces.** [Clarification Statement: Examples of devices that use electrical and magnetic forces could include electromagnets, electric motors, or generators. Examples of data could include the effect of the number of turns of wire on the electromagnet or the effect of increasing the number or strength of magnets on the speed of an electric motor.] [Assessment Boundary: Assessment about questions that require quantitative answers is limited to proportional reasoning and algebraic thinking.]
MS-PS2-4.	**Construct and present arguments using evidence to support the claim that gravitational interactions are attractive and depend on the masses of interacting objects.** [Clarification Statement: Examples of evidence for arguments could include data generated from simulations or digital tools; and charts displaying mass, strength of interaction, distance from the Sun, and orbital periods of objects within the solar system.] [Assessment Boundary: Assessment does not include Newton's Law of Gravitation or Kepler's Laws.]
MS-PS2-5.	**Conduct an investigation and evaluate the experimental design to provide evidence that fields exist between objects exerting forces on each other even though the objects are not in contact.** [Clarification Statement: Examples of this phenomenon could include the interactions of magnets, electrically-charged strips of tape, and electrically-charged pith balls. Examples of investigations could include first-hand experiences or simulations.]
MS-PS3-2.	**Develop a model to describe that when the arrangement of objects interacting at a distance changes, different amounts of potential energy are stored in the system.** [Clarification Statement: Emphasis is on relative amounts of potential energy, not on calculations of potential energy. Examples of objects within systems interacting at varying distances could include: the Earth and either a roller coaster cart at varying positions on a hill or objects at varying heights on shelves, changing the direction/orientation of a magnet, and a balloon with static electrical charge being brought closer to a classmate's hair. Examples of models could include representations, diagrams, pictures, and written descriptions of systems.] [Assessment Boundary: Assessment is limited to two objects and electric, magnetic, and gravitational interactions.]

Significant Connections to California's Environmental Principles and Concepts:
None

In Instructional Segment 2, students develop and use models of the Earth-Sun-Moon system (MS-ESS1-1). This system involves ***a variety of effects caused*** by 3 different solar system objects, 2 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. Students need to be able to vis

ualize phenomena from the perspective of an observer from space in addition to their familiar Earth-bound perspective. In the course of their exploration, students will practice **using and developing models** 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 NGSS classrooms, the pedagogic philosophy is to have students engage more in the science and engineering practices involved with building models rather than simply showing them the current consensus completed models. Instructional materials and teachers can choose the relative amount of emphases to place on developing models and on using established models. The vignette below illustrates one way of balancing both the **developing models and the using models** aspects of scientific modeling in the context of phases of the Moon.

Vignette: Using and Developing Models of the Moon's Phases
(Adapted from NGSS Lead States 2013a, Case Study 3)

The vignette presents an example of how teaching and learning may look like in the classroom when the *CA NGSS* are implemented. The purpose is to illustrate how a teacher engages students in three-dimensional learning by providing them with experiences and opportunity to develop and use the science and engineering practices and the crosscutting concepts to understand the disciplinary core ideas associated with the topic in the Instructional Segment.

It is important to note that the vignette focuses on only a limited number of performance expectations (PE's). It should not be viewed as showing all instruction necessary to prepare students to fully achieve these PE's or complete the Instructional Segment. Neither does it indicate that the PE's should be taught one at a time, nor that this is the only way or the best way in which students are able to achieve the indicated PE's.

Introduction

During Instructional Segment 1, Ms. O had strategically alerted students to **observe** the Moon in the sky throughout multiple days and to **record** changes in what they saw. Also, she often started the day by showing pictures of the Moon she had taken with her cell phone or had found online, and she posted students' or her pictures with a label indicating date and time. Most of the students knew already that the Moon appears different across different days of the month. Students also had calculated based on their observations that it takes the Moon about 29 days to complete its cycle. Most of them, however, had not observed the Moon during daytime, and they were surprised when they observed it during daylight.

Introduction - Exploring calendars and heavenly motions

Ms. O began the first day of Instructional Segment 2 by reminding students that the cycle of Moon phases takes 29.5 days. As a whole class, they agreed that this time duration was related to how long it took the Moon to go around the Earth. She then asked students to discuss with a partner what they would need to know in order to calculate how fast the Moon must be moving around Earth. After students agreed that they needed to know the distance of the Moon's complete orbit, Ms. O told them that the distance was about 2,400,000 km (1,500,000 miles). Based on the number of days, they **calculated** the Moon's orbital speed to be about 3,400 km/hour (2,100 miles/hour).

After discussing that the notion of a month was based on the time it takes for the Moon to complete one cycle, Ms. O challenged the students to work in groups to **develop two different models** of the Earth-Sun system that would **explain** what ***causes*** Earth's day/night cycle. She provided **data** about Earth's diameter, Earth's circumference, the average distance from Earth to the sun, the total distance of Earth's annual orbit around the sun, the number of hours in a day, and the number of days in a year. For each of the two models, students **calculated** the speed of an important motion that **explained** why there are 24 hours in a day. After much discussion and sharing, students were able to demonstrate both a heliocentric model (Earth rotating at about 1,000 miles per hour) and an Earth-centric model with the Sun speeding around the Earth at about 70,000 miles per hour.

Ms. O reminded the class that **scientists use models to explain phenomena and to make predictions**. She then displayed an illustration showing that Eureka, California and New York City are at about the same latitude, and are about 3,000 miles apart. She asked them to **predict** based on the Sun-centered model what the time difference would be between the two cities, and to **explain** using that heliocentric model what direction Earth must be rotating with respect to the Sun.

The introduction to the Earth-Sun-Moon System ended with students comparing lunar and solar calendars. They discussed in groups whether a culture that had developed a lunar calendar of 12 months and a solar calendar of 365 days would experience any calendar problems over the course of a decade. Based on those discussions, Ms. O offered extra credit to any team that wanted to research and later make a presentation to the class how a specific culture reconciled lunar and solar calendars to organize information about agriculture, seasons, holidays, or the positions of planets and stars in the night sky. While only a few groups started these research projects, many students commented that these class periods had helped them understand our peculiar system of months with different amounts of days, and also why our calendars include an extra leap day every four years.

Exploring Earth-Sun-Moon relationships

Ms. O transitioned to tangible representational models by providing student groups with rulers, tape measures, and a variety of spherical objects. She asked each group to select an object to represent Earth, a suitably sized object to represent the Moon, and to predict how far apart those two objects would need to be in order to accurately ***scale*** the actual distance separating Earth and Moon. After they shared and discussed their initial ideas, Ms. O provided data about the diameters of Earth and Moon as well as the distance separating them. Student groups then adjusted their models appropriately, and made presentations explaining their current model and the adjustments they had made.

Ms. O downloaded an open-source planetarium software onto her interactive whiteboard- connected computer. Ms. O launched the program on the interactive whiteboard, introduced the students to the software, and showed them how to change the date and set up the scale Moon so they could see the phases. Each student then **created a 5-week calendar** that they could use to **collect data** obtained via the software. Ms. O also showed how the Moon's and Earth's orbital planes are offset by 5 degrees to help students understand how sunlight can illuminate the Moon and not be blocked by Earth's shadow when the Moon is on the other side of Earth.

Using the projected computer model, students as a whole class **recorded data** for the first three days on their calendar. Students recorded the time and direction of moonrise and moonset as well as the apparent shape of the Moon in the sky for each of those days. To make sure that students understood the process and were recording accurately, Ms. O walked through the room and checked student work throughout the lesson.

Once Ms. O was satisfied that the students had a foundation for data collection, she held the next class session(s) in the school computer lab. Students worked individually and/or with a partner to complete the **data collection** about moonrise, moonset and shape of the Moon for the five weeks on their calendar. Group and whole class discussions back in the classroom helped elucidate ***key patterns*** and key concepts related to light and shadows.

In the next lesson set, students **modeled** Moon phases using Styrofoam balls, their heads, and a lamp with a bare bulb (Figure 11). In small groups students stood in a circle around a lamp representing the Sun, holding a Styrofoam ball on a stick representing the Moon. They took turns holding the ball at arm's length and rotating their bodies using their heads as a representation of Earth. In this way, they could see the lit portion of the ball as an "Earth view" of the Moon in its different phases. Each student made drawings in his/her notebook to illustrate and summarize what they had seen.

Small groups allowed Ms. O to make sure that all students could see the lit portion on the Styrofoam balls for each phase and were able to accurately illustrate the phases in the model, giving her the opportunity to help them as necessary. She frequently checked with students in the groups to have them show each other how their notebook drawing illustrated the ***pattern of connections*** between Moon orbital position and Moon phase.

Using and Developing Models of Moon Phases Modeling with a Styrofoam Ball

Figure 11: Students model Moon phases using a bright light and a Styrofoam ball on a stick.

Ms. O challenged students to develop a two-dimensional drawing model on a sheet of chart paper where they could compare an “Earth View” and a “Space view” of the phases of the Moon over the course of a month. They engaged with this activity while taking turns with the Styrofoam ball/big light setups. After all groups had engaged with that setup and their attempts to develop a two-dimensional model showing both the Earth-centered and space perspectives, each group **posted a chart paper communicating** its current modeling effort. Each group then examined at least two other groups’ models and put color-coded sticky notes on those models **noting what they liked** (green), what they were not sure about (yellow with a question included), and any aspects that they **thought should be changed and why** (orange).

Each group then considered what they had seen in other groups’ models and also the post-it comments that had been posted on their model. Students then had opportunities to **discuss/revise** their model, and engage in discussions with other groups and with the whole class. As a result, the whole class then agreed to a consensus model (Figure 12) that was recommended (but not mandatory) for the ensuing lessons and modeling. In this consensus two views model, students could draw a box associated with each

Moon position and show in that box the way that the Moon looked as observed from Earth at that particular time of the monthly cycle.

Two Views Moon Phase Model

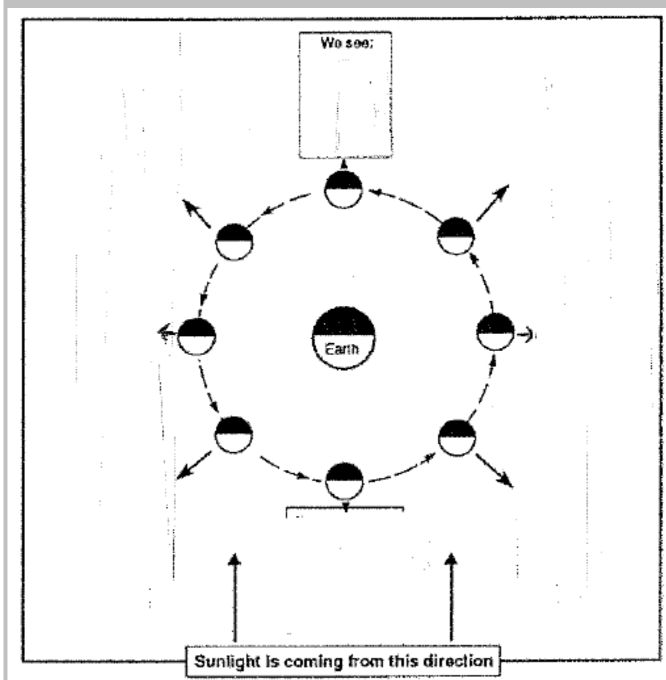

Figure 12: Organizing model for correlating a “Space view” (planet Earth showing eight Moon orbital positions) and an “Earth view” (drawing in a box what the Moon looks like from Earth at each of eight Moon orbital positions).

Ms. O then introduced another type of physical model showing Moon phases. This model used golf balls that were painted black on half of the sphere, leaving the other half showing the side of the Moon lit by the Sun.[15] The golf balls were drilled and mounted on tees so they would stand up on a surface. Ms. O had two sets – one set up on a table that showed the Moon in orbit around the earth in eight phase positions as the “Space view” model (left side of Figure 13), and the other set with the model Moons set on eight chairs circled in the eight phase positions to show the “Earth view” model (right side of Figure 13).

Student groups rotated in exploring these space view and Earth view models. For the Earth view model, one at a time students physically got into the center of the circle of chairs and viewed the phases at eye level. They drew in their notebooks what they

[15] Young, T., and M. Guy. 2008. “The Moon’s Phases and the Self Shadow.” *Science and Children* 46 (1): 30.

observed in each of the models and their interpretations of those observations. Then each group used these experiences to complete their two-dimensional two-view model either using as a format the class consensus model (based on Figure 12) or their own special model. They then had opportunities to share with other groups and the whole class how their model **illustrated and explained** the sequence of all the phases of the Moon.

Space and Earth View Moon Phases with Painted Golf Balls

Figure 13: Space view (left) and Earth view (right) models of Moon phases using golf balls painted black on half of the sphere.

Throughout the lesson sequence, Ms. O continually formatively assessed students' progression of learning through observations and classroom discourse. She was pleased to note that this succession of activities made it easier for students to both develop and use the two-view diagram, which is often found in books and worksheets. In previous years, students had more problems understanding this model, and she had almost decided to stop using it.

Modeling Expanded to the Solar System

Ms. O reminded students how they had used balls to appropriately **model** the sizes of Earth and the Moon as well as the distance separating them. She then handed out a chart with the size of the Sun and the sizes of the eight planets including their average distances from the Sun. Students then worked in groups to create a physical model of the solar system that accurately represented the ***scale of these sizes and distances***. The other criterion for their modeling was that their entire solar system model had to fit within the length of a football field. They could also choose to enhance their models by including other resources (e.g., photos or hands-on materials) that could be displayed at the different planet locations to **provide additional data** about the properties of those solar system objects.

Through this activity students gained more experiences with the crosscutting concepts of ***scale and proportion*** and also with ***mathematical thinking*** about ratios and proportions. Some of the students used and referred other students to NASA solar system resources such as Solar System Math.[16] At the end of the solar system modeling, Ms. O provided an additional handout that included information about nearby stars, the Milky Way Galaxy and more distant galaxies. She wanted to help students realize the ***huge scales*** of distances in the universe as a comparison for the huge scale of geologic time that would be featured in the next Grade 8 Instructional Segment.

