Preferred CA Integrated Learning Progression Courses for Middle Grades
Grade Seven

Introduction to the Grade 7 Integrated Course

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

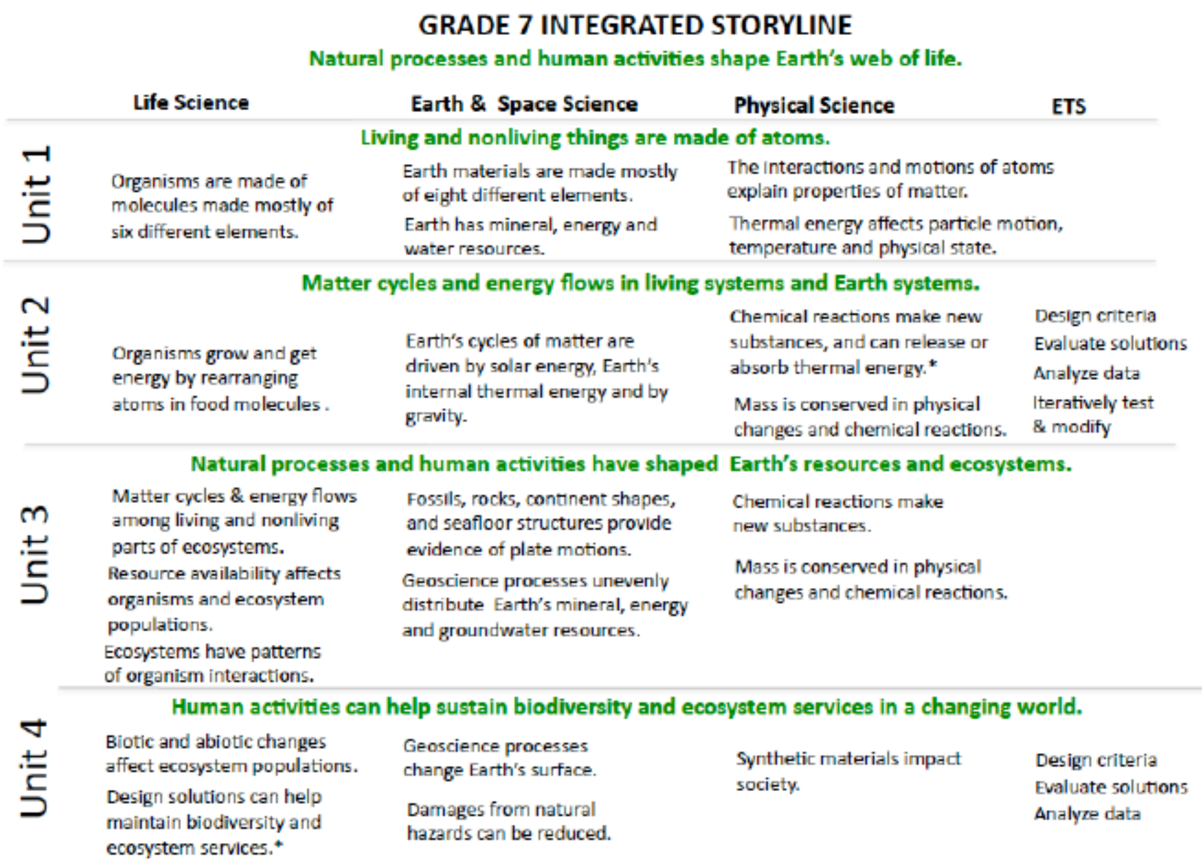


Figure 1: Storyline for Integrated Grade 7 showing the flow of the ideas and the distribution of disciplinary content within and across the Instructional Segments.

A primary goal of this section is to provide an example of how to bundle the Performance Expectations into integrated groups that can effectively guide instruction in four sequential Instructional Segments. There is no prescription regarding the relative amount of time to be spent on each Instructional Segment. As shown in Figure 1, the overarching guiding concept for the entire year is that, “Natural processes and human activities shape Earth’s web of life.” Notice how concepts across the disciplines integrate within each of the four Instructional Segments. Each Instructional Segment has a summary sentence, such as for Instructional Segment 1, “Living and nonliving things are made of atoms.” Figure 1 also indicates a sequence of concepts within each discipline such as the progression in life science from the idea that organisms are made of molecules (Instructional Segment 1) to photosynthesis (Instructional Segment 2) to ecosystem cycles of matter (Instructional Segment 3) to biodiversity concepts (Instructional Segment 4).

Students begin their **investigations** by categorizing the kinds of living and nonliving matter in a natural environment. Guided research and hands-on investigations lead to discussions and understandings about atoms and molecules. By comparing various solids, liquids and gases, students begin constructing an understanding that the interactions and movements of submicroscopic particles result in properties of matter that we observe at our macroscopic level of reality. Thoughtful applications of a crosscutting concept (CCC) can help with the learning of the specific topic and simultaneously deepen the understanding of the CCC. This kind of experience can help students use CCCs more effectively to deepen their science knowledge.

A snapshot in Instructional Segment 1 focuses on extended molecular structures (MS-PS1-1) such as graphite. This Instructional Segment 1 snapshot models NGSS 3-dimensional learning by weaving together two science and engineering practices (SEP) and three CCCs. Instructional Segment 2 expands the instructional focus by including both a snapshot and a highly detailed vignette that describes instruction over a much longer time period.

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

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

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

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

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

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

Table 1 provides another way to view the features of the four different Instructional Segments. This summary of each Instructional Segment includes highlighted science and engineering practices (SEP), crosscutting concepts (CCC), disciplinary core ideas (DCI), and performance expectations (PE). Each Instructional Segment begins with a somewhat different kind of Table that include guiding questions, and the Instructional Segment's performance indicators, DCIs, SEPs and CCCs.

Table 1: Summary table for Integrated Grade7

<table>
<tr><td rowspan="7">Instructional Segment 1: Organisms and Nonliving Things Are Made of Atoms</td><th colspan="3">Instructional Segment 1:
Performance Expectations Addressed</th></tr>
<tr><td colspan="3">MS-LS2-1, MS-ESS3-1, MS-PS1-1, MS-PS1-4</td></tr>
<tr><th>Highlighted SEP</th><th>Highlighted DCI</th><th>Highlighted CCC</th></tr>
<tr><td>• Developing and Using Models
• Constructing Explanations and Designing Solutions</td><td>PS1.A: Structure and Properties of Matter
PS3.A: Definitions of Energy
LS2.A: Interdependent Relationships in Ecosystems
ESS3.A: Earth’s Natural Resources</td><td>• Cause and Effect: Mechanism and Explanation
• Patterns
• Systems and System Models</td></tr>
<tr><th colspan="3">Summary of DCI</th></tr>
<tr><td colspan="3">A river environment provides an initial context to explore different forms of living and nonliving matter (ESS3.A and LS2.a). The deeper understandings in these life science performance expectations and DCIs are mostly addressed in later Instructional Segments. In Instructional Segment 1, these PEs and DCIs provide the contexts for investigating the underlying physical science of matter. In addition to the distinction between organisms and Earth materials, forms of matter at our macroscopic level of reality have properties such as different physical states (solid, liquid and gas). Macroscopic physical properties arise from structures and interactions at the atomic-level of reality. Through exploring both PS1.A and PS3.A, students connect their learning of atomic-level structure and processes with the properties and phenomena that they can observe at our level of reality. This DCI-based understanding also directly relates to the crosscutting concepts of patterns and of cause and effect,</td></tr>
</table>

Instructional Segment 2: Matter Cycles and Energy Flows in Living Systems and Earth Systems	**Instructional Segment 2 Performance Expectations Addressed**		
	MS-LS1-6, MS-LS1-7, MS-ESS2-1, MS-PS1-2, MS-PS1-5, MS-PS1-6 MS-ETS1-1, MS-ETS1-2, MS-ETS1-3, MS-ETS1-4		
	Highlighted SEP	**Highlighted DCI**	**Highlighted CCC**
	• Planning and Carrying out Investigations • Engaging in Argument from Evidence • Analyzing and Interpreting Data	LS1.C: Organization for Matter and Energy Flow in Organisms PS1.A: Structure and Properties of Matter PS1.B: Chemical Reactions ESS2.A Earth's Materials and Systems ETS1.A: Defining and Delimiting Engineering Problems ETS1.B: Developing Possible Solutions ETS1.C: Optimizing the Design Solution	• Energy and Matter: Flows, Cycles, and Conservation • Systems and System Models • Stability and Change
	Summary of DCI		
	Photosynthesis and respiration provide the basis for how matter and energy flow through organisms (LS1.C). While these major life science concepts have been introduced at earlier grade levels, middle school significantly deepens the understanding by focusing on the molecular structures (PS1.A) and the chemical reactions that are involved (PS1.B). By also including Earth's materials and systems, the students can develop a much deeper understanding of the universality of the underlying physical science concepts such as the conservation of matter, and the flows of matter and energy at the macroscopic levels of organisms and Earth materials.		

<table>
<tr><td rowspan="6">Instructional Segment 3: Natural Processes and Human Activities Shape Earth's Resources and Ecosystems</td><td colspan="3">Instructional Segment 3
Performance Expectations Addressed</td></tr>
<tr><td colspan="3">MS-LS2-1, MS-LS2-2, MS-LS2-3, MS-ESS2-3, MS-ESS3-1,
MS-PS1-2, MS-PS1-5</td></tr>
<tr><td>Highlighted SEP</td><td>Highlighted DCI</td><td>Highlighted CCC</td></tr>
<tr><td>• Analyzing and Interpreting Data
• Constructing Explanations
• Developing and Using Models</td><td>LS2.A Interdependent Relationships in Ecosystems
LS2.B Cycles of Matter and Energy Transfer in Ecosystems
ESS2.B Plate Tectonics and Large Scale System Interactions
ESS3.A Earth's Natural Resources
PS1.B Chemical Reactions</td><td>• Energy and Matter: Flows, Cycles, and Conservation
• Cause and Effect: Mechanism and Explanation
• Systems and System Models</td></tr>
<tr><td colspan="3">Summary of DCI</td></tr>
<tr><td colspan="3">Students have touched on ecosystems in Instructional Segments 1 and 2. In contrast, ecosystems become the focus of attention in Instructional Segment 3 (LS2.A and LS2.B). The flows of matter and energy traced in organisms become more clearly distinguished as cycles of matter and flows of energy at the ecosystem level. Within an ecosystem, matter tends to stay longer and recycle more than energy.
The distribution, movements and changes of Earth materials (ESS2.B and ESS3.A) happen at a different scale than photosynthesis and respiration. Exploring these Earth System contexts deepens understanding of energy in the Earth system and of chemical reactions (PS1.B).</td></tr>
</table>

Instructional Segment 4: Sustaining Biodiversity and Ecosystem Services in a Changing World

Instructional Segment 4 Performance Expectations Addressed		
MS-LS2-4, MS-LS2-5*, MS-ESS2-2, MS-ESS3-1, MS-ESS3-2, MS-PS1-3 MS-ETS1-1, MS-ETS1-2, MS-ETS1-3		
Highlighted SEP	**Highlighted DCI**	**Highlighted CCC**
• Obtaining, Evaluating & Communicating Information • Constructing Explanations and Designing Solutions • Engaging in Argument from Evidence	LS2.C Ecosystem Dynamics, Functioning and Resilience LS4.D Biodiversity and Humans ESS2.A Earth Materials and Systems ESS2.C Roles of Water in Earth's Surface Processes ESS3.A Natural Resources ESS3.B Natural Hazards PS1.B: Structure and Properties of Matter ETS1.A: Defining and Delimiting Engineering Problems ETS1.B: Developing Possible Solutions ETS1.C: Optimizing the Design Solution	• Stability and Change • Cause and Effect: Mechanism and Explanation • Connections to Engineering, Technology & Applications ofScience
Summary of DCI		
The Instructional Segment 4 Life Science DCIs (LS2.C and LS4.D) and Earth Science DCIs (ESS2.A, ESS2.C, ESS3.A. and ESS3.B) broadens the context in terms of geographic scope, population of organisms, and roles, vulnerabilities and responsibilities of humans. In particular LS4.D highlights that, "Changes in biodiversity can influence humans' resources, such as food, energy, and medicines, as well as ecosystem services that humans rely on." The corresponding performance expectation (MS-LS2-5) focuses on designing solutions for maintaining biodiversity and ecosystem services.		

Table 2 - Grade 7 - Instructional Segment 1 Organisms and Nonliving Things Are Made of Atoms
Guiding Questions: What are living and nonliving things made of? How does adding or removing thermal energy affect the physical states of matter? How do interactions at the atomic level help us understand the observable properties of organisms and nonliving matter? **Highlighted Scientific and Engineering Practices** • **Developing and Using Models** • **Constructing Explanations** ***Crosscutting Concepts:*** • ***Cause and Effect: Mechanism and Explanation*** • ***Patterns*** Performance expectations associated with this Instructional Segment: **MS-LS2-1. Analyze and interpret data to provide evidence for the effects of resource availability on organisms and populations of organisms in an ecosystem.** [Clarification Statement: Emphasis is on cause and effect relationships between resources and growth of individual organisms and the numbers of organisms in ecosystems during periods of abundant and scarce resources.] **MS-ESS3-1. Construct a scientific explanation based on evidence for how the uneven distributions of Earth's mineral, energy, and groundwater resources are the result of past and current geoscience processes.** [Clarification Statement: Emphasis is on how these resources are limited and typically non-renewable, and how their distributions are significantly changing as a result of removal by humans. Examples of uneven distributions of resources as a result of past processes include but are not limited to petroleum (locations of the burial of organic marine sediments and subsequent geologic traps), metal ores (locations of past volcanic and hydrothermal activity associated with subduction zones), and soil

(locations of active weathering and/or deposition of rock).]

MS-PS1-1. Develop models to describe the atomic composition of simple molecules and extended structures. [Clarification Statement: Emphasis is on developing models of molecules that vary in complexity. Examples of simple molecules could include ammonia and methanol. Examples of extended structures could include sodium chloride or diamonds. Examples of molecular-level models could include drawings, 3D ball and stick structures, or computer representations showing different molecules with different types of atoms.] [Assessment Boundary: Assessment does not include valence electrons and bonding energy, discussing the ionic nature of subunits of complex structures, or a complete description of all individual atoms in a complex molecule or extended structure is not required.]

MS-PS1-4. Develop a model that predicts and describes changes in particle motion, temperature, and state of a pure substance when thermal energy is added or removed. [Clarification Statement: Emphasis is on qualitative molecular-level models of solids, liquids, and gases to show that adding or removing thermal energy increases or decreases kinetic energy of the particles until a change of state occurs. Examples of models could include drawings and diagrams. Examples of particles could include molecules or inert atoms. Examples of pure substances could include water, carbon dioxide, and helium.]

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.

Instructional Segment 1 Teacher Background and Instructional Suggestions:

Many of the Integrated Grade 7 performance expectations and disciplinary core ideas relate to organisms, ecosystems and natural environments. One way to engage students in phenomena related to these topics is to have them sequentially build their understanding of the types of matter and energy interactions, and compare them across different contexts. For example, diagrams of different natural environments can be downloaded for free from WestEd's Making Sense of Science professional development project.[9] Over the course of the first three Instructional Segments, the class as a whole

[9] http://we-mss.weebly.com/teacher-resources.html Click on "Environment Diagrams."

can analyze one environment (e.g., rivers) while they also work in groups on other very different environments (e.g., other environments accessed from the web and/or created by student teams).