NGSS Connections and Three-Dimensional Learning

Performance Expectations		
MS-ESS1-1 Earth's Place in the Universe *Develop and use a model of the Earth-sun-moon system to predict and describe the cyclic patterns of lunar phases, eclipses of the sun and moon, and seasons.* **MS-ESS1-3 Earth's Place in the Universe** *Analyze and interpret data to determine scale properties of objects in the solar system.*		
Science and engineering practices	**Disciplinary core ideas**	**Crosscutting concepts**
Developing and Using Models *Develop and use a model to describe phenomena.* **Analyzing and Interpreting Data** *Analyze and interpret data to determine similarities and differences in findings*	**ESS1.A The Universe and Its Stars** *Patterns of the apparent motion of the sun, the moon, and stars in the sky can be observed, described, predicted, and explained with models.* **ESS1.B Earth and the Solar System** *The solar system consists of the sun and a collection of objects, including*	**Patterns** *Patterns can be used to identify cause-and-effect relationships* **Scale, Proportion, and Quantity** *Time, space, and energy phenomena can be observed at various scales using models to study systems that are too large or too small.*

[16] NASA, Solar System Math: http://quest.nasa.gov/vft/#wtd (scroll down to "What's the Difference?" and "Solar System Math)

	planets, their moons, and asteroids that are held in orbit around the sun by its gravitational pull on them. This model of the solar system can explain tides and eclipses of the sun and the moon.	
Connections to the CA CCSSM: MP.4; 8.F.1–5		
Connections to CA CCSS for ELA/Literacy: RST.6–8.2, 3; WHST. 6–8.7; SL.8.1, 4		
Connection to CA ELD Standards: ELD.PI.6-8.1, 9		

Vignette Debrief

The *CA NGSS* require that students engage in science and engineering practices to develop deeper understanding of the disciplinary core ideas and crosscutting concepts. The lessons give students multiple opportunities to engage with core ideas in space science (Moon phases and the solar system), helping them to move towards mastery of the three dimensions described in the *CA NGSS* performance expectations (PE’s). In this vignette, the teacher selected two performance expectations and in the lessons described above she engaged students only in selected portions of these PE’s. Full mastery of the PE’s will be achieved throughout subsequent Instructional Segments. Students were engaged in a number of science practices with a focus on **developing and using models** and **analyzing and interpreting data***.* Space science lends itself well to the use of models to describe ***patterns*** in phenomena and to construct explanations based on **evidence**.

CCSS Connections to English Language Arts and Mathematics

Students are engaged in small group work activities, both listening to their peer’s ideas and sharing their own thoughts. **CDE: any other connections to CA CCSS for ELA??** When comparing sizes and distances, students were challenged to find ways of comparing numbers, applying the CA CCSSM Standard for Mathematical Practice 1 (MP.1). In addition, students used rounding and estimation to calculate the quotients in the ratios, both skills developed in earlier grades. Throughout the Instructional Segment, students reasoned quantitatively as they compared the sizes of the Earth and Moon, Standard for Mathematical Practice 2 (MP.2). As students made conclusions about which ball was the moon, they argued for their selection and agreed or disagreed with each other using their calculation, Standard for Mathematical Practice 3 (MP.3)

MP.1 Make sense of problems and persevere in solving them.
MP.2 Reason abstractly and quantitatively.
MP.3 Construct viable arguments and critique the reasoning of others.

Instructional Segment 2 Teacher Background and Instructional Suggestions

In addition to large-scale phenomena involving gravity such as the Moon phases and the solar system, during Instructional Segment 2 students return to investigating local phenomena involving forces and motions. Just as calculations of Earth's rotational and orbital velocities were used in the vignette to link Instructional Segments 1 and 2, drawing force diagrams can be used to link the local phenomena investigated in Instructional Segment 1 as they are revisited and applied to the solar system in Instructional Segment 2 (see Snapshot).

Instructional Segment 2 Snapshot:
Gravity and the Flashing Laser Lanterns

This snapshot presents an example of how teaching and learning may look like in the classroom when the *CA NGSS* are implemented. The purpose is to illustrate how a teacher engages students in three-dimensional learning by providing them with experiences and opportunities to develop and use the Science and Engineering Practices and the Crosscutting Concepts to understand the Disciplinary Core Ideas associated with the topic in the Instructional Segment. A Snapshot provides fewer details than a Vignette.

Dropped Flashing Laser Lanterns Observed From Space

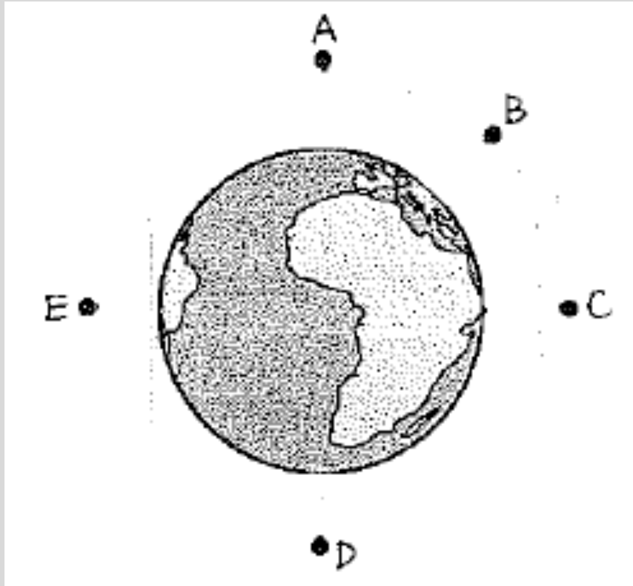

Figure 14: Identical flashing laser lanterns were simultaneously dropped from hot air balloons 1,000 meters above the ground at positions A, B, C, D and E.

Ms. O asked students to individually consider what an observer outside the Earth would see with respect to the lanterns. The resulting discussions elicited that unlike an observer on the ground, the space observer would **describe** motions in five different directions. For the space observer, lantern D would look like it was accelerating upwards. In contrast, observers on the ground at each position would all say that the lanterns were falling.

Modeling force arrows for the 5 lanterns elicited even more animated discussions. Ms. O guided these discussions by reminding students to consult their notebooks about the science of forces, and how to ***use force arrows to model*** both direction and magnitude. Eventually the class reached consensus that the acceleration of each lantern ***resulted from*** Earth's gravitational attraction. Newton's Third Law also **provided evidence to conclude** that in each case, two force arrows of the same magnitude should be drawn going in opposite directions between the Earth and each lantern. ***Because*** Earth has so much mass compared with the lantern, each lantern would accelerate towards Earth, but the acceleration of the planet toward any lantern would be immeasurably small.

NGSS Connections in the Snapshot

Performance Expectations
MS-PS2-1. Apply Newton’s Third Law to design a solution to a problem involving the motion of two colliding objects.

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.

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.

Disciplinary Core Ideas

PS2.A: Forces and Motion
PS2.B: Types of Interactions

Scientific and Engineering Practices

Constructing Explanations
Apply scientific ideas, principles, and/or evidence to construct, revise, and/or use an explanation for real-world phenomena, examples, or events.

Engaging in Argument from Evidence
Respectfully provide and receive critiques about one’s explanations, procedures, models, and questions by citing relevant evidence and posing and responding to questions that elicit pertinent elaboration and detail.

Crosscutting Concepts

Cause and Effect
Cause and effect relationships may be used to predict phenomena in natural or designed systems.

CCSS Connections
CA CCSS for ELA/Literacy: SL.8.1, 3
Connection to CA ELD Standards: ELD.PI.6-8.1
CA CCSSM: 8.F.1-2
The *CA NGSS* promote a vision of science learning as an interdisciplinary undertaking and each standard includes the connections to the *CA CCSS for ELA/Literacy* and the *CA CCSSM*.

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

Students can illustrate the forces in these circular motions with a rope (Figure 14). One person stands in the center and holds the rope while the other starts moving away. Once the rope is taut, both people feel the rope tugging them together. The pull of the rope changes the moving person's direction, constantly pulling that person back on course so that he or she moves only in a circular motion around the other person. A significant ***limitation of this model*** is that it gives the impression that the central mass must rotate as part of the motion.

Kinesthetic Model of an Orbit

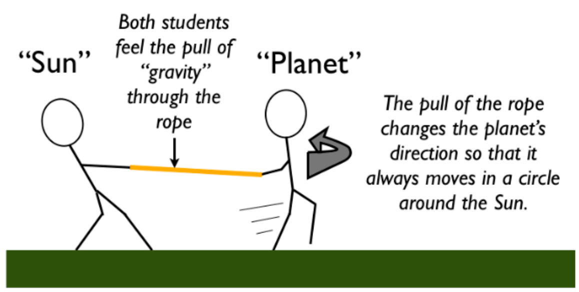

Figure 14: Two people can use a rope to model Earth's orbit around the sun. (Illustration courtesy of Dr. Matthew d'Alessio)

Isaac Newton was the first person to develop and **mathematically prove** the idea of gravity as the ***cause*** of orbital motions in the solar system. As part of his thinking process, Newton **developed a conceptual model** 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.[17]

One of the most Earth-shaking aspects of Newton's theory of gravity is that he showed that the same force that ***causes*** apples to fall from trees also causes the Moon to travel around Earth. The same science principles that **explain** what is happening on planet

[17] http://spaceplace.nasa.gov/how-orbits-work/en/

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. If either or both of the objects have more mass, then the gravitational attraction between them is stronger. Because of the huge masses of planets, stars and galaxies, gravity plays a major role in the structures and motions observed in solar systems and galaxies.

Before eighth grade, middle school students have been hearing and talking about gravity. However if they are asked to compare how strongly Earth pulls on a bowling ball and on a baseball, they are very likely to say that Earth pulls equally hard on each. Based on all our Earthly experiences of falling objects, it is very logical to think that gravity is a special property of Earth. Similar to other properties of matter such as density or color, the Earth property of gravity would then be independent of the object that it is pulling. However, the force of Earth's gravitational pull on an object varies depending on the mass of the object. This example provides a strong connection to Instructional Segment 1 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 15). The Golden Gate Bridge in San Francisco and the Dodger Stadium in Los Angeles pull on each other and also pull on every person in California. The reason we do not notice these pulls is that they are so weak compared with the attraction towards the planet itself. Since all mass is attracted to all other mass in the universe, it is also true that the Sun itself pulls on every student. Why don't students fly up in the sky towards the hugely massive Sun?

The answer is that the strength of the gravitational force 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.

Contact Forces and Noncontact Forces

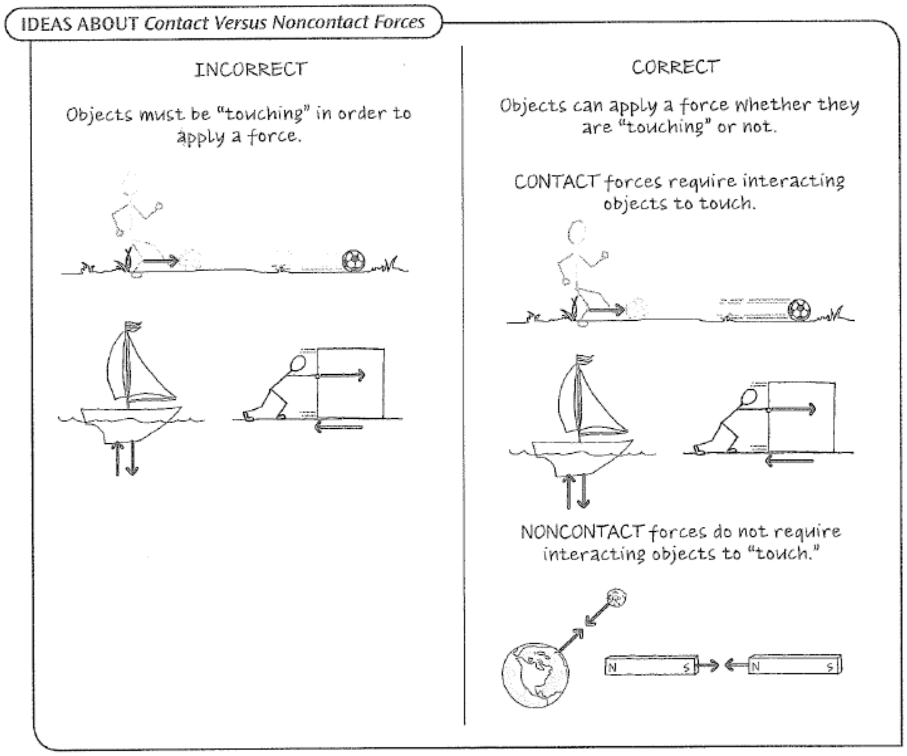

Figure 15: Objects can apply a force even if they are not "touching." (Illustration from Making Sense of Science *Forces & Motion* course, courtesy of WestEd)

Just as students investigated the sum of forces when objects are touching in Instructional Segment 1 (MS-PS2-2), any overall change in motion is ***caused*** by the sum of all the forces. 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 or 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.[18]

Figure 15 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. The modern explanation of the puzzling phenomenon of noncontact forces is that fields exist between objects that exert noncontact forces on each other. Students probably have ideas about force fields based on science fiction movies Students at middle school level are not expected to understand the physics concept of fields, but they can begin to approach a more scientific understanding of force fields by **gathering evidence** to measure the strength of these fields under a variety of conditions.

Performance Expectation MS-PS3-2 connects these **investigations** of fields with the concept of potential energy. Students are expected to describe that changing the arrangement of objects interacting at a distance ***causes*** different amounts of potential energy to be stored in the system. During Instructional Segment 1 of Integrated Grade 8, 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 7 students had also encountered the concept of potential energy with respect to the chemical energy stored in molecules. In food web models of ecosystem ***energy flows***, 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 4.

[18] American Museum of Natural History, GRACE Watches Earth's Water: http://www.amnh.org/explore/science-bulletins/earth/documentaries/grace-tracking-water-from-space/article-grace-watches-earth-s-water

TABLE 4: 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 (KE) Thermal Energy (TE) [often called Heat Energy] Light Energy (LE) Sound Energy (SE) Electrical Energy (EE)	Gravitational Potential Energy (GPE) Elastic Potential Energy (EPE) Chemical Potential Energy (CPE) Magnetic Potential Energy (MPE) Electrostatic Potential Energy (EPE)

(Table 4 based on Making Sense of Science *Energy* course, courtesy of WestEd)

Unlike gravitational fields around stars and planets that are hard to visualize, students can easily **collect data** about the strength of magnetic fields using simple bar magnets and iron filings (*MS-PS2-5*). Placing the iron filings on top of a thin, flat piece of clear plastic, Students can place various magnets and magnetic objects under a thin, flat piece of clear plastic. They can then **predict and record** the resulti***ng patterns*** that they observe after sprinkling iron filings on top of the sheet. Students should begin to ***ask questions*** about the spatial ***patterns*** 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 ***correlate the strength*** of the invisible magnetic field with their observations. Students can **design and conduct similar investigations** 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*** from frame-by-frame video analysis of a compass needle, students can determine the conditions that ***cause*** the needle to gain the most kinetic energy. They can use these observations to support their ***model*** that the arrangement of objects ***determines*** the amount of potential energy stored in the ***system*** (Figure 16).

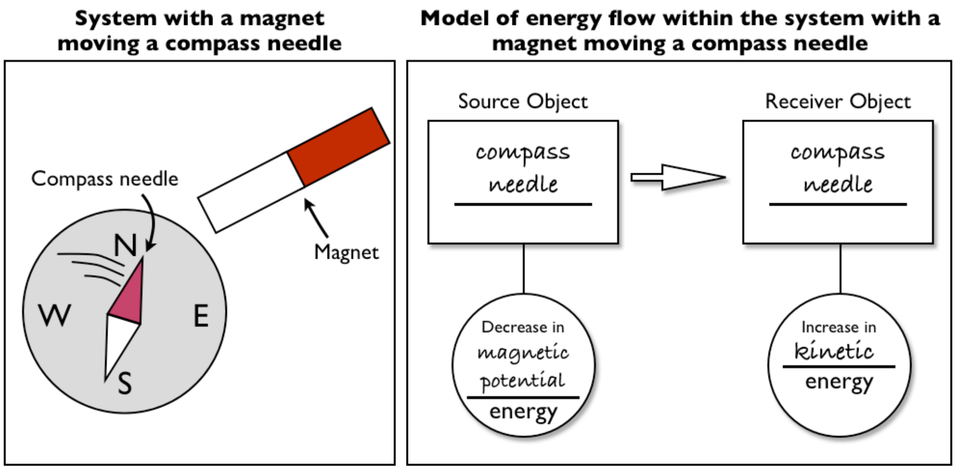

Figure 16. Schematic diagram and model of energy flow within a system of a magnet moving a compass needle. (Courtesy of Dr. Matthew d'Alessio)

Students can also iron filings to **investigate electromagnets** and gather evidence about the spatial ***patterns*** of the magnetic fields created by electromagnets. Students can try to create the strongest electromagnet, allowing different groups to *ask questions* 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 16 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*** 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 8 Instructional Segment 2 provides an opportunity to reflect on the progression of major physical science concepts, particularly ***flows of energy***, throughout the integrated science middle school grade span. In Grade 6, students explored many transformations of energy, especially those that involved thermal energy, such as in the water cycle and weather conditions. In Grade 7, 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 8 Instructional Segments, students again **investigated**, **collected evidence**, **made arguments**, **developed models**, and **constructed explanations** involving major energy concepts. Although the NGSS middle school physical science PE's and DCI's 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 Instructional Segments 1 and 2 could help solidify student understanding and better prepare to apply this concept as they continue to encounter and wonder about phenomena.

Table 5 – Grade 8 – 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?	
Highlighted Scientific and Engineering Practices: • **Analyzing and Interpreting Data** • **Constructing Explanations** • **Engaging in Argument from Evidence**	
Highlighted Cross-cutting concepts: • *Patterns* • *Cause and Effect: Mechanism and Explanation* • *Stability and Change*	
MS-ESS1-4.	**Construct a scientific explanation based on evidence from rock strata for how the geologic time scale is used to organize Earth’s 4.6-billion-year-old history.** [Clarification Statement: Emphasis is on how analyses of rock formations and the fossils they contain are used to establish relative ages of major events in Earth’s history. Examples of Earth’s major events could range from being very recent (such as the last Ice Age or the earliest fossils of homo sapiens) to very old (such as the formation of Earth or the earliest evidence of life). Examples can include the formation of mountain chains and ocean basins, the evolution or extinction of particular living organisms, or significant volcanic eruptions.] [Assessment Boundary: Assessment does not include recalling the names of specific periods or epochs and events within them.]
MS-LS3-1.	**Develop and use a model to describe why structural changes to genes (mutations) located on chromosomes may affect proteins and may result in harmful, beneficial, or neutral effects to the structure and function of the organism.** [Clarification Statement: Emphasis is on conceptual understanding that changes in genetic material may result in making different proteins.] [Assessment Boundary: Assessment does not include specific changes at the molecular level, mechanisms for protein synthesis, or specific types of mutations.]

MS-LS4-1.	**Analyze and interpret data for patterns in the fossil record that document the existence, diversity, extinction, and change of life forms throughout the history of life on Earth under the assumption that natural laws operate today as in the past.** [Clarification Statement: Emphasis is on finding patterns of changes in the level of complexity of anatomical structures in organisms and the chronological order of fossil appearance in the rock layers.] [Assessment Boundary: Assessment does not include the names of individual species or geological eras in the fossil record.]
MS-LS4-2.	**Apply scientific ideas to construct an explanation for the anatomical similarities and differences among modern organisms and between modern and fossil organisms to infer evolutionary relationships.** [Clarification Statement: Emphasis is on explanations of the evolutionary relationships among organisms in terms of similarity or differences of the gross appearance of anatomical structures.]
MS-LS4-3.	**Analyze displays of pictorial data to compare patterns of similarities in the embryological development across multiple species to identify relationships not evident in the fully formed anatomy.** [Clarification Statement: Emphasis is on inferring general patterns of relatedness among embryos of different organisms by comparing the macroscopic appearance of diagrams or pictures.] [Assessment Boundary: Assessment of comparisons is limited to gross appearance of anatomical structures in embryological development.]
MS-LS4-4.	**Construct an explanation based on evidence that describes how genetic variations of traits in a population increase some individuals' probability of surviving and reproducing in a specific environment.** [Clarification Statement: Emphasis is on using simple probability statements and proportional reasoning to construct explanations.]
MS-LS4-5.	**Gather and synthesize information about the technologies that have changed the way humans influence the inheritance of desired traits in organisms.** [Clarification Statement: Emphasis is on synthesizing information from reliable sources about the influence of humans on genetic outcomes in artificial selection (such as genetic modification, animal husbandry, gene therapy); and, on the impacts these technologies have on society as well as the technologies leading to these scientific discoveries.]
MS-LS4-6.	**Use mathematical representations to support explanations of how natural selection may lead to increases and decreases of specific traits in populations over time.** [Clarification Statement: Emphasis is on using mathematical models, probability statements, and proportional reasoning to support explanations of trends in changes to populations.]
Significant Connections to California's Environmental Principles and Concepts: None	

Instructional Segment 3 Teacher Background and Instructional Suggestions

Instructional Segment 3 focuses on Earth's extremely long geological history and the changes in Earth's web of life over billions of years. When Earth scientists observe Earth's current landforms, they are usually looking at the results of Earth processes that occurred over millions of years and involved thousands of miles of area. These ***time and distance scales*** 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.

Students in Integrated Grade 7 experienced some of these Earth Science practices as they investigated rock cycle processes such as erosion and sedimentation. Also in learning about continental drift and plate tectonics, students analyzed and interpreted continental shapes and data on the distribution of fossils and rocks (MS-ESS2-3). In Integrated Grade 8 they now build on those learning experiences to use evidence from rock strata to explain how the geologic time scale organizes Earth's 4.6-billion-year-old history (MS-ESS1-4).

While we can readily say phrases such as "4.6-billion-years," most of us cannot realistically experience how long that time span really is and the kinds of changes that can happen over that ***scale*** of time. 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). Each day on that calendar represents about 12.5 million years.

Geologists organize this immense time scale in a variety of ways, mostly based on data from fossils that were found in layers of sedimentary rock. Earth scientists read these layers of rocks like the pages of a history book. The composition and texture of each layer of rock reveals a snapshot of what the world looked like when that layer formed, and the sequence of layers reveals how environmental conditions and organisms changed over time. Generally the higher layers correspond to later periods of time.

TABLE 5: ONE YEAR CALENDAR MODEL OF GEOLOGIC TIME SCALE		
EVENT	**ACTUAL DATE**	**ONE YEAR CALENDAR**
Earth Formed	4,550,000,000 years ago	January 1
First single-celled organisms	3,500,000,000 years ago	March 24
First multicellular organisms	1,200,000,000 years ago	September 22
First hard-shelled animals	540,000,000 years ago	November 18
First land plants	425,000,000 years ago	November 27
First reptiles	350,000,000 years ago	December 3
First mammals	225,000,000 years ago	December 13
Dinosaur extinction	66,000,000 years ago	December 26
First primates	60,000,000 years ago	December 27
First modern humans	200,000 years ago	11:33 pm on December 31

(Information from *Dr. Art's Guide to Science*, courtesy of WestEd)

Much of science resembles a crime science detective activity, and this analogy is especially true with respect to Earth history. "What Killed the Dinosaurs?" is one of the most famous of these crime stories, and, as illustrated in the vignette below, it provides a very engaging way to learn about Earth's history and the science practices that scientists use to discover what happened many millions of years ago.

Vignette: The Day the Mesozoic Died

Introduction

Like most of his students, Mr. Rex is fascinated by dinosaurs, how they lived and dominated ecosystems in the air, ocean and land for about 135 million years, and, of course, that they became extinct. He enjoyed using the asteroid impact theory in Instructional Segments 1 and 2 to introduce the physical science of forces, motions and collisions. Through that introduction he became familiar with the wealth of resources about extinction, evolution and the asteroid impact that are available for free from the Howard Hughes Medical Institute (HHMI) biointeractive.org website. In particular, he determined to teach about Earth's geological time scale, extinction, and evolution using the film "The Day the Mesozoic Died" and its associated resources and lessons.[19]

Act 1: An Earth-Shattering Hypothesis

The entire film is about 34 minutes long and the website includes a teacher In-Depth Film Guide. Before viewing the film, students individually and then in small groups discussed what they knew about the rock cycle, fossils, erosion, sedimentation, and the extinction of the dinosaurs. Mr. Rex facilitated the discussions with related images and concepts that students had encountered in the Earth Science embedded within Integrated Grade 7. In their notebooks, students made notes about key ideas and terms.

Mr. Rex provided a homework reading based on the first two pages of the short article resource from BioInteractive with the same title as the film. Students **obtained information** to answer questions about the timing of the Mesozoic Era and the K-T Boundary, what geologist Walter Alvarez was doing in Gubbio, Italy, which fossil organisms he was **gathering data** about in the rock layers, and what **science question** he was asking. The next day Mr. Rex showed the first 5 minutes of the film, then students in groups discussed the film and their homework, and, following student requests, he showed the next 5 minutes where they learned about a Dutch geologist who was gathering similar evidence. Students used their notes about both scientists to it to answer the main questions that Mr. Rex had posed, "Which science practice or practices were shown in these 10 minutes of the film? What is **your evidence**?"

The resulting small group and whole class discussion unearthed two key SEPs: **carrying out investigations** involving gathering data about forams (foraminifera: tiny ocean plankton that are major producers in ocean ecosystems) and **asking questions**. Students cited good science questions such as, "Why had the forams disappeared?" and, "Did the extinction of forams have anything to do with the dinosaurs?"

[19]All accessed at < http://www.hhmi.org/biointeractive/day-mesozoic-died>. Film can be downloaded, ordered for free shipment, or streamed at https://www.youtube.com/watch?v=tRPu5u_Pizk&feature=youtu.be

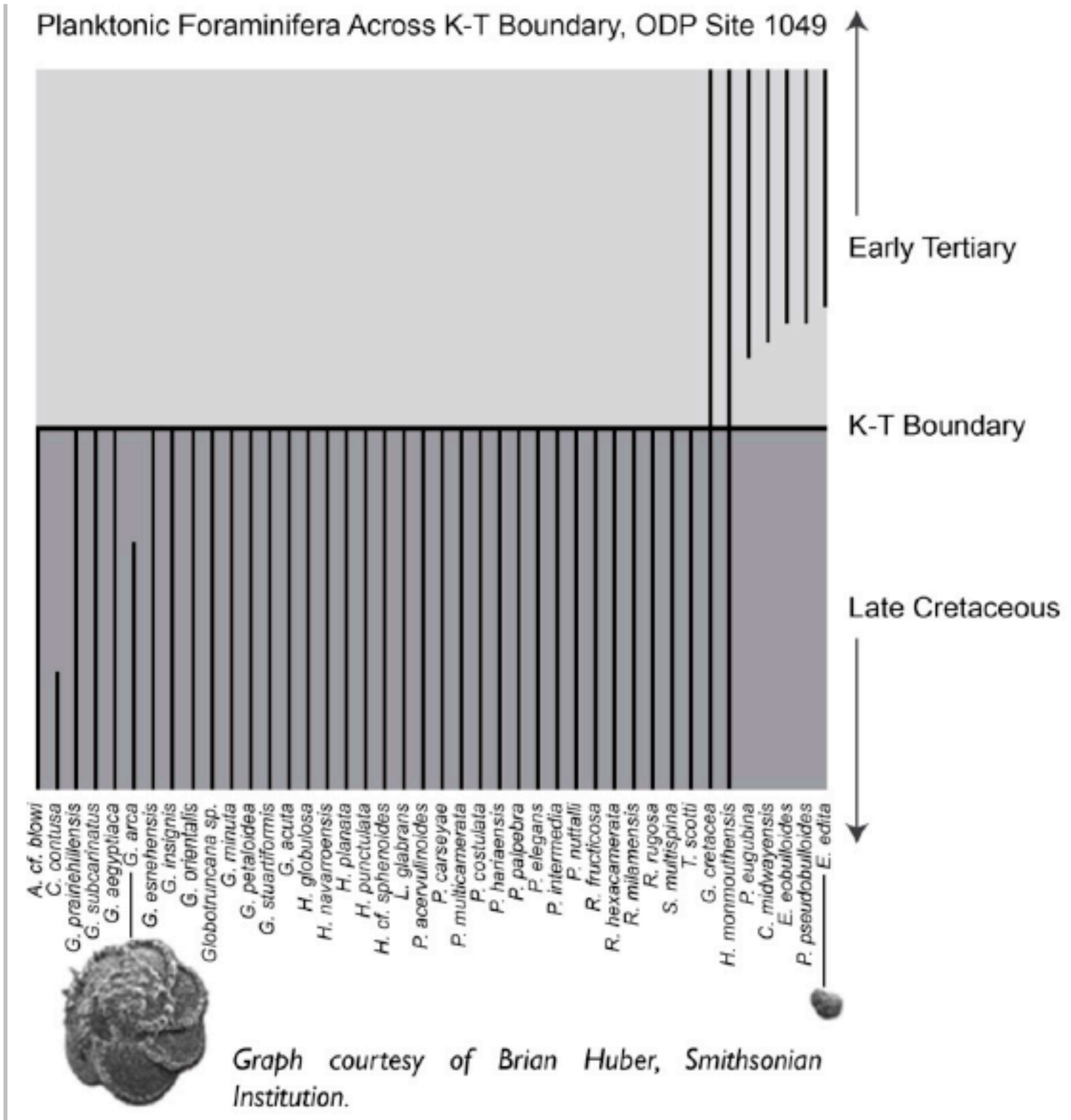

Figure 17: Species of forams that existed before and after the K-T Boundary at a location. (From student lesson accessed at BioInteractive website, courtesy of HHMI)

The next day students did an investigation based on the BioInteractive lesson, "Weighing the Evidence for a Mass Extinction Part 1: In the Ocean." They **measured** lengths of forams based on illustrations all at the same scale of about 10-fold magnification, and **concluded based on that evidence** that Tertiary forams were much smaller than the forams that had existed before the K-T time boundary. They also **calculated based on data** from geologists that more than 90% of the forams at "ODP Site 1049" became extinct at the time of the K-T Boundary (Figure 17). Each vertical line within Figure 17 represents a foram species and which rock strata contain fossils of that species. Students can **analyze that data** to conclude that only 2 of the Cretaceous foram species survived whatever had happened at that time Boundary. Looking at what happened afterwards in time during the Early Tertiary, students can **conclude** that 5 new foram species appeared after the K-T time Boundary.