Instructional Segment 1 focuses on the matter in these different environments. Using the river diagram as the shared class environment (Figure 2), it is natural to begin by considering the kinds of matter that are living, nonliving, once living, solid, liquid, and gas, and then to focus on the water. Recognizing that water vapor also exists in the air raises physical science concepts related to the molecular structure of water and to the properties and physical states of water.

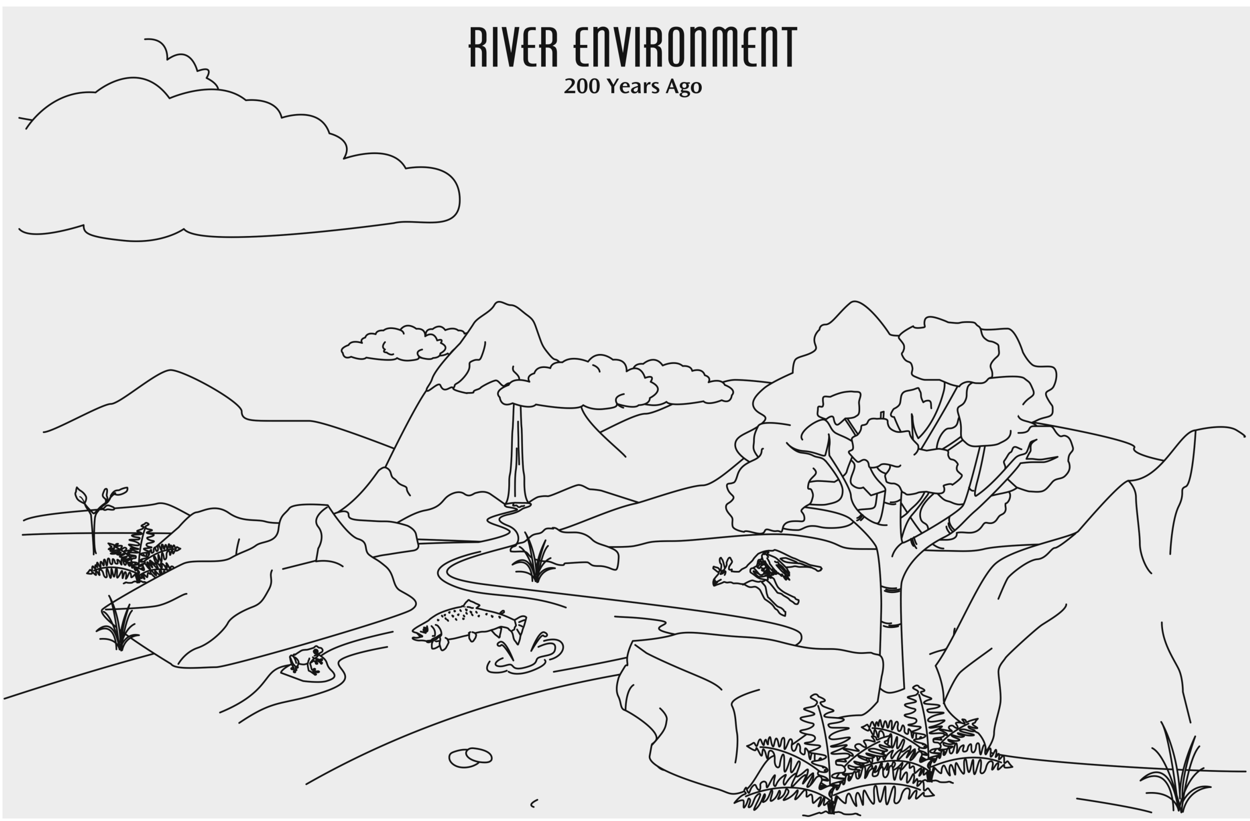


Figure 2: A river environment with diverse forms of living and nonliving matter. (Illustration from Making Sense of Science *Earth Systems* course, courtesy of WestEd)

The environment diagrams can lead to discussions about air being a mixture of predominantly diatomic gases (nitrogen and oxygen) with varying amounts of water vapor (the familiar H_2O), argon (another mono-atomic inert gas), and carbon dioxide. Through this analysis, six of the most important elements for life (carbon, oxygen, hydrogen and nitrogen) are identified as well as three of the main molecules involved in photosynthesis and respiration (water, carbon dioxide and oxygen).

The environment diagrams also serve as an introduction to the deeper concepts involved in performance expectations MS-LS2-3 (living and nonliving parts of environments) and MS-ESS3-1 (uneven distributions of resources in different environments). In Instructional Segment 1 students begin to research the forms of matter in these environments. In succeeding Instructional Segments these environment diagrams can become more detailed and enriched with **models** of ***cycles of matter, flows of energy***, geoscience processes, and distributions of resources. The identified forms of matter, especially water, serve as the lead-in to the Instructional Segment 1 physical science performance expectations and disciplinary core ideas.
Just as organisms are made of building blocks (cells) that are too small to see with the naked eye, all of matter is made of building blocks (atoms) that are orders of magnitude smaller, and that cannot be seen even with the most powerful light microscopes. The atomic nature of matter underlies almost all of the science that students explore in middle school and high school.

This atomic theory actually includes several features that go beyond merely stating that matter is made of building blocks called atoms. These features include:

* atoms combine with each other to form molecules and other extended structures;
* atoms and molecules are always moving;
* atoms and molecules can attract and/or repel each other; and
* atoms consist of parts that have positive and negative electrical charges.

It should be noted that CA NGSS in middle grades includes the first three of these features, but does not refer to the existence of electrical charges within atoms (or use the terms electrons and protons). Clearly, middle grade science teachers should know these atomic electrical charges, but what about middle school students?

A very relevant consideration is that CA NGSS also does not mention the periodic table of the elements until high school. This omission represents a very significant departure from most current practices, especially in California where the previous science education standards included the periodic table in grades 3, 5 and 8. Instructional

Segment 1 in integrated grade seven follows the CA NGSS in not including the periodic table or naming the electrical charges within atoms. However, teachers may choose to include some of these concepts based on their classroom contexts, particularly to answer questions about what makes one kind of atom different from another kind of atom, or the electrical nature of the attractions that happen at the atomic and molecular levels.

These attractions and the movements of atoms are particularly important in **explaining** the nature of solids, liquids, and gases. Since students are familiar with the three states of water and have explored the water cycle in grade 6, H_2O provides a particularly attractive molecule (pun intended) to **model** the relationships among particle kinetic energy, particle attractions, properties of solids/liquids/gases and changes in physical state.

In Integrated Grade 6, students learned to explain that the temperature of a substance is a property that results from the average kinetic energy of the particles of that substance. This statement implies that any given sample of a substance will have particles that have different kinetic energies. Students should be able to demonstrate that understanding by **modeling** in various ways that the particles of a substance at any given temperature have a fairly wide range of kinetic energies. They should then **use these models as evidence** to support claims that the addition or removal of thermal energy (i.e., heating or cooling) changes the temperature of the substance because the average particle kinetic energies have changed.

Using water as an example substance, students can describe the everyday experience that heating water with electricity or gas adds thermal energy, such that the distribution of particle kinetic energies shifts to higher values As a result our bodily sensors (skin and mouth) and our thermometers indicate that the temperature has increased. Note that changes at the invisible particle level are causing changes at our macroscopic level of reality. The crosscutting concepts of both ***cause and effect*** and ***scale*** directly apply to these common experiences of temperature changes.