The following day, students watched the next 5 minutes of the film until the end of Act 1. Mr. Rex had provided a list of key questions based on those 5 minutes. Once the students started discussing those questions, they asked for opportunities to watch the 5 minutes again. Mr. Rex showed it this time in even briefer segments giving them time to take notes and talk about each of those shorter sections. By the end of the class, they had made some progress answering his questions but they still needed more time.

Mr. Rex had anticipated this situation, and provided an illustrated homework reading that summarized the key points. The next day in class they watched the last 5 minutes of Act 1 again, and progressed much faster in their class discussions. Now students identified in the film situations where scientists engaged in the practices of:

Asking questions: For what length of time did the clay layer at the K-T Boundary represent?

Planning and carrying out investigations: measuring the amount of iridium in the clay layer and in the sedimentary rock strata above and below it.

Analyzing and interpreting data: finding out that the iridium amount was way higher in the K-T Boundary clay layer than in the rock strata above and below it; interpreting that data to mean that an outer space catastrophic event had occurred.

Planning and carrying out investigations: measuring the amount of plutonium in the clay layer.

Analyzing and interpreting data: not finding the plutonium in the clay layer, and interpreting that absence to mean that the hypothesized outer space event was not a supernova explosion.

Using mathematics and computational thinking: Luis Alvarez, Walter's famous physicist father, **calculating** based on the amount of iridium that if the outer space event was an asteroid collision, the asteroid would have been as big as Mount Everest and traveling at 80,000 kilometers per hour when it slammed into Earth.

Asking questions: what other kind of data could be gathered as evidence of an asteroid impact?

Mr. Rex made sure that students noticed and commented that the practices kept being revisited and repeated, that scientists do not engage in the practices in a linear manner. Following this discussion of science practices, Mr. Rex posted a slide listing the 7 NGSS crosscutting concepts, and asked students to discuss and give evidence for which of these CCCs were most connected with the film so far. After much small group discussion and whole class sharing, students voted for three main CCCs:

Patterns**:** the geologists had found the same foram fossil patterns in rock strata that are in very distant parts of the Earth. Cretaceous rock strata had many diverse species including many larger forams, and after the K-T Boundary the Tertiary rock strata had very few species and they were all small.

Cause and Effect**:** an asteroid impact caused iridium to appear all around the planet in unusually high concentrations in a thin clay layer about 65-million-years-old. The impact would have caused huge fires, sunlight to be blocked, poisoned the oceans, and killed producers, all of which would disrupt ecosystems globally.

Stability and Change**:** as evidenced by fossils in rock strata, the populations of forams during the Cretaceous were stable and then suddenly these populations changed drastically with a lot of extinctions.

Some students pointed out that the iridium in the K-T Boundary clay layer was indeed caused by the impact, but the iridium did not cause any extinctions. Instead of iridium being a cause, the iridium was strong **evidence for the claim** that an asteroid impact had occurred.

Act 2: Following the Trail of Evidence

Act 2 in the film is packed with information about the search for the impact site crater where the asteroid crashed into Earth. Before showing this section to students, Mr. Rex led a whole class discussion about the **science question** that had emerged at the end of Act 1, "What other evidence besides the iridium in the clay layer could prove whether an asteroid had crashed into Earth around 66 million years ago?"

Students discussed this question in groups and then shared as a whole class. Mr. Rex served as a facilitator charting key points, and helping to keep the conversation on task. He helped the class discussion coalesce around the concept of a crater. Mr. Rex then displayed the beginning part of Act 2 showing scientists discussing attempts to find a crater with the right age and size, worrying about the possibility that the asteroid had crashed into the middle of the ocean, and finally **concluding based on the evidence** of rocks with shocked quartz crystals that the asteroid ***must have*** crashed on or very near land.

To help students use science practices to engage with the "trail of evidence" about the crater, Mr. Rex used the BioInteractive materials to create an illustrated reading that summarized key points. He helped the class form small groups to use this resource to **research and then report** about six key aspects related to the crater:

- ejecta - all the material blasted outward (ejected) due to the collision
- spherules – glassy spheres embedded within ejected rocks
- tektites – irregularly shaped glassy melted rock located within ejected rocks
- spinels – a mineral rich in nickel that formed when the asteroid passed through Earth's atmosphere
- shocked quartz – quartz grains that fractured due to the impact, and
- breccia – large chunks of broken-up rock

TABLE 6: Possible Evidence from Ejecta

	Close to Impact	**Not Close, Not Far**	**Far from Impact**
Thickness of Ejecta	> 10 cm	1 – 10 cm	< 1 cm
Breccia	Maybe	None	None
Spherules	Maybe	Maybe	Maybe
Shocked Quartz	Maybe large and small	Maybe large and small	Maybe small
Tektites	Maybe	Maybe	None

As the student teams presented their reports, all the students wrote key information in their notebooks. Mr. Rex advised them to pay special attention to how different kinds of ejecta could be used as **evidence** whether a location was close to or far away from the asteroid impact site. After all the reports and note-taking, students worked in groups to create a guide for **analyzing data** about 66-million-year-old rocks in a location. Student groups shared their ideas, and then the whole class created a guide that they would all use for the next activity (Table 6).

Students worked in pairs or small groups to locate10 different sites where scientists had obtained rocks and soil from about 65 million years ago. They used a world map marked with longitude and latitude lines spaced 5^0 apart. Using data, photos and illustrations for each of the sites, the students **analyzed and interpreted the data** to decide whether the ***pattern*** at each site indicated whether it was close to, far from, or at an intermediate distance from the impact site. They then used the global ***pattern*** to make an **evidence-based claim** about the probable location of the asteroid impact. This activity concluded with Mr. Rex showing the complete Act 2 of the video ending with the definitive identification of the Chicxulub Crater in the Yucatan region of Mexico as the asteroid impact site.

Next Steps

Mr. Rex planned to show “Act 3: Mass Extinction and Recovery” to introduce the major Instructional Segment 3 topic of evolution. However before making that transition, he wanted to help the students apply the crosscutting concept of ***Stability and Change*** to the topic of extinctions as a preparation for exploring evolutionary change. As a whole class discussion, he asked students what they remembered from the film or previous learning experiences about the pace of changes. Several students mentioned that fossil scientists had rejected the Alvarez impact hypothesis because they investigated ***slow but steady changes*** in the Earth. Other students remembered featured scientist Sean Carroll saying that “something had come from outer space and rewritten the history of life in almost an instant.” Other students described that the rock cycle features both slow and steady changes as well as sudden volcanic eruptions.

NGSS Connections and Three-Dimensional Learning

Performance Expectations

MS-ESS1-4 History of Earth
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.

MS-LS4-1 Biological Evolution: Unity and Diversity
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.

Science and engineering practices	Disciplinary core ideas	Cross cutting concepts
Analyzing and Interpreting Data *Analyze and interpret data to provide evidence for phenomena.* **Constructing Explanations** *Apply scientific reasoning to show why the data or evidence is adequate for the explanation or conclusion.* **Obtaining, Evaluating and Communicating Information** *Evaluate data, hypotheses and/or conclusions in scientific and technical texts in light of competing information or accounts.*	**ESS1.C The History of Planet Earth** *The geologic time scale interpreted from rock strata provides a way to organize Earth's history. Analyses of rock strata and the fossil record provide only relative dates, not absolute dates.* **LS4.A Evidence of Common Ancestry and Diversity** *The collection of fossils and their placement in chronological order (e.g., through the location of the sedimentary layers in which they are found or through radioactive dating) is known as the fossil record. It documents the existence, diversity, extinction, and change of many life forms throughout the history of life on Earth.*	**Cause and Effect: Mechanism and Prediction** *Phenomena may have more than one cause, and some cause-and-effect relationships in systems can only be described using probability.* **Stability and Change** *Stability might be disturbed either by sudden events or gradual changes that accumulate over time.* **Patterns** *Patterns can be used to identify cause-and-effect relationships.* **Scale, Proportion, and Quantity** *Time, space, and energy phenomena can be observed at various scales using models to study systems that are too large or too small.*

Connections to the CA CCSSM:

Connections to CA CCSS for ELA/Literacy: **RST.6–8.1, 4, 8, 9; WHST. 6–8.7, 8; SL.8.1, 4**
Connection to CA ELD Standards: ELD.PI.6-8.1, 9 **Connections to CA CCSSM:** MP. 3, MP.4; 8.EE.4

Vignette Debrief

The *CA NGSS* require that students engage in science and engineering practices to develop deeper understanding of the disciplinary core ideas and crosscutting concepts. The lessons give students multiple opportunities to engage with the core ideas in space science (moon phases), helping them to move towards mastery of the three components described in the *CA NGSS* performance expectation.

In this vignette, the teacher selected two performance expectations and in the lessons described above he engaged students only in selected portions of these PEs. Full mastery of the PEs will be achieved throughout subsequent units.

The inherently fascinating topic of the dinosaur extinction event connects major life science concepts of extinction and biodiversity with the major Earth science concept of the geologic time scale. The teacher used excellent free resources that dramatically showed scientists engaging in the science practices emphasized within NGSS. Mr. Rex used those examples to help students understand how specific practices actually play out in a complex research topic, especially that scientists apply them as they are appropriate rather than in a tightly programmed linear fashion.

During the vignette, the students observed very clear images of rock strata, and the fossils in different rock layers as the scientists explained what they were seeing. The students themselves engaged with science practices in uncovering and applying the clues about the asteroid impact event. Coming from lessons in the physical sciences where they could manipulate variables and immediately observe changes in results, these same practices looked quite different when they were used to investigate an event that happened 66 million years ago.

Throughout the impact lessons, students engaged with arguments based on ***cause and effect mechanisms.*** Ultimately the arguments that scientists used related to the phrase in MS-LS4-1 about “the assumption that natural laws operate today as in the past.” Scientists keep applying the same cause and effect arguments unless the phenomena ultimately demand that they consider new alternatives. Students also connected the asteroid impact event with the crosscutting concept of ***stability and change*** that they will soon explore in greater depth in succeeding lessons about evolution.

Resources for the Vignette

- < http://www.hhmi.org/biointeractive/day-mesozoic-died>

Instructional Segment 3 Teacher Background and Instructional Suggestions (continued)

After viewing and analyzing the asteroid impact DVD or other high quality educational resources, students will have very clear images of walls of sedimentary rock that are extremely stratified and very tall. They will know that each stratum of rock has fossils and other evidence representing the forms of life and environmental conditions during the time that rock layer was laid down. Students will also have learned that information from rock strata in different areas help provide a continuous record of Earth’s long ***geological scale of time***. The kinds of fossils in rock strata provide evidence of the relative age of different rock layers but they do not tell us absolute ages. For that information, scientists rely on radioactive dating, a concept whose details are generally not appropriate at the middle school level.

Act 3 of the Mesozoic extinction DVD raises the issue of how life has recovered over the millions of years after a period of mass extinction. These recoveries were evident in Figure 2, which shows an overall ***pattern*** of increasing marine biodiversity despite the five major extinction events. After the asteroid impact, the relatively few species of mammals increased tremendously in diversity, size, number and ecosystem prominence. Mammals had co-existed with dinosaurs for millions of years, but mammals flourished only after the dinosaurs had disappeared.

Natural Selection

The science process of natural selection **explains** how species change over time so they continue to survive and reproduce in changing environments (Figure 18). This ***cause and effect mechanism*** is based on four related science concepts. The first three of these concepts shown in the illustration are often readily observed. As students learned in Integrated Grade 7: organisms have variable traits that are inherited, most organisms produce for more offspring than survive, and individuals in a population compete with each other for resources. Darwin's genius consisted in linking these ideas together and adding a big inference: organisms that have traits that increase their success 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.