TABLE 3: Comparing Solids, Liquids and Gases

Physical State	Molecular Perspective	Macroscopic Properties
Solid State associated with lowest temperatures and/or highest pressures.	Particles have least freedom of motion. Forces of attraction between particles lock them in their local neighborhood where they vibrate in place.	Solids maintain their volume and keep their shape independent of their container.
Liquid State associated with "moderate" temperatures and/or "moderate" pressures.	Particles have some freedom of motion. Forces of attraction keep each particle associated with nearby particles. Particles have too much kinetic energy for the attraction to lock them in place, so the particles slide past each other and change their neighborhoods.	Liquids flow as a unit and maintain their volume. Liquids adapt their shape to the shape of their container. If the container has more volume than the liquid, then the liquid does not fill the container.
Gas *(3) Students fill in this blank space third.*	*(2) Students fill in this blank space second.*	*(1) Students fill in this blank space first, then the middle and lastly the left column blank space.*

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

Changes in particle kinetic energy can have other dramatic effects at our macroscopic level, notably changes in physical state. Table 3 summarizes the particle interactions that happen under different conditions and the resulting macroscopic properties of solids, liquids and gases. Starting with water as the sample substance and temperature as the main variable, students can use everyday experience as **evidence** that as long as ice is not melting; the ice keeps its shape and the amount of space that it takes up (its volume). Similarly, their daily experiences reinforce that liquid water also keeps its volume, but that it will adapt its shape to that of its container. If the container is larger than the volume of water, the liquid does not fill the container. We tend to describe the glass as being half-full.

Students have already investigated the gas state in grade 5 and Integrated Grade 6, so they should have the knowledge to make the claim that the empty space in the unfilled glass actually has matter in the gas state (air consisting mostly of nitrogen gas and oxygen gas). If students have been provided with a copy of Table 3, they can work individually and then in teams to fill in the blank spaces in the bottom row for the gas state. Untying a filled balloon provides **evidence** that a gas does not have a fixed volume, and that it will go into whatever space is available to it. Students can use that and similar evidence to make a claim in the middle column of the bottom row that the gas state results from particles having so much kinetic energy that they break completely free of the attractive force that would keep them in the liquid state.

In the left-hand column of the phase change table, temperature and pressure typically have opposite effects. Mathematically inverse relationships often confuse learners. To **cause** a liquid to evaporate into a gas, we can increase the temperature or decrease the pressure. Students can **explain** this inverse relationship as arising from the competing effects of attractive forces and motion energy at the microscopic particle level. When the temperature is increased, the water molecules have so much kinetic energy that they break free of the attractive forces, and transition from the liquid state to the gas state. Pressure has the opposite effect. Increasing the pressure tends to make a gas condense into a liquid because the higher pressure forces the particles to stay closer together, experience more strongly the force of attraction, and not move away from each other. As a result, higher pressure ***causes*** condensation while higher temperature ***causes*** evaporation.

While this analysis of physical states is interesting for its own sake, it is particularly valuable because it illustrates a key physical science concept that NGSS emphasizes. The properties of materials at our macroscopic level result from the interactions and motions of particles at the level of atoms and molecules. Phenomena that we observe and wonder about result from structures and events that are happening at levels that we cannot see. Science helps us understand the atomic level structures and interactions, and technologies help us use that scientific knowledge to solve problems.

Students can use the crosscutting concept (CCC) of ***cause and effect: mechanism and explanation*** to understand the properties of solids, liquids and gases. As described in the CA NGSS, one feature of this CCC in the middle grade span is that, “Cause-and-effect relationships may be used to predict phenomena in natural or designed systems.” Up until grade 7, students probably have utilized this CCC only in situations that involved purely macroscopic considerations, such as using a force to cause the motion of a visible object to change. In describing that particle behavior ***causes*** the physical states of water, this causality CCC helps build understanding of the phenomenon that is being studied. A corollary benefit of applying the ***cause and effect*** CCC in this case is that we expand the understanding of the CCC itself***. Cause and effect*** becomes an even more powerful CCC when students realize they can use it to understand and help **explain** phenomena at our level of reality as arising from interactions at the particle ***scale***.

The CCC of ***patterns*** also assists learning in Instructional Segment 1. Students **investigate** the macroscopic patterns of phase changes, such as how solids, liquids and gases behave. They also research the patterns of how temperature and pressure affect changes in these states of matter. In NGSS, the CCC of Patterns at the middle school level is also associated with the concept that, “Macroscopic patterns are related to the nature of microscopic atomic-level structure.” By including this aspect of the Patterns CCC in the instruction, the learning about the roles of particles in determining physical states of matter is assisted AND the understanding of the CCC is broadened. By experiencing the Patterns CCC in this way, students acquire a conceptual tool that they can use in many other contexts. When confronted with a puzzling phenomenon, their new habit of mind may prompt students to look for a ***pattern*** at the atomic level that will help them understand and **explain** the ***causes*** of that macroscopic phenomenon.

Students can apply what they have learned about states of water to predict the behavior of different substances. For example, atoms of helium do not react (attract or repel) with each other or with other atoms or molecules. What would students predict about the states of helium and its phase changes? How would helium compare with nitrogen, the main gas in air?

TABLE 4: Physical States at Normal Atmospheric Pressure			
ELEMENT	**GAS STATE**	**LIQUID STATE**	**SOLID STATE**
Helium	Above -270^{0}C	Below -270^{0}C	Never
Nitrogen	Above -196^{0}C	From -196^{0}C to -210^{0}C	Below -210^{0}C
Copper	Above $2,560^{0}$C	From $1,084^{0}$C to $2,560^{0}$C	Below $1,084^{0}$C

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

As shown in Table 4, helium needs to be cooled a lot more than nitrogen in order to transition from the gas state to the liquid state. In addition, further cooling will ***cause*** nitrogen to solidify, but helium will never solidify at normal atmospheric pressure. However, with higher pressure, helium can solidify at about -272^{0}C. Students can make claims about the effects of changing temperature and pressure on the physical states of matter, and use **evidence** from different substances to support or disprove their claims. They should be able to **explain** why changes in thermal energy or pressure have these effects (e.g., higher pressure forces the helium molecules to be closer together so they can actually transition to the solid state). Students could also **argue from this evidence** about the relative strengths of forces of attractions between different molecules or atoms (e.g., that the evidence indicates that nitrogen molecules attract each other more than helium atoms attract each other).

Including the example of copper extends the learning by showing that even a metal will melt or turn into a gas if the temperature is high enough. Further, copper provides the contrasting example of an element whose atoms have a very strong force of attraction for each other. The very strong force of attraction makes it much harder for the particles to overcome that attractive force even when they have a lot of kinetic energy. As a result, copper tends to exist in the solid state even at very high temperatures. Yet, even the metal copper can melt or boil if its particles have enough kinetic energy.

While MS-PS1-4 focuses on changes in state and on temperature, MS-PS1-1 focuses on the atomic/molecular composition of matter. In Instructional Segment 1, students **develop and use a variety of models** to explore and describe the atomic composition of simple molecules. Succeeding Instructional Segments in grade 7 include life science and Earth science contexts that involve extensive discussion of simple molecules such as water, carbon dioxide, oxygen, and also somewhat more complex molecules such as glucose, the sugar product of photosynthesis. MS-PS1-1 also includes the concept of extended structures, referring to a different particle arrangement that is characteristic of metals, salts and many crystalline substances (see snapshot).

Instructional Segment 1 Snapshot:
Extended Atomic and Molecular Structures

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 (e.g., the Instructional Segment 2 Vignette “Organism Physical and Chemical Changes”).

Ms. V used lead pencils to introduce the topic of extended structures. She told students that the “lead” in the pencils is actually a form of carbon known as graphite. Ms. V projected a model showing how the carbon atoms in graphite connect with each other (Figure 3). She pointed out that the model just illustrates a tiny section of the structure that actually greatly extends in all three dimensions.

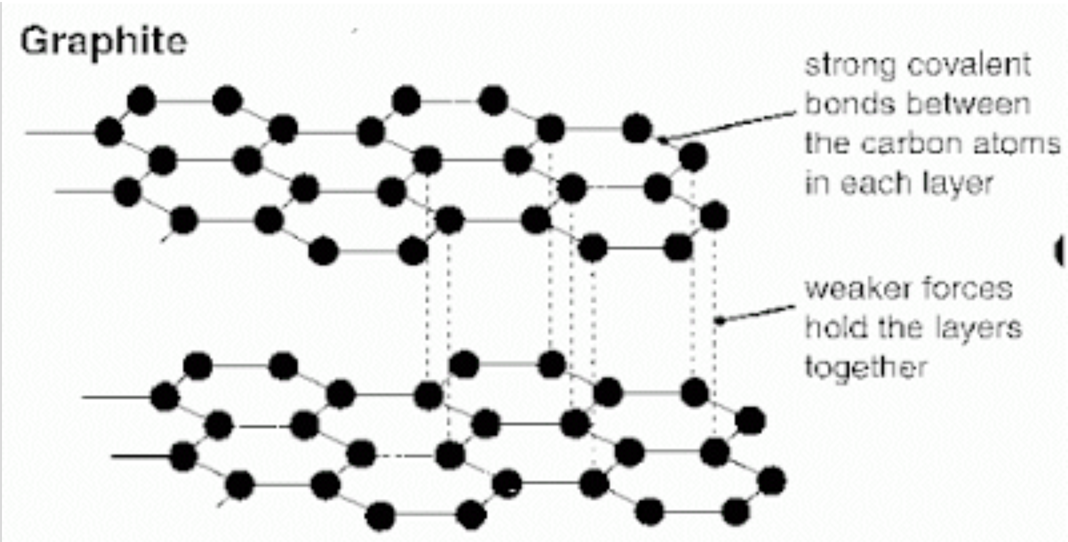


Figure 3: Model of the extended structure of graphite. Black circles are carbon atoms. Solid lines within layers are strong connections. Dotted lines between layers are weak connections. (IGCSE Chemistry Notes 2009)

In small groups, students listed the properties of the lead in their pencil, and discussed how the atomic structure might ***cause*** those properties. Ms. V also instructed the student teams to brainstorm different ways they might create physical models of graphite. Teams shared their discussions that resulted in a consensus claiming that graphite is a solid because of the very many strong connections among the carbon atoms. They also agreed that the weak connections between the layers ***caused*** graphite's ability to break off in flakes that leave marks on paper. As a result of small group and whole class discussions, the class decided on three different types of models that they would work in groups to build the next day.

Ms. V said that they could not work on building the models the next day unless they completed the homework assignment, which was to read and annotate a 1-page handout describing extended structures (Figure 4). The school district emphasized a literacy strategy called "Talk to the Text." By grade 7 students had sufficient experience with this strategy to proceed without further instruction. Ms V knew that many interesting concepts about molecular bonding and structures could emerge from the student reading, annotations and discussions, and she expected to see lots of comments on the handout (Figure 5).

HOMEWORK READING: Extended Structures

Many natural and synthetic solids consist at the atomic/molecular level of extended structures. These structures have repeating units that connect with each other in all three dimensions. As shown in the Table below, the repeating unit can be:

one neutral kind of atom (such as carbon atom);
two or more electrically charged atoms (called ions);
a small molecule such as a water molecule; or
a larger molecule such as a compound made of glucose and fructose.

Substances Made of Extended Structures

Type of Repeating Unit	Unit that Repeats	Macroscopic Substance
One Kind of Neutral Atom	Carbon Atom	Graphite Diamond
Two or More Different Ions	Sodium Ion (Na^+) and Chlorine Ion (Cl^-)	Table salt
Small Molecule	H_2O	Ice
Larger Molecule	$C_{12}H_{22}O_{11}$	Packaged Sugar

The properties of the macroscopic substance are directly related to the kind of repeating unit and how the repeating unit is connected to itself within the extended structures. For example, both graphite and diamond are made just of carbon atoms. They are both solids, but graphite is so soft you can write with it, and diamond is one of the hardest known substances. The big difference is how the carbon atoms are interconnected at the molecular level.

Table salt is made of positively charged sodium ions and negatively charged chlorine ions (called chloride). Chlorine is a poisonous green gas and sodium is very explosive – if you put a chunk of sodium in water, it will cause a dangerous, big fire. Yet, the extended structure made of sodium and chloride ions is one of the safest substances. We put it in and on our food.

Packaged sugar and starch are examples of macroscopic substances where the repeating unit is a larger molecule that has more than 20 atoms connected to each other. Of course, the larger extended structure in all these cases has many millions of atoms connected to each other.

Figure 4: Homework handout from Ms. V for students to read and annotate. (Created by Dr. Art Sussman, courtesy of WestEd)

Students read and annotated the “Extended Structures” homework using a “Talk to the Text” Literacy Strategy. Students annotated questions, ideas and other comments that they had while reading and trying to make sense of the text.

Sample Annotated Text

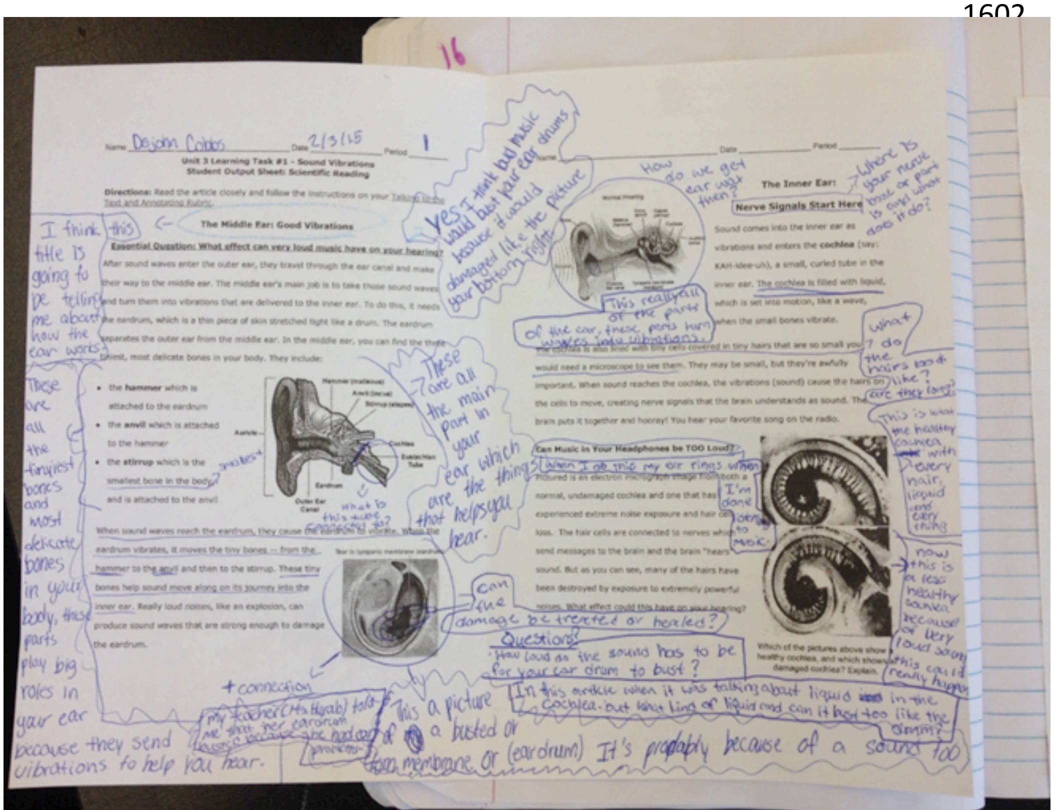


Figure 5: Sample of student annotated text from a different science homework reading. (Illustration courtesy of Oakland Unified School District)

After the students handed in their homework, they worked in teams that focused on building different physical **models** of graphite. One team had researched the structure of diamond and received permission from Ms. V to try to build a diamond model rather than graphite. While the students worked in their teams, Ms. V provided necessary guidance and also had some time to look through the homework to help plan for continuing discussions about substances, molecules and extended structures. She wrote a note to herself to look for and help elicit from the students the ***cause and effect CCC*** and the ***patterns CCC*** about the causal connection from the atomic particle level to the macroscopic level of substances that have distinctive and observable resulting properties.