Natural Selection Based on Four Science Concepts

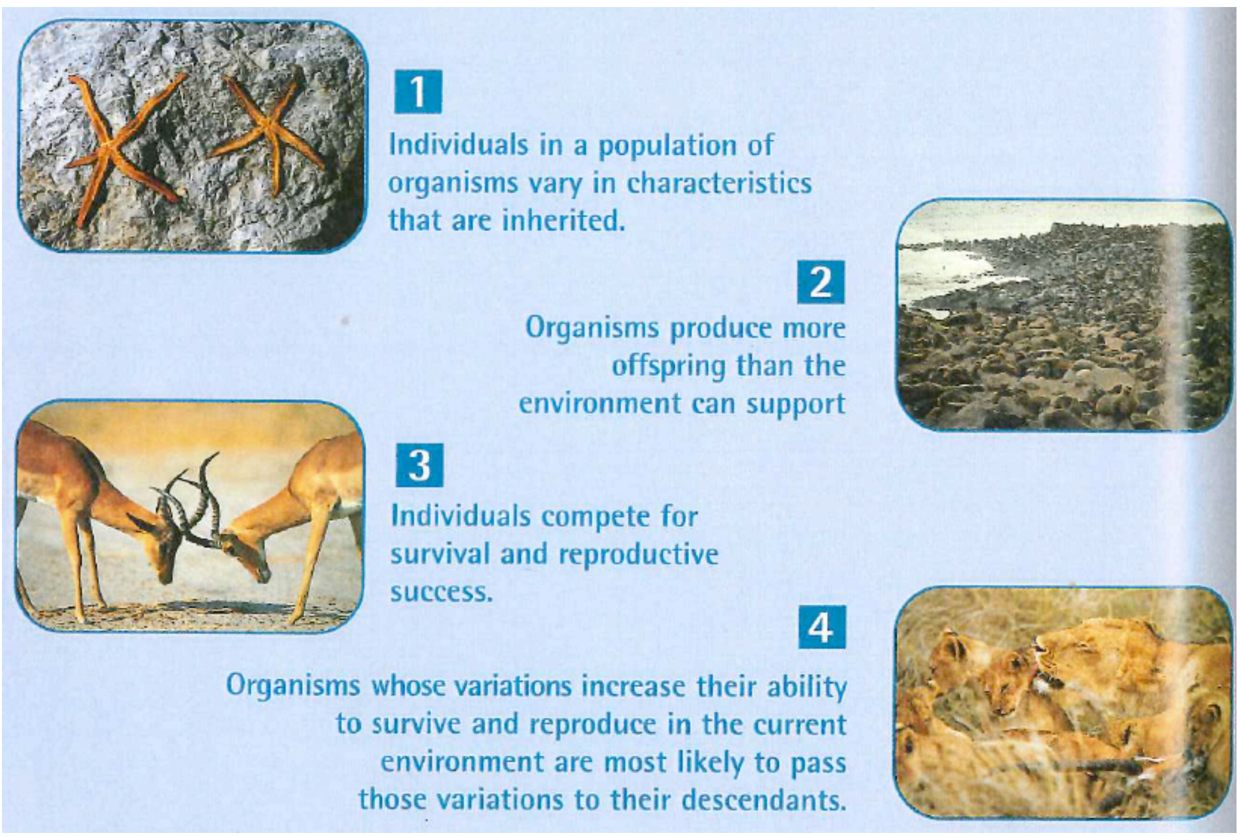

Figure 18: Darwin's theory of natural selection is based on four related concepts. (Illustration from *Dr. Art's Guide to Science*, courtesy of WestEd)

Darwin lived in England in the mid- to late 1800's. His country led the world in geology, and provided evidence for the major idea that Earth had an immensely long history, and that changes generally happened very slowly. Long periods of time enable a sequence of change at the species level of many small changes, each of which provides only a small increase in the ability to survive and reproduce, leading over time to a major change, such as the ability to see the world clearly, which provides a huge advantage.

Vision provides a very instructive example. Based on the fossil record and the anatomy of different kinds of eyes that exist today, scientists have **concluded** that eyes have independently evolved many times. Figure 19 illustrates a process of many small steps, each of which could provide a survival advantage, leading from lack of vision to increasing perceptions of light/shadows/shapes/movements to an eye that enables clear vision.

Natural selection works only if each of the kinds of changes shown in Figure 19 can be passed on through inheritance. Compared to their peers who do not have that heritable change, the descendants have a significant advantage that better enable them to survive and reproduce. The organisms themselves are not trying to change. Variations in the traits happen randomly and naturally. Those organisms that are lucky enough to have variations that improve their chances of success in the current environment are the ones that get to pass on their traits. As a result, the frequency of these advantageous traits increases in the population of that organism. The concept of adaptation works at the level of populations of a species. Teachers and students can use science language carefully by saying that species or populations adapt and avoiding saying that individual organisms adapt. To fully engage with this concept, students must **use mathematical representations** to help explain how natural selection can ***cause*** increases and decreases of specific traits in populations (MS-LS4-6).

Evolution of an Eye Via Many Small Steps

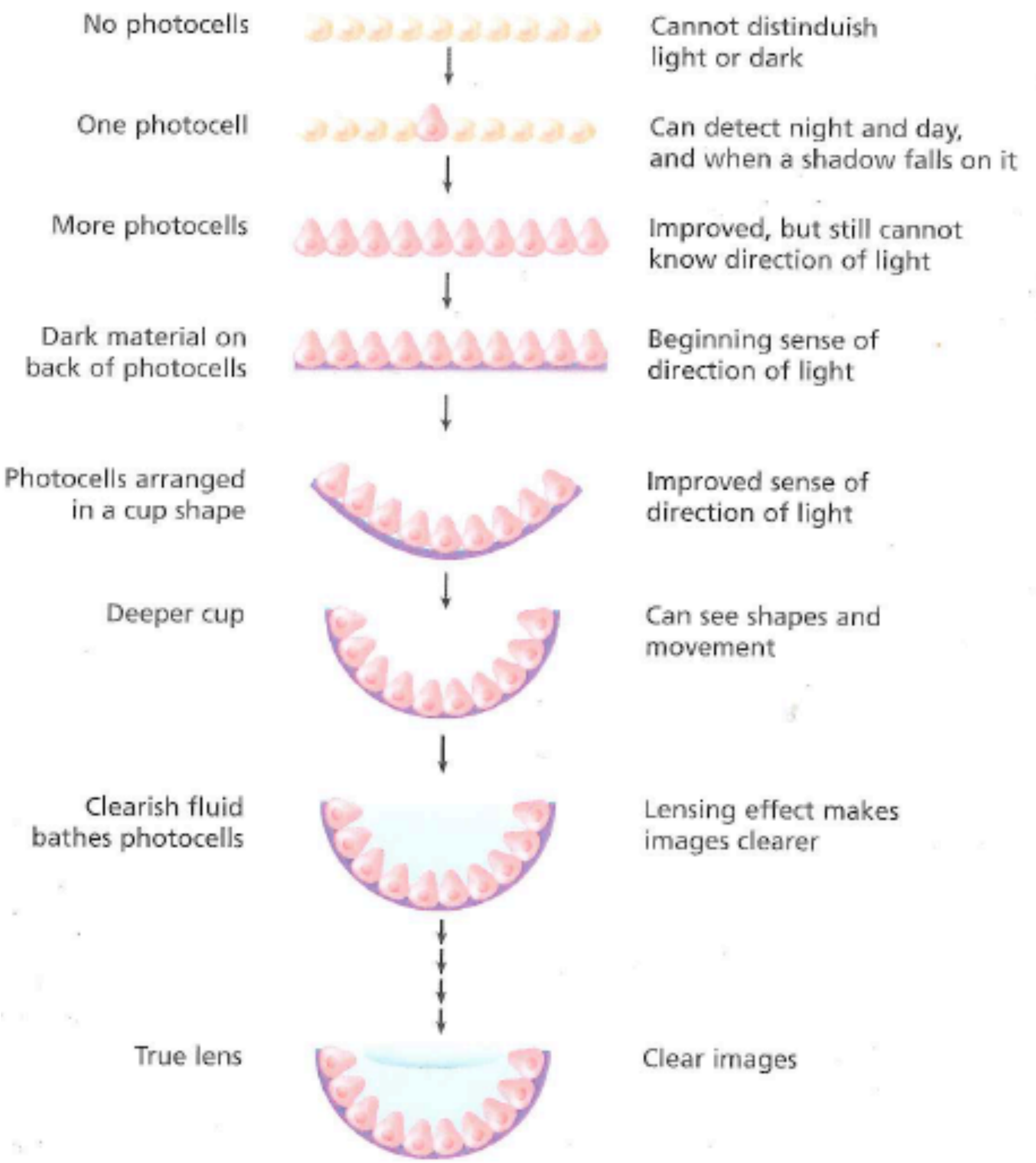

Figure 19: Overview of a process leading from lack of vision to the evolution of a clearly seeing eye. (Illustration from *Dr. Art's Guide to Science*, courtesy of WestEd)

Darwin used **evidence** from artificial selection **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 want. Examples from Darwin's time are dogs that help us hunt or that control the behavior of our farm animals such as sheep, the kind of sheep that gave us the best quality wool, trees that gave us the biggest and sweetest fruit, crop plants that grew quickly, and cows that gave us the most milk.

Student can individually or in small teams **research** different examples from pets, crops, farm animals, microscopic organisms such as yeast, and genetic engineering. Dogs provide a great example because students may know about or can easily get photos of many different kinds of dogs including tiny Chihuahuas, huge Great Danes, fierce pit bulls, smart sheep dogs, gentle pugs specifically bred to being companion dogs, and elongated dachshunds. All these types of dogs originated from an ancestral species that first transitioned from being wild to becoming a member of human communities. Student teams can **communicate** their finding in different ways, and the teacher can use these reports as a way to highlight key features of artificial selection.

Students can then 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 population. Nature provides random variations in traits and human beings select the traits that they want. In the case of natural selection, nature provides both the random trait variations and the selection. The traits are unconsciously and naturally selected on the basis of whether a trait variation helps that kind of organism to survive and reproduce in the current environment. Students can conclude that artificial selection and natural selection are similar but different kinds of ***causal mechanisms that result in*** Earth's biodiversity.

Engineering Challenge: Engineer a bird beak

Engineering Connection

Different animals eat different types of food, and their bodies must have the correct **structures** to enable them to eat that food effectively. Birds in particular have large variation in their beak shapes based upon their food source. Students can design a "beak" from a fixed set of materials that will allow them to eat as much "food" as possible[20]. They begin by defining the problem and establishing the criteria they will use to measure success (*MS-ETS1-1, MS-ETS1-2*). Will they compare the amount of food in

[20] Curiosity Machine, Engineer a bird beak: https://www.curiositymachine.org/challenges/4/

one bite or the amount of food in a set amount of time? Which of these criteria is probably a better approximation of what helps birds survive in nature? Are there any specific challenges that this particular type of food presents (powders, foods encased in hard shells, and foods that crumble easily all require different solutions)? Are there any obvious disadvantages to bigger or smaller beaks? (To represent the fact that bigger organisms require more ***energy*** to survive, the activity can be set up so that the amount of points a team receives depends on the ratio of food mass eaten to their beak mass.) After testing their design, students make improvements to improve their chance of survival (*MS-ETS1-4*). The students then compare their solutions to actual bird beaks, including the location and size of muscles (and attachment points) and the shapes of the beaks. They discuss the process of iterative improvements that they used and then compare and contrast it with evolution by natural selection and also with artificial selection. What was the source of the variations? What or who did the selecting?

Life is Bilingual

Both natural selection and artificial selection require random inheritable variations in traits? What ***causes*** these random variations in heritable traits? Darwin and his contemporaries at the end of the nineteenth century did not know. 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 the second half of the twentieth century scientists discovered that life on Earth is bilingual, and that all Earth organisms – from bacteria to mushrooms to plants to humans – at the level of molecules essentially speak the same two languages. This language analogy aims to convey major understandings about living systems.

One of the languages is a protein language. Proteins are huge molecules that can bend into a wide variety of shapes. Proteins are involved in practically everything that organisms do. All organism traits essentially ***result from*** the work that proteins do at the molecular level.

The other language of life is what scientists call nucleic acids, especially a huge type of molecule called DNA. Nucleic acids are the basis of heredity. DNA stores the information so an organism can make each of its proteins. Genes are made of DNA. In sexual reproduction, an offspring gets half of its DNA information from each of its parents (the molecular basis of MS-LS3-2 taught in Integrated Grade 6).

Proteins and DNA are huge, very long molecules. They are examples of extended molecular structures that students learned about in Grade 6 physical science (MS-PS1-1). The reason we can talk about these molecules as being languages is that both proteins and DNA are made of molecules that we can call building blocks. There are 20 different building blocks that are used to make proteins. DNA is made of four different building blocks that are a different kind of molecule than the protein building blocks.[21] Each protein can be thought of as a giant chain of 20 different "letters," one letter after the previous letter in an order that is specific to that kind of protein. Each of the proteins folds into a shape that enables it to perform its functions, and that shape is determined by the order of its building block letters. In this analogy, the DNA is like a computer hard drive that has a file corresponding to each of the proteins. That file is a sequence of the four DNA building block "letters" that somehow encodes the information for assembling one or more specific proteins. Each of those DNA files corresponds to a gene.

Notice that because there are two different languages with two different sets of letters, there must be a code that connects the DNA language with the protein language. In fact, that code is called the genetic code. The Integrated Grade 8 Performance Expectation related to genes and heredity (MS-LS3-1) does not specify the nature of proteins or DNA. However, the concept of random mutations is best understood in the context of these two languages of life. The recommendation here is to introduce these concepts at an appropriate level for Grade 8, and not get into details that are best learned in high school biology.

MS-LS3-1 specifies that, "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 an organism." Using our language metaphor, students can understand mutations as ***resulting from*** changes in the sequence of DNA

[21] Teachers and students are more likely to have heard of protein building blocks (amino acids) compared with DNA building blocks (nucleotides).

letters that make up a gene. That change in the DNA could cause a change in one or more of the letters that make up a protein. As a result (Table 7), the protein could fold in a variety of ways that either result in no change (neutral mutation), a bad change so the protein can no longer function properly (harmful mutation) or, much less likely but possible, a good change so the protein performs its function better or even does something new that helps the organism survive and reproduce (beneficial mutation).

TABLE 7: 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
Benficial	Protein can fold in a different way	Protein functions better or even helps in a new way

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

Sickle cell anemia provides a very instructive example of the nature of genes, mutations and natural selection. Hemoglobin is a protein in red blood cells that binds oxygen and carries it from the lungs to cells. Hemoglobin consists of 177 amino acids (the letters of the protein language) joined together in a very specific order. The disease of sickle cell anemia is ***caused by*** a change in just one of those amino acids. That amino acid change ***results from*** a change in one of the letters in the gene (DNA) that codes for that amino acid in the hemoglobin chain. This single change ***reduces the ability*** of hemoglobin to carry oxygen, and ***results in*** episodes of pain, chronic anemia, and severe infections. Based on Table 7, students would classify this change in the DNA as a harmful mutation.

People have severe sickle cell anemia if they have two copies (alleles) of the bad gene (one from each parent). The disease is much less severe if the person has only one sickle cell allele (called sickle cell trait rather than disease). It turns out that sickle cell mutations have an unusually high frequency in areas of the world where malaria is a common disease. This mutation actually provides significant protection against dying from malaria. If the person has just one sickle cell allele and malaria is very prevalent, then the benefits of the mutation can outweigh its disadvantages. As a result, in some areas of Africa as much as 40% of the population has at least one sickle anemia allele.[22] As a result of this heritage, about 1 in 13 African American babies is born with sickle cell trait (having one sickle cell allele), and sickle cell disease is significantly prevalent in black American populations.