NGSS Connections in the Snapshot

Performance Expectations

MS-PS1-1. Develop models to describe the atomic composition of simple molecules and extended structures.

Disciplinary Core Ideas

PS1.A: Structure and Properties of Matter

Scientific and Engineering practices

Developing and Using Models

Develop and/or use a model to predict and/or describe phenomena. Develop a model to describe unobservable mechanisms.

Obtaining, Evaluating and Communicating Information

Critically read scientific texts adapted for classroom use to determine the central ideas and/or obtain scientific and/or technical information to describe patterns in and/or evidence about the natural and designed world(s).

Crosscutting Concepts

Patterns

Macroscopic patterns are related to the nature of microscopic and atomic-level structure.

Cause and Effect

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

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.

ELD Connections: RST.6–8.1, 10; RI.7.3, 8; SL.7.1

Table 5 - Grade 7 - Instructional Segment 2

Matter Cycles and Energy Flows through Organisms and Rocks

Guiding Questions:

How do matter cycle and energy flow in living systems and Earth systems?

What are rocks and minerals and how do they change?

What is the difference between physical changes and chemical reactions?

What changes happen to mass and to energy as a result of chemical reactions?

Highlighted Scientific and Engineering Practices:

Developing and Using a Model

Analyzing and Interpreting Data

Engaging in Argument from Evidence

Highlighted Crosscutting Concepts:

Energy and Matter: Flows, Cycles and Conservation

Systems and System Models

Patterns

Performance expectations associated with this Instructional Segment:

MS-LS1-6. Construct a scientific explanation based on evidence for the role of photosynthesis in the cycling of matter and flow of energy into and out of organisms. [Clarification Statement: Emphasis is on tracing movement of matter and flow of energy.] [Assessment Boundary: Assessment does not include the biochemical mechanisms of photosynthesis.]

MS-LS1-7. Develop a model to describe how food is rearranged through chemical reactions forming new molecules that support growth and/or release

	energy as this matter moves through an organism. [Clarification Statement: Emphasis is on describing that molecules are broken apart and put back together and that in this process, energy is released.] [Assessment Boundary: Assessment does not include details of the chemical reactions for photosynthesis or respiration.]
MS-ESS2-1.	Develop a model to describe the cycling of Earth's materials and the flow of energy that drives this process. [Clarification Statement: Emphasis is on the processes of melting, crystallization, weathering, deformation, and sedimentation, which act together to form minerals and rocks through the cycling of Earth's materials.] [Assessment Boundary: Assessment does not include the identification and naming of minerals.]
MS-PS1-2.	Analyze and interpret data on the properties of substances before and after the substances interact to determine if a chemical reaction has occurred. [Clarification Statement: Examples of reactions could include burning sugar or steel wool, fat reacting with sodium hydroxide, and mixing zinc with hydrogen chloride.] [Assessment Boundary: Assessment is limited to analysis of the following properties: density, melting point, boiling point, solubility, flammability, and odor.]
MS-PS1-5.	Develop and use a model to describe how the total number of atoms does not change in a chemical reaction and thus mass is conserved. [Clarification Statement: Emphasis is on law of conservation of matter and on physical models or drawings, including digital forms that represent atoms.] [Assessment Boundary: Assessment does not include the use of atomic masses, balancing symbolic equations, or intermolecular forces.]
MS-PS1-6.	Undertake a design project to construct, test, and modify a device that either releases or absorbs thermal energy by chemical processes.* [Clarification Statement: Emphasis is on the design, controlling the transfer of energy to the environment, and modification of a device using factors such as type and concentration of a substance. Examples of designs could involve chemical reactions such as dissolving ammonium chloride or calcium chloride.] [Assessment Boundary: Assessment is limited to the criteria of amount, time, and temperature of substance in testing the device.]
MS-ETS1-1.	Define the criteria and constraints of a design problem with sufficient precision to ensure a successful solution, taking into account relevant scientific principles and potential impacts on people and the natural environment that may limit possible solutions.
MS-ETS1-2.	Evaluate competing design solutions using a systematic process to determine how well they meet the criteria and constraints of the problem.
MS-ETS1-3.	Analyze data from tests to determine similarities and differences among several design solutions to identify the best characteristics of each that can be combined into a new solution to better meet the criteria for success.
MS-ETS1-4.	Develop a model to generate data for iterative testing and modification of a proposed object, tool, or process such that an optimal design can be achieved.

Environmental Principles and Concepts:

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

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

As a result of applying a variety of science practices in Instructional Segment 1, students will have built a strong foundation with respect to atomic structure and macroscopic properties of matter. The begin Instructional Segment 2 by investigating changes that happen to the organisms and Earth materials in the environment(s) that they explored in Instructional Segment 1.

Grade 7 Instructional Segment 2 Vignette

Organism Physical and Chemical Changes

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 opportunities to develop and use the science and engineering practices and the crosscutting concepts to understand some of the disciplinary core ideas associated with Instructional Segment 2.

Classifying changes in a natural environment

In Instructional Segment 1 students noted the kinds of matter that exist in natural environments. They had begun with whole class discussions focused on the river environment (Figure 2), then worked in groups on different natural environments, and then iteratively updated the whole class and group-specific environments. Mr. G similarly initiated Instructional Segment 2 by distributing a diagram of the river environment today (Figure 6).