How do mutations happen such as the change in one DNA letter in the hemoglobin gene? Many different kinds of events can cause changes in the letter sequence of the DNA code. These events include mistakes in copying the code during germ cell division; damage caused by cosmic rays, radioactivity, X-rays, UV-radiation, or environmental chemicals; and viruses and other parasitic elements within the cell nucleus cutting and splicing DNA sequences. The key feature of all these damages is that the mistakes just happen: mutations are not designed to lead to any specific outcome. Nonetheless, these random mistakes do have an extremely important general outcome. Random mistakes result in an enormous amount of potential variation in organism traits. This potential has manifested in the great diversity of Earth's web of life. We can celebrate that life has diversity built into its very core!

Unity and Diversity of Life

An overview of Earth's biodiversity reveals two very different but also complementary features: a unity of life and a huge diversity of species. With respect to unity, all Earth organisms share essentially the same genetic code described in the previous section. In addition to the genetic code being the same, at the molecular level even vey different organisms such as humans, sunflowers and fruit flies have very similar molecules that perform vital life functions.

The Grade 8 Performance Expectations focus on the macroscopic rather than the molecular level. At the macroscopic level, the same underlying bone structures enable humans to throw, bats and birds to fly, whales to swim, frogs to jump, and lizards to run (Figure 20). Students can recognize the ***pattern*** that even though all these organisms

[22] http://www.pbs.org/wgbh/evolution/library/01/2/l_012_02.html

look very different from each other, they share the exact same bone structure (including the number of bones and their relative position). Students can use as **evidence for this claim** the data that these “arms” all have a single upper bone (Humerus) that is attached at a joint to two different bones (Radius and Ulna) that is then attached in the wrist area to the Carpal bones and then radiate outward through many-boned fingers.

Comparing Limb Bone Structures in Different Animals

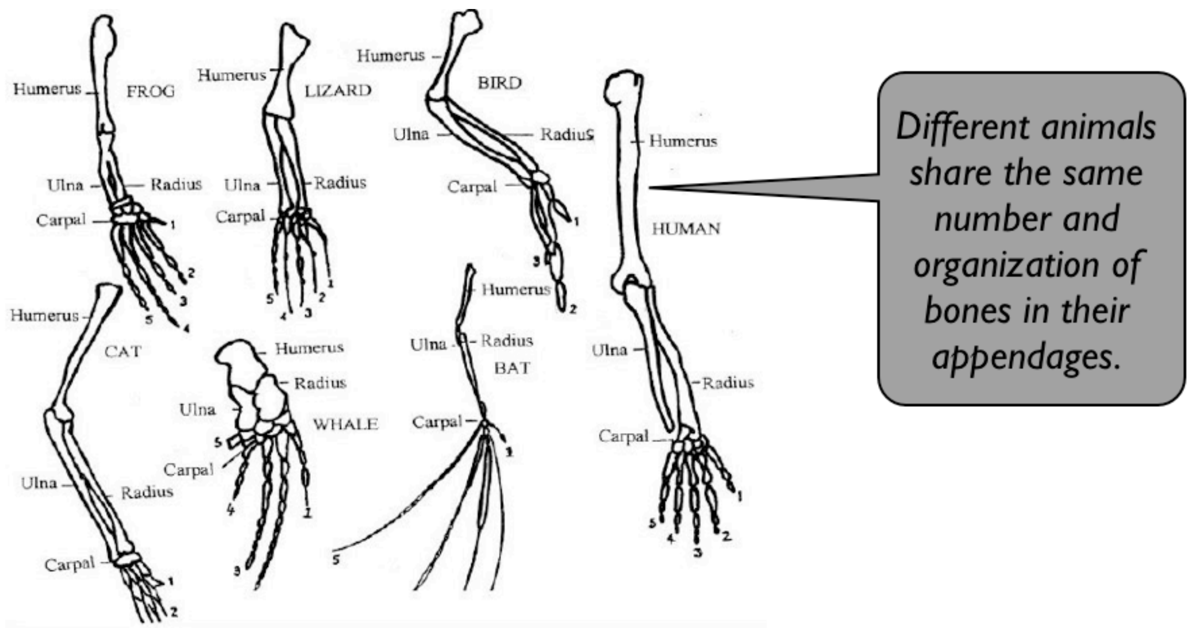

Figure 20: Anatomy reveals both the unity of basic bone structures and the diversity of organisms. (Wikibooks 2015)

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*** of the bones relates to the ***function*** of the arm. In an organism like a bat that uses its front appendage for flight, certain bones must be much longer. Organisms that walk on four legs must have bones sturdy enough to support weight, while those that walk on two legs can have front arms that are much lighter in weight than their back legs.

The similarity of organisms at molecular and macroscopic scales is best **explained** by the idea that life originated as single-celled organisms that progressively became more complex as organisms adapted to living in very different environments. Students can trace this history of life in the calendar of Earth's geologic time scale (Table 5). 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. However, life existed for about three billions years before that time, mostly as single cell organisms. Microscopic fossils are as important a part of the fossil record as more visible and dramatic fossils of larger organisms.

In addition to this unity of life, evolution accounts for life's diversity. Species are different because their locations and ancestral histories have diverged over the ages. A few fruit flies were blown to the Hawaiian islands where fruit is abundant. In this new environment, natural selection enabled fruit flies to diversify into 600 different species to take advantage of all the different island locations that had no insect like them to compete with. As a result, there are almost as many different fruit fly species in Hawaii as in the rest of the world combined. On a much bigger scale, mammals diversified to succeed in new ways of life that became available after the dinosaurs disappeared (Act 3 of the BioInteractive Mesozoic DVD).

Students can explore life's unity and diversity by **gathering and synthesizing information** about the anatomical features and the ancestral histories of a particular class of organisms or a specific species. For example, students can find patterns in the fossil record (MS-LS4-1) related to many whales whose history include land mammals that diversified and adapted to living deep in the ocean. The anatomy of Boa constrictors reveals a simple pelvis and leg bones hidden, unused within their bodies. A five-week human embryo has a beginning tail that is about 10% of its length. Very rarely, a human baby is born with an external tail. These and similar examples from anatomy (MS-LS4-2) and embryology (MS-LS4-3) provide data that students can **analyze** and use as evidence to **construct evidence-based explanations** based on resemblances due to shared ancestry and differences due to the effects of natural selection in different environments (MS-LS4-2).

Evolution and extinction are ongoing, not just processes that happened in Earth’s deep past. Populations continue to evolve today, and unfortunately, the rate of extinctions appears to be rapidly accelerating due to human actions. Instructional Segment 4 explores how human actions harm biodiversity and also how humans can help sustain Earth’s biodiversity.

Table 8 – Grade 8 – 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?

Highlighted Scientific and Engineering Practices:

- **Obtaining, Evaluating, and Communicating Information**
- **Constructing Explanations and Designing Solutions**
- **Engaging in Argument from Evidence**

Highlighted Crosscutting concepts:

- ***Systems and System Models***
- ***Cause and Effect: Mechanism and Prediction***
- ***Stability and Change***

Students who demonstrate understanding can:

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

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

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

[Clarification Statement: Emphasis is on a basic understanding that waves can be used for communication purposes. Examples could include using fiber optic cable to transmit light pulses, radio wave pulses in Wi-Fi devices, and conversion of stored binary patterns to make sound or text on a computer screen.] [Assessment Boundary: Assessment does not include binary counting. Assessment does not include the specific mechanism of any given device.]

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

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

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

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

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

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

Environmental Principles and Concepts:

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

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

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

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

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

Instructional Segment 4 Teacher Background and Instructional Suggestions

This Instructional Segment features a very important concept related to the NGSS Earth and Space Science strand: "Earth and Human Activity." Increases in human population and in per-capita consumption of natural resources impact Earth's systems (MS-ESS3-4). In this Instructional Segment, students re-visit life science concepts that they explored in the previous Instructional Segment: 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. As described in the vignette closing this chapter, student teams engage in projects that illustrate and apply these concepts across the three science disciplines and engineering design.

These student projects help serve as a capstone for Integrated Grade 8 and also for many concepts and practices in Integrated Grades 6 and 7. With respect to "Earth and Human Activity," students in Integrated Grade 6 designed methods to monitor and minimize a human impact on the environment (MS-ESS3-3), and they interpreted evidence related to global warming (MS-ESS3-5). Also in Integrated Grade 6 students used models related to unequal heating of the planet (MS-ESS2-6). Here in Grade 8 they build upon their earlier spatial modeling to show how a **model** of the Earth-Sun system ***helps explain*** the regional differences in seasons (MS-ESS1-1).

To better understand seasons and Earth's global and regional climates, students investigate the wave nature of electromagnetic radiation such as sunlight and infrared radiation. These explorations are part of a more general understanding of the nature of waves (MS-PS4-1 and MS-PS4-2) that helps tie together ***flows of energy*** concepts that have been progressively building in depth in the integrated middle school grade span.

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** with real-world objects can be complemented with technology. Computer or smartphone apps provide interactive simulations of simple waves[23], ripple tanks[24] 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*** 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, transmission of a wave past a row of posts, and even addition of multiple waves to make complex waveforms. Placing floating objects at the surface and drops of colored dye below the surface allow students to track the motion of particles within the tank. These observations of phenomena should provoke students to ***ask questions*** 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*** for the

[23] http://phet.colorado.edu/en/simulations/category/physics/sound-and-waves
[24] Falstad, P. Virtual Ripple tank: http://www.falstad.com/ripple/

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** 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 21). 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.

Model of a Typical Wave

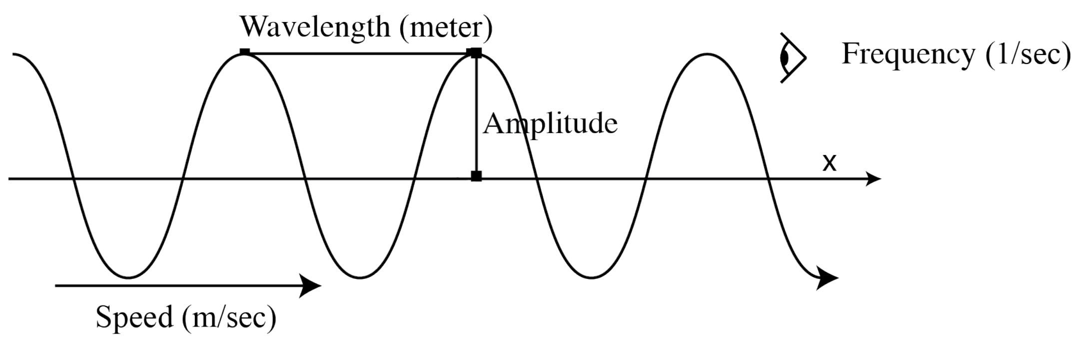

Figure 21: Some properties that distinguish waves from each other include wavelength, amplitude, frequency, and speed of wave movement.

Having become familiar with the properties of waves and developed ways to represent and describe travelling waves, students are ready to think about and to model waves and/or wave pulses as carriers of ***energy***. They can readily recognize that a wave or wave pulse of water in the open ocean transmits energy (in the form of motion of the medium): they can see the motion of the water up and down by observing a boat bobbing at the surface (motion = kinetic energy). They can also see that more of this up and down motion results in a higher amplitude, thus qualitatively connecting the growth in amplitude of the wave to an increase in the energy it transmits (*MS-PS4-1*). Students can make this representation quantitative by dropping different size objects into a tank and measuring the height of waves generated (perhaps with the aid of digital photography to allow more precise measurements of the fast-moving waves). Students' **models** of wave motion, amplitude, and ***energy*** can help them **explain** 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 explore 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. Waves breaking at a beach are not a travelling wave pattern, but rather the result of the shallowness of the sea-floor disrupting a travelling wave pattern that was established in deeper water. Students can cite floating corks in a ripple tank as strong **evidence supporting a claim** that the water goes mostly up and down while the wave moves across the tank.

Sound Waves

Sound waves introduce a different kind of wave that students can investigate. 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** of sound traveling as the back and forth motion within a solid material. Students can then readily **generalize this model to explain** how sound travels through a gas, where the movement of air must be happening but cannot be seen.

Model of a Sound Wave in Air

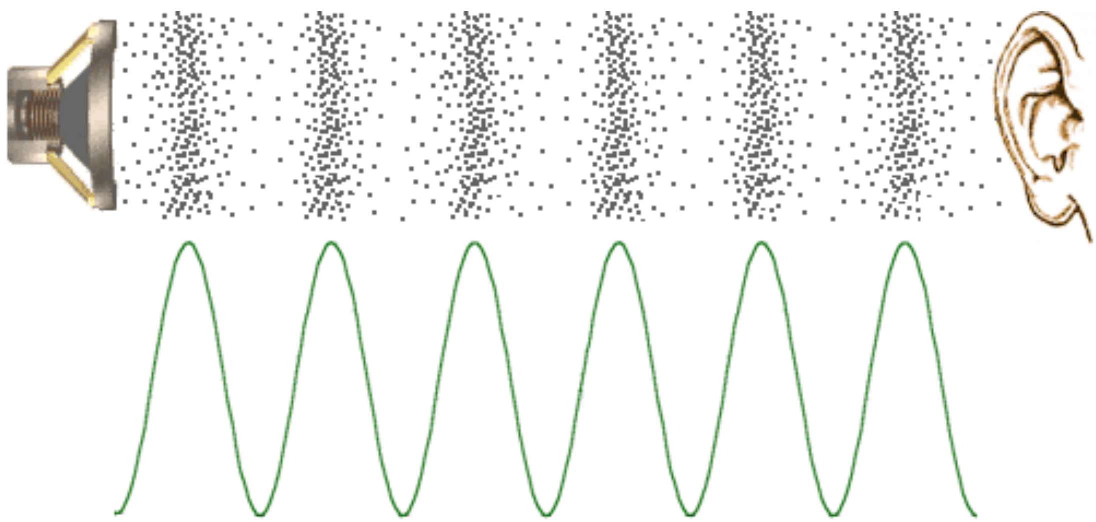

Figure 22: Two representations of how sound travels as a wave in air. Accessed at http://www.mediacollege.com/audio/01/sound-waves.html

We can think of sound as a traveling wave of pressure differences in the air. The black dots in Figure 22 represent air molecules packed together very tightly or less tightly. ***Because of*** the vibrations in the speaker, the air varies in density in a ***wave-like pattern*.** The dots and the wave-line provide two complementary ways to **model** 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*** our conscious perception of sound (Integrated Grade 6 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 that both of these wave patterns transfer energy through a medium across a distance, that the individual particles move only a very small distance. In both cases, waves reflect or are absorbed at various surfaces or interfaces, and two waves can pass through one another and emerge undisturbed. In the case of a water wave, the particles move perpendicular to the wave direction. In the case of sound wave, the particles move parallel to the wave direction.