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

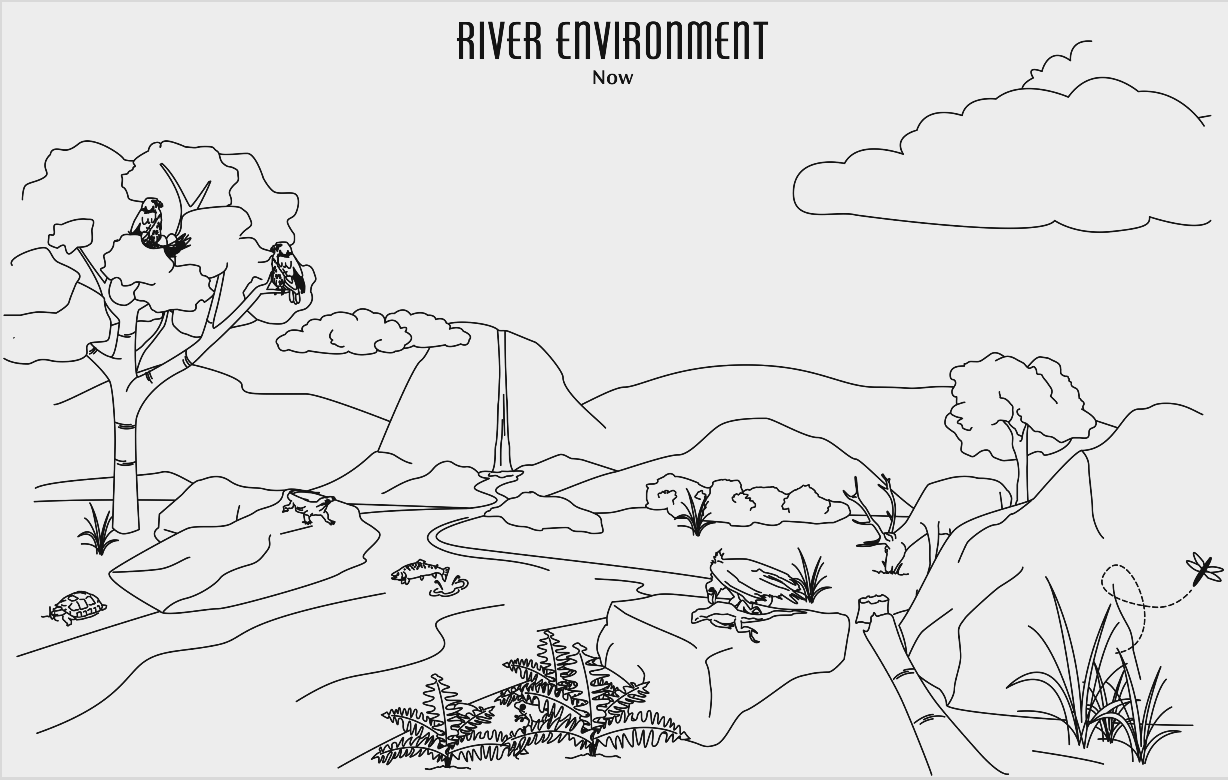


Figure 6: The previously viewed river environment 200 years later. (Adapted from Making Sense of Science *Earth Systems* course, courtesy of WestEd)

After whole class sharing and reaching a class consensus about the changes, Mr. G distributed a short illustrated reading about the differences between a physical change and a chemical reaction. Reading and writing individually, and then discussing in pairs, students generated a list of scientific **questions** they had about the changes that had happened in the natural environment. In the subsequent whole class sharing and discussions, questions emerged about physical and chemical changes.

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

The next day student discussions were more focused on the specific changes in physical properties (change in color, bubbling of a gas, or an increase in temperature) that tended to indicate a chemical change had happened. Students liked the idea that the changes in physical properties were similar to clues in a mystery story or crime scene investigation. The homework had included some examples that appeared to be chemical changes (gas bubbling out of a soda can) but that were really *just* physical changes, an emphasis in word phrasing that was helping to distinguish between the two kinds of changes.

Juanita shared a Venn diagram that she had made to answer her own previous question about whether something could be both a physical and a chemical change. Her diagram showed that both kinds of changes had alterations in physical properties (the shared circle in the middle), but only chemical changes had changes in the bonding of the atoms within molecules. The physical change circle showed water boiling with the words “it’s all still H_2O.” The chemical change circle showed a wood fire and smoke with the words, “new substances appear.” This claim and **evidence** about new substances and changes in connections at the atomic level had moved the discussion in favor of two mutually exclusive categories (physical changes and chemical changes), but there were still a lot of questions about what those changes in atomic connections really meant.

Chemical reaction of photosynthesis

In the next lesson, Mr. G connected the student questions about changes in atomic connections with the chemical change that all the student groups had identified in the river environment – the photosynthesis that had enabled the tree to grow so much. He wrote the balanced equation for photosynthesis on the board, and provided LEGOs to students to **model** that reaction. Each group of students had a variety of LEGO pieces that they could assemble in their work areas.

Marco, the reporter for one student group, described how they used a different type of LEGO for each molecule. Most of the other student groups had used a similar type of modeling. Marco explained how their **model** represented carbon dioxide with the small black LEGO (“just like coal”), water with the small blue LEGO (“just like the ocean”), glucose with the big white LEGO ("just like a sugar cube"), and oxygen with the small red LEGO ("just like fire"). Kelly, another member of the same student group, proudly added that they had used six of each type of LEGO except for only one white LEGO so their model was just as correct as the equation that Mr. G had put on the board. She also pointed out, "In case you did not notice it, I was making an **argument based on evidence**."

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

Mr. G used this discussion as an opportunity to share illustrations of models that scientists use to represent the bonding within molecules and the shapes of common molecules (carbon dioxide, water, glucose and oxygen). He asked teams of students to discuss what kind of materials that they might use to represent those molecules and the photosynthesis equation. As student presented their ideas, the discussion lead to consideration of the criteria and constraints for the students to work in groups and make molecular models using inexpensive materials that could still be reasonably accurate. One significant criterion was that there would be different representations for each kind of atom so they could track the changes in bonding associated with the reaction. By the end of the class period, students had reached a consensus on using different colored sticky notes to represent the three different types of atoms involved. Students also wanted to use a smaller size sticky note to represent hydrogen since they knew that it was the smallest atom.

Model of a Glucose Molecule

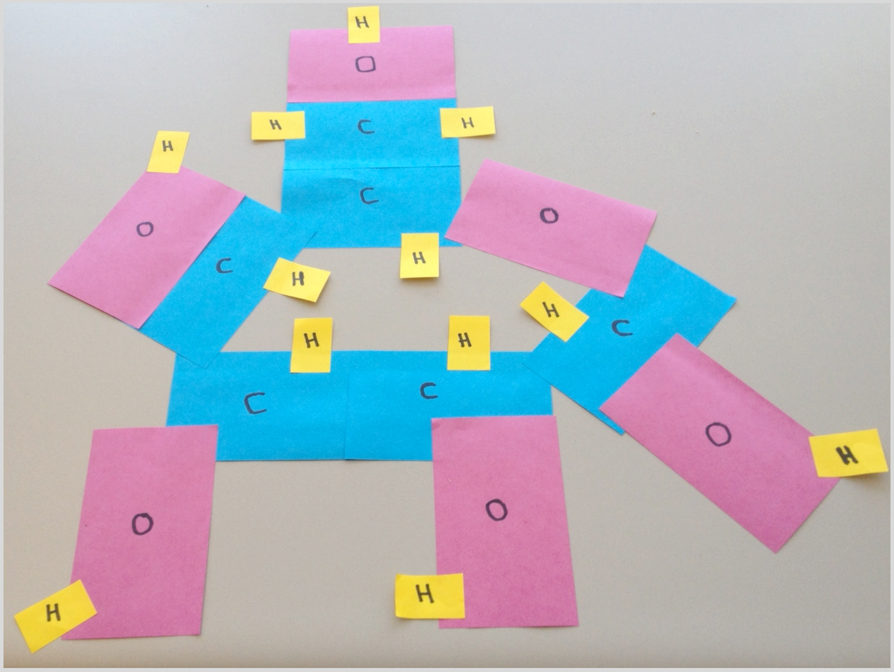


Figure 7: A model of a glucose molecule with different colors representing carbon (C), oxygen (O) and hydrogen (H). (Provided by Dr. Art Sussman, courtesy of WestEd)

The next day, each of the student groups gathered their supplies of sticky notes and began to assemble them to **model** photosynthesis. As shown in Figure 7, most of the student groups successfully created a model of a glucose molecule. They had also used the correct numbers of all the molecules. They were able to **use evidence to explain** that in the reaction none of the atoms had disappeared, and that there were also no new atoms in the products. The products side of their model had exactly the same numbers and kinds of atoms as the reactants side of their model. Mr. G reinforced their use of the term “Conservation of Matter” to describe this feature of chemical reactions, and they readily noted that physical changes also featured this rule of Conservation of Matter.

Energy and the chemical reaction of respiration

In the next lesson, Mr. G displayed the two river environment diagrams and facilitated the students in discussing and reporting about the different chemical reactions. They all identified the deer and the bird as examples of organisms that were doing respiration.