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

Electromagnetic 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*** 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. For grade 8, visible light serves as a familiar form of energy that illustrates how electromagnetic radiation can transfer energy very quickly across huge distances.

Students in Integrated Grade 6 encountered the concept that sunlight is a form of electromagnetic radiation that transfers energy from the Sun to Earth. In explaining global warming due to human emissions, they referred to the electromagnetic spectrum to contrast sunlight bringing energy into the Earth system and infrared radiation carrying energy out of the Earth system. Having measured electromagnetic fields in Instructional

Segment 1, grade 8 students are better prepared to discuss the concept of electromagnetic radiation as a way that electricity and magnetism work together to ***transmit energy*** across space.

Earth's Annual Orbit Around the Sun

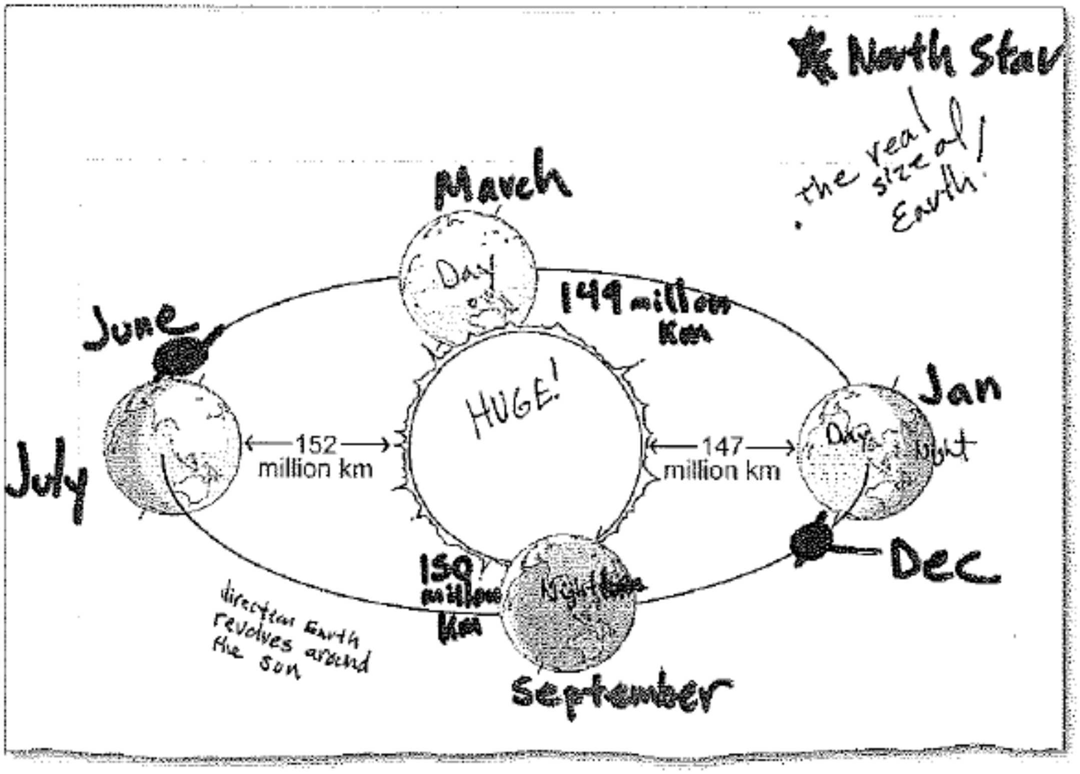

Figure 23: The trip Earth makes around the Sun each year. Note the dot showing the more correctly scaled size of Earth. (Illustration from Making Sense of Science *Weather and Climate* course, courtesy of WestEd)

This Instructional Segment includes the concept of seasons, wherein students revisit **models of spatial relationships and motions** in the solar system (MS-ESS1-1). In particular, understanding seasons involves researching and modeling the ***changes in the absorption of sunlight*** at different latitudes during Earth's annual orbit (Figure 23). Earth's tilt on its axis relative to the plane of its orbit causes the Northern Hemisphere to receive more direct sunlight in June through mid-September (North America summer/South America winter) and the Southern Hemisphere to receive more direct sunlight in December through mid-March (South America summer/North America winter).

The University of Nebraska-Lincoln Astronomy Education website has excellent simulations that **model** and **explain** seasonal and latitudinal changes in sunlight and temperature over the course of a year.[25] Similar to the lunar phase models in Instructional Segment 2, these simulations provide space-view perspectives and Earth-view perspectives. Students can change the planetary location and the date of the year to **investigate** how these variations affect the intensity of sunlight and ***cause*** seasonal variations in temperature and the sun's position in the sky.

Waves Can Encode and Transmit Information

After having researched water waves, sound, light and electromagnetic radiations (EM), students can be challenged to summarize the characteristics of each of these with respect to:

- wavelength/frequency;
- amplitude; and
- wave speed.

The students can 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 9 illustrates one kind of summary.

TABLE 9: Characteristics of Waves

Type of Wave	Wavelength/Frequency Associated With	Amplitude Associated With	Wave Speed
Water wave	Physical distance between top of water waves	Height of the physical wave	Depends mainly on winds
Sound wave	Pitch of the sound	Loudness of the sound	1,235 km/hour in dry air at 20^0C
Light wave	Color of the light	Brightness of the light	108,000,000 km/hour in vacuum
All EM Waves	Type of EM wave (x-ray, UV, light, IR, microwave)	Intensity of that EM wave	108,000,000 km/hour in vacuum

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

[25] "Motions of the Sun Simulator" at
http://astro.unl.edu/naap/motion3/animations/sunmotions.html
"Seasons and Ecliptic Simulator" at:
http://astro.unl.edu/naap/motion1/animations/seasons_ecliptic.html

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*** 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** that even in the absence of modern technologies, each of us is constantly interacting with invisible waves of energy. All the information and experiences that we get through sight or hearing comes to us as waves that our senses and nervous systems enable us to detect and experience. A string-and-tin-can “telephone” or a stringed instrument can provide a quick and very direct experience that waves can communicate information.

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

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

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

Digitizing a Screen Picture

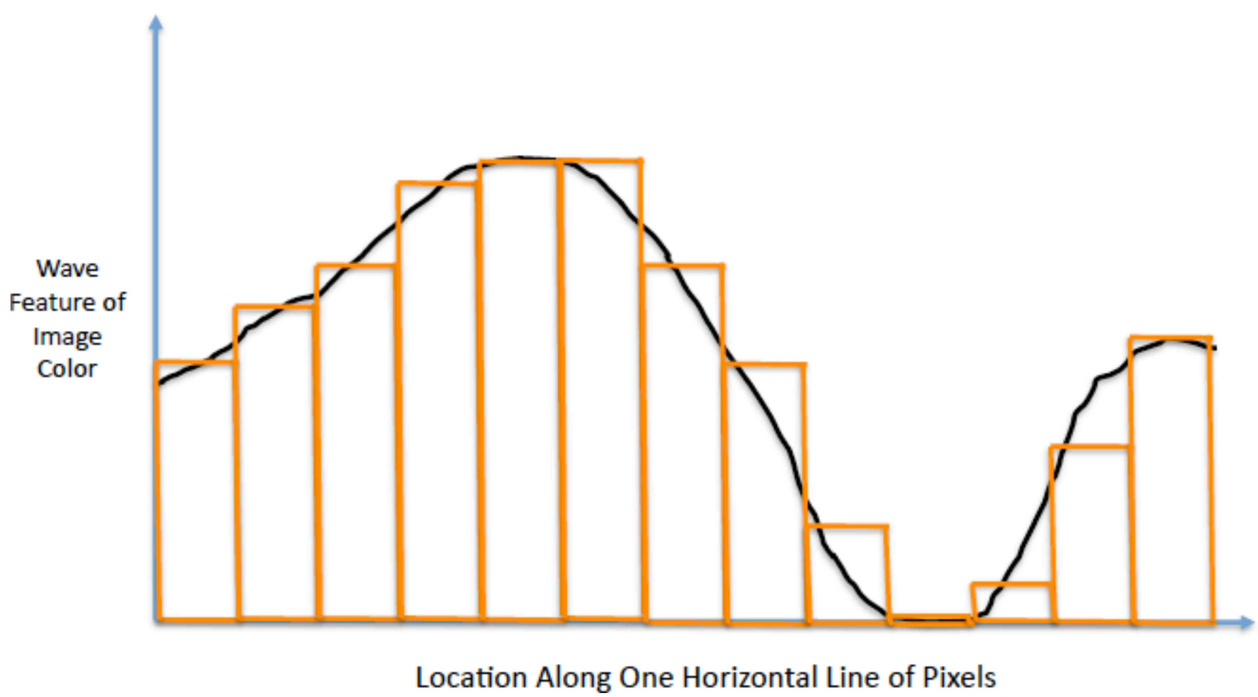

Figure 24: The features of an electromagnetic wave can be converted into numbers that change over a spatial location. These numbers can then be converted into computer-friendly digital formats so a very clear image can be displayed on a screen. (Illustration by Dr. Art Sussman, courtesy of WestEd)

Figure 24 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 at a point along the line. The horizontal position specifies where that point is horizontally located on the line. The rectangular boxes sample the average value of the color at thirteen different locations, and summarize the color at each of those thirteen locations as a number. Specifying the color of only 13 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.

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. This Instructional Segment includes students evaluating the claim that digitized signals offer significant advantages with respect to encoding and transmitting information (MS-PS4-3). In the vignette that concludes this narrative, student groups engage with a design challenge focused on sustaining Earth's systems in which they use and evaluate at least one digital technology in researching their challenge and/or designing their solution.

Vignette: Grade 8 Instructional Segment 4
Student Capstone Projects

The vignette presents an example of how teaching and learning may look in the classroom when the *CA NGSS* are implemented. The purpose is to illustrate how a teacher engages students in three-dimensional learning by providing them with experiences and opportunity to develop and use the science and engineering practices and the crosscutting concepts to understand the disciplinary core ideas associated with the topic in the Instructional Segment.

It is important to note that the vignette focuses on only a limited number of performance expectations (PE's). It should not be viewed as showing all instruction necessary to prepare students to fully achieve these PE's or complete the Instructional Segment. Neither does it indicate that the PE's should be taught one at a time, nor that this is the only way or the best way in which students are able to achieve the indicated PE's.

Introduction

Students in groups and as a whole class shared what they know or estimate about human population numbers. 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 helped chart that information, and then guided the discussion towards estimates of consumption patterns. After a while, students concluded that for each country or continental area, they should probably get data about total consumption and per-capita consumption.

Having established that background, Ms. D provided each group of students with information about world populations[26] and about consumption of natural resources in the year 2012. In both cases, the datasets include information at the country level (e.g., Brazil) and at a regional level (e.g., South America). The data for consumption was provided as the number of millions of metric tons of carbon dioxide emitted from the consumption of energy resources.[27] Since the total amount of data from the sources was somewhat overwhelming and also not 100% 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** that Ms. D had provided, **calculated** per-capita consumption based on emitted carbon dioxide from energy resources, and created model representations of the data. Some student groups used the **model** of color-coding maps to compare per-capita consumption. Other groups superimposed on global

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[26] Data from the Population Reference Bureau report accessed at http://www.prb.org/Publications/Datasheets/2012/world-population-data-sheet.aspx

[27] Data from the U.S. Energy Information Administration accessed at http://www.eia.gov/cfapps/ipdbproject/IEDIndex3.cfm?tid=90&pid=44&aid=8

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 that included both total consumption and per-capita consumption in comparing regions and highlighted countries (Table 10).

TABLE 10: Energy Consumption Patterns
Based on Carbon Dioxide Emissions in 2012

Region or Country	Population in 2012 (number of people)	Total CO_2 Emitted in 2012 (tons)	Per-Capita Emission of CO_2 (tons/person/year)
Africa (Nigeria)	1,100 million (170 million)	1,200 million (83 million)	1.1 (0.5)
Asia (China)	4,300 million (1,400 million)	14,000 million (8,100 million)	3.3 (5.8)
East Europe (Russia)	300 million (1400 million)	2,700 million (1,800 million)	9.0 (13)
West Europe (Germany)	190 million (82 million)	1,700 million (790 million)	8.9 (9.7)
South America (Brazil)	400 million (200 million)	1,200 million (500 million)	3.0 (2.5)
Middle East (Saudi Arabia)	230 million (79 million)	2,000 million (590 million)	8.7 (7.5)
North America (USA)	350 million (310 million)	5,800 million (5,300 million)	17 (17)

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

Each student group posted its representation on a big chart. The whole class then did a gallery walk where they examined each of the charts and listened to the group's presentation about their chart. Students asked questions, and wrote down notes to inform later discussions. After the gallery walk and while the charts were still visible, the whole class discussed the ***benefits and disadvantages of the different representational models***, the most important ***patterns*** of per-capita consumption, and any **evidence-based claims** that they might want to make.

Some students had noticed a ***pattern*** 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 hypothesized 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** correlations with other countries that produce and export large amounts of fossil fuels.

Ms. D recognized many connections to ***California's Environmental Principles*** in this instructional segment and so posted them on her classroom wall. One of the students asked if the data they had analyzed was an example of California Environmental Principle II (*The long-term functioning and health of terrestrial, freshwater, coastal and marine ecosystems are influenced by their relationships with human societies*). 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. (Principle II, concept a)

Capstone Projects

Ms. D then led a class discussion about the student group projects that would conclude their immersion in middle school science. Most of the student projects should focus on higher levels of impacts to Earth's systems due to increasing human populations and increasing consumption of natural resources (MS-ESS3-4). Student teams would refer to and use concepts and practices that they had learned in grade 8 but also in earlier integrated middle school science grades to:

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

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.[28] 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 the two crosscutting concepts of ***Cause and Effect*** and ***Stability and Change*** as they relate to:

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

Ms. D helped transition 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, produce better, and consume more wisely. While they were processing these readings in teams and as a whole class, students began brainstorming potential solutions related to the impacts that had been raised by the first set of readings. Student facilitators helped s**ummarize 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

[28] Report can be downloaded at no cost at http://www.worldwildlife.org/publications/living-planet-report-2014

changed and stabilized around a variety of projects. Four teams focused on climate change but had 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, as well as a 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 8, 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.

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 as well as expanding the feedback to the student groups. At the end of the projects, student groups across the different Grade 8 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 had 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 **h**abitat by building dams, and also **o**verharvesting timber and gravel along the stream banks. In addition, people have stocked streams with **i**nvasive nonnative fish species and **p**olluted the water. The students proposed plans to increase public awareness related to stream overharvesting and pollutions practices, and identified constraints that needed to be addressed in reducing these practices. (California Environmental Principle II) (See the EEI 7th grade unit "Extinction: Past and Present" for more information and a lesson on HIPPO)

The genetic engineering group had become interested in comparing the genetic code with the encoding involved in digital files. They provided **evidence for their claim** that the genetic code was neither analog nor digital, but instead was uniquely biological. They **explained** that the genetic code resembles a digital coding in some ways, but consists of four "digits" (the letters of the DNA "language") instead of just two. In addition, they provided **evidence for claims** that genetic engineering of food crops did not significantly endanger personal health (e.g., cancer) but that genetic engineering had a significant constraint with respect to potentially endangering the health of ecosystems. (California Environmental Principle 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** from their school and the Green School, and made recommendations based on those analyses. In addition, they **shared information** about digital tools that schools can use to collect and analyze that kind of data as well as to 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 were made at the district level rather than the school level. (California Environmental Principle V)

One of the asteroid impact teams had changed projects. They had remembered that the HHMI BioInteractive website about the impact crater had included remote digital data that had originally identified the crater in the Yucatan. While checking other links, they discovered that the HHMI BioInteractive website included conservation efforts at the Gorongosa National Park in Mozambique.[29] The students explained that this park provided a case study in ecology and conservation science. They had gotten particularly excited when they learned that park scientists use GPS satellite collars and motion-sensitive cameras to gather data about the recovery of the park's lion population. In addition to sharing pictures and video, the students used educational resources from the website to **explain** the park ecology, the conservation recovery plans and significant constraints that needed to be addressed to promote successful restoration. (California Environmental Principle V)

[29] http://www.hhmi.org/biointeractive/gorongosa-national-park

Global Warming and Climate Change

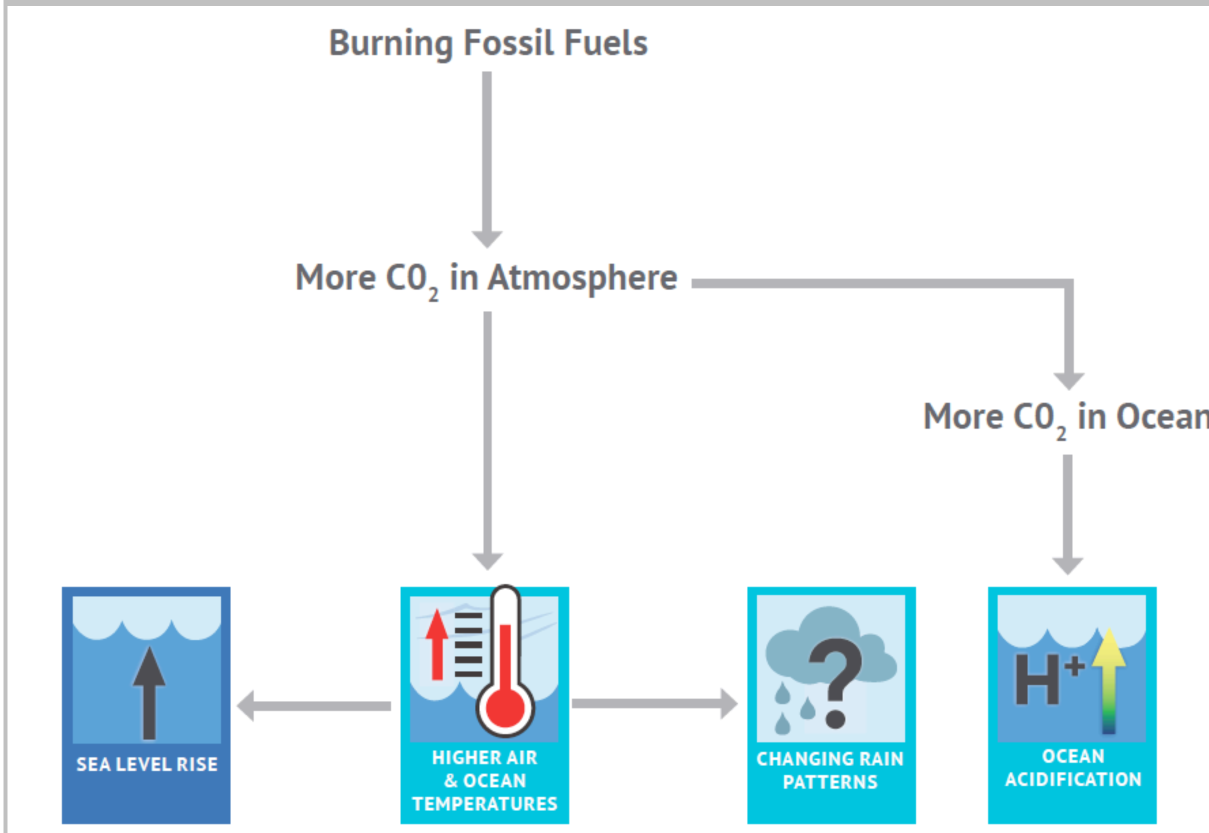

Figure 25: Increased emissions of carbon dioxide cause global warming (higher air and ocean temperatures) and three other climate change impacts. (Illustration by Dr. Art Sussman and Lisa Rosenthal, courtesy respectively of WestEd and WGBH)

The different student groups working on climate change issues jointly identified as a constraint that people had a lot of confusion about global warming and climate change. They consulted with their Grade 6 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 website that has a computer interactive explaining four main impacts of climate change (Figure 25).[30] Higher concentrations of atmospheric CO_2 directly result in global warming and ocean acidification. The increased thermal energy trapped in the Earth system ***causes*** other

[30] http://www.pbslearningmedia.org/resource/pcep15-sci-ess-impacts/impacts-climate-change-pacific-region/

changes such as sea level rise and changing precipitation patterns. (California Environmental Principle IV)

Projected Average Temperatures in California

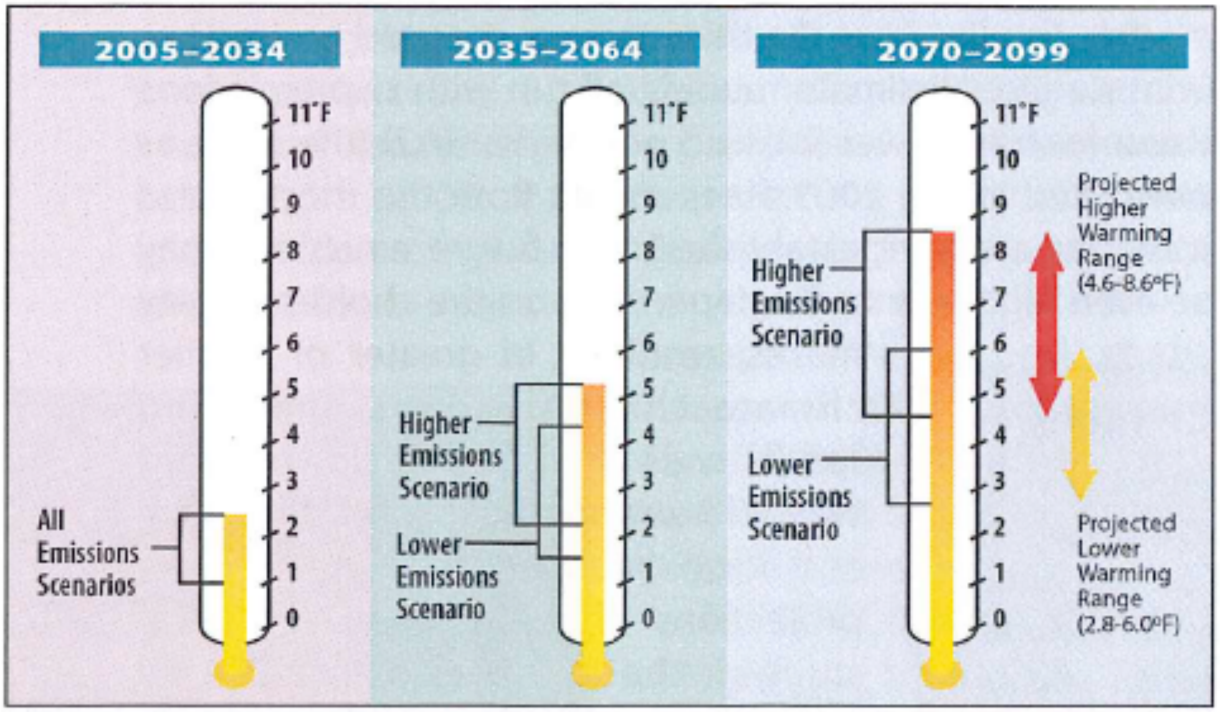

Figure 26: Projected increases in statewide annual temperatures during this century. From *Our Changing Climate 2012*, a Summary Report on the Third Assessment from the California Climate Change Center.[31]

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. They noted that reductions in emissions of greenhouse gases could reduce the amount of heating (Figure 26). They also learned that communities could engage in individual and collective actions that increase the fire safety of homes.

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 had been using digital tools to communicate with a school on the island of Majuro. The

[31] http://www.climatechange.ca.gov/climate_action_team/reports/third_assessment/index.html

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 had been communicating with each other, a King Tide caused serious flooding in the area of the Majuro school. The group presentation included **explanation** of how climate change ***causes 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 units “The Greenhouse Effect on Natural Systems” provide additional resource materials on climate change and greenhouse gases.)

In each of the three middle school grades, students had learned about the Environmental Principles and Concepts that had been adopted 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 about that related to any of the five Environmental Principles. Students then shared their ideas in a whole class discussion. They were surprised how many of them had 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.

NGSS Connections and Three-Dimensional Learning

Performance Expectations
MS-ESS3-4 Earth and Human Activity *Construct an argument supported by evidence for how increases in human population and per-capita consumption of natural resources impact Earth’s systems.* **MS-PS4-3 Waves and Their Applications in Technologies for Information Transfer**

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.

MS-LS4-4 Biological Evolution: Unity and Diversity
Construct an argument supported by evidence for how increases in human population and per-capita consumption of natural resources impact Earth's systems.

MS-ETS1-1 Engineering Design
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 Engineering Design
Evaluate competing design solutions using a systematic process to determine how well they meet the criteria and constraints of a problem.

Science and engineering practices	Disciplinary core ideas	Crosscutting concepts
Obtaining, Evaluating, and Communicating Information *Gather, read, and synthesize information from multiple appropriate sources and assess the credibility, accuracy, and possible bias of each publication and methods used, and describe how they are supported or not supported by evidence.* **Constructing Explanations and Designing Solutions** *Undertake a design project, engaging in the design cycle, to construct and/or test a design of an object, tool, process, or system.* **Engaging in Argument from Evidence**	**ESS3.C Human Impacts on Earth Systems** *Typically as human populations and per-capita consumption of natural resources increase, so do the negative impacts on Earth, unless the activities and technologies involved are engineered otherwise.* **PS4.C Information Technologies and Instrumentation** *Digitized signals (sent as wave pulses) are a more reliable way to encode and transmit information.* **LS4.B Natural Selection** *Natural selection leads to the predominance of certain traits in a*	**Patterns** *Patterns can be used to identify cause-and-effect relationships* **Cause and Effect: Mechanism and Prediction** *Phenomena may have more than one cause, and some cause-and-effect relationships in systems can only be described using probability.* **Stability and Change** *Explanations of stability and change in natural or designed systems can be constructed by examining the changes over time and processes at different scales, including the atomic scale.*

Construct, use, and/or present an oral and written argument supported by empirical evidence and scientific reasoning to support or refute an explanation or a model for a phenomenon or a solution to a problem.	*population and the suppression of others.* **ETS1.A Defining and Delimiting Engineering Problems** *The more precisely a design task's criteria and constraints can be defined, the more likely it is that the designed solution will be successful. Specification of constraints includes consideration of scientific principles and other relevant knowledge likely to limit possible solutions.*	
Connections to the CA Environmental Principles and Concepts: **Principle I:** The continuation and health of individual human lives and of human communities and societies depend on the health of the natural systems that provide essential goods and ecosystem services. **Principle II:** The long-term functioning and health of terrestrial, freshwater, coastal and marine ecosystems are influenced by their relationships with human societies. **Principle III:** Natural systems proceed through cycles that humans depend upon, benefit from and can alter. **Principle IV:** The exchange of matter between natural systems and human societies affects the long-term functioning of both. **Principle V:** Decisions affecting resources and natural systems are based on a wide range of considerations and decision-making processes.		
Connections to the CA CCSSM: 8.EE.4–6, 8.F.1–5, 8.SP.1–4		
Connections to CA CCSS for ELA/Literacy: RST.6–8.1, 2, 7, 9; RI.8.3; SL.8.1, 4, 6		
Connection to CA ELD Standards: ELD.PI.6-8.1, 9		

Vignette Debrief

The *CA NGSS* require that students engage in science and engineering practices to develop deeper understanding of the disciplinary core ideas and crosscutting concepts. The lessons give students multiple opportunities to engage with core ideas in space science (Moon phases and the solar system), helping them to move towards mastery of the three dimensions described in the *CA NGSS* performance expectations (PE’s). In this vignette, the teacher selected performance expectations across the three science disciplines and engineering. In the lessons described above she engaged students only in selected portions of these PE’s. Full mastery of the PE’s will be achieved throughout this Instructional Segment. The vignette integrated major concepts in Earth Science (Human Impacts and Earth systems), Physical Science (Information Technologies and Instrumentation), Life Science (Natural Selection), and Engineering Design (Defining and Delimiting Engineering Problems).

After students analyzed data related to impacts on Earth systems caused by increasing populations and per-capita consumption, they formed groups to deeply engage with a specific project that involved key concepts in Instructional Segment 4. They also considered other concepts and practices from the entire year, and were encouraged to connect their projects with concepts and practices from Integrated Grades 6 and 7. Over the course of their projects, students interacted within and across groups as well as with the teacher. During their project development and final presentations, students also taught each other and reinforced middle school learning experiences that deepened their understanding of California’s Environmental Principles and Concepts.

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