Marco added that the plants were also doing respiration, and noted that back in grade 6 they had learned that respiration happened in plant cells and in animal cells.

Following that introduction, Mr. G challenged the students to use the sticky notes to **model** the reaction of respiration. There was some grumbling about having to make the sugar molecule again, but Mr. G reminded them that not only did plants always make sugar without any whining, the plants also did not complain about being eaten.

When it was time to share in groups, the students seemed comfortable with the concept that photosynthesis and respiration were examples of chemical reactions. They also cited the **evidence** that in chemical reactions the atoms changed their connections and that the amount of mass remained constant. However, some of the students wondered about how to model the energy in these chemical reactions.

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

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

During the following sequence of lessons, students discussed everything they knew and wondered about energy from their previous science classes and real world experiences. They developed and compared Frayer diagrams about the concept of energy, and concluded that there was no simple definition of energy that they could memorize and repeat back word for word on a test question to prove that they understood the science concept of energy. Some students seemed to find some consolation when they could not agree on a definition of “love.” Alex summed it up by saying, “I can’t define love, but I know different kinds of love when I see and feel them. Maybe it will be the same with energy.”

Student groups conducted a variety of hands-on **investigations** that Mr. G called their “energy love” investigations. Those lessons resulted in a summary Table (see Table 6) that listed examples of “Energy of Motion” and “Energy of Position.” With that common background established, Mr. G steered the class back to the chemical reactions of photosynthesis and respiration.

TABLE 6: 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 based on Making Sense of Science *Energy* course, courtesy of WestEd)

The final investigation in the “energy love” series had involved **modeling** the changes in potential energy in using a slingshot to propel a walnut across a distance. The prompt involved listing examples of three types of potential energy (EPE, GPE and CPE), and the changes in those forms of potential energy. Perry’s diagram was typical for the class (Figure 8).

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

After Marco pointed out that the walnut is food, Perry replied, “Okay, the walnut is food and has CPE, but the CPE didn’t change in the experiment. The walnut was not eaten or burned.”

Perry’s Potential Energy Diagram

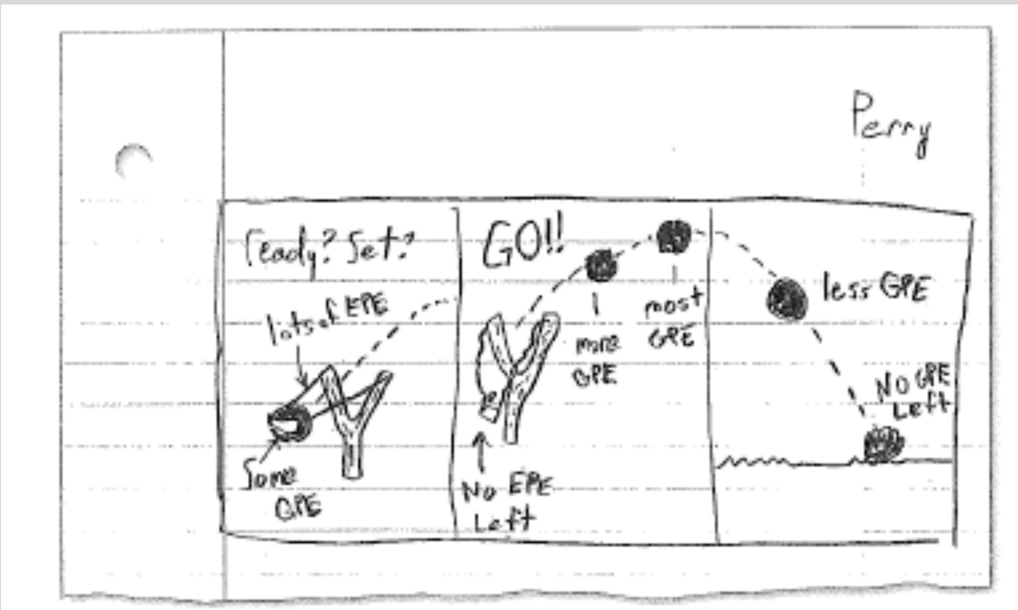


Figure 8: Student diagram of changes in potential energy accompanying the propulsion of a walnut by a slingshot. (Illustration from Making Sense of Science *Energy* course, courtesy of WestEd)

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

After presenting about and discussing their revised diagrams, the class transitioned to more deeply exploring the ***energy*** *changes in chemical reactions*. To make the connections more real to the students’ everyday lives, Mr. G had the students do a quick-draw to illustrate phenomena in their immediate environment where respiration and photosynthesis were happening. During the debrief, Mr. G was encouraged when students described and ***causally*** connected the changes in matter at the macroscopic and atomic levels. In contrast, he noted that students described the changes in energy only at the macroscopic level.

Mr. G began the next lesson by summarizing the end of the last discussion, and pointing out that they had not yet addressed the atomic/molecular level when they described the energy changes in photosynthesis and respiration. He distributed a handout that briefly explained that energy changes in chemical reactions depend on the differences between the total CPE of the reactants compared with the products. That handout included a summary illustration (Figure 9).

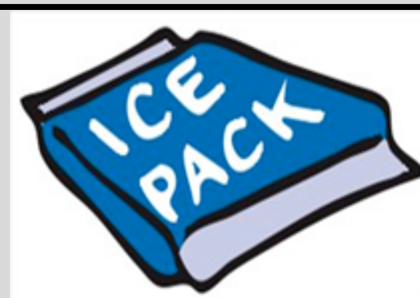
Energy Changes in Chemical Reactions	
Energy Releasing Reactions	**Energy Absorbing Reactions**
Total Energy of Reactants > Total Energy of Products	Total Energy of Reactants < Total Energy of Products
	

Figure 9: Comparing the total energy of reactants and of products, and relating their relative amounts to whether a reaction releases or absorbs energy. (Provided by Dr. Art Sussman, courtesy of WestEd)

Mr. G then challenged the students to apply what they learned from processing the handout to what is happening in respiration. Specifically, he asked, “What can you write or draw that explains why the reaction of sugar with oxygen releases energy instead of absorbing energy?”

Student groups initially talked a lot about different bonds being higher or lower in energy. After a while, they transitioned to referring to the handout, and started focusing on the total molecular CPE in reactants and in products. Students then began to claim that there must be a conservation of energy that is parallel to the conservation of mass. ***If*** the products have X amount less total CPE than the reactants, then X amount of energy will be released, generally in the form of thermal energy and light energy. If the products have X amount more total CPE than the reactants, then X amount of energy must be absorbed in order for the reaction to occur.

Applying the CCCs they had used in Instructional Segment 1, students developed and communicated ***causal* explanations** that changes in CPE at the molecular level determined whether there would be release or absorption of thermal energy at the macroscopic level. Their drawings showed that 1 glucose molecule plus 6 oxygen molecules have more chemical potential energy than 6 carbon dioxide molecules plus 6 water molecules.

Organism energy/matter system diagram

Mr. G transitioned the class to considering the ***cycles of matter and the flows of energy*** from the point of view of whole organisms. He first elicited from the students what they knew about ***systems and system models*** in terms of drawing the boundary of a system, identifying the parts of the system, and identifying the system's inputs and outputs. As a whole class, they agreed on the conventions they would use in drawing the system.

Returning to the River Environment diagram, students worked in pairs and developed a system model to illustrate the ***flows of matter and energy*** into and out of the deer and also into and out of the grass. Figure 10 shows the consensus diagram that emerged after students worked on their individual team diagrams, critiqued each other's diagrams, iteratively improved them, and then finalized the diagram after whole class discussion.

A Deer-Grass System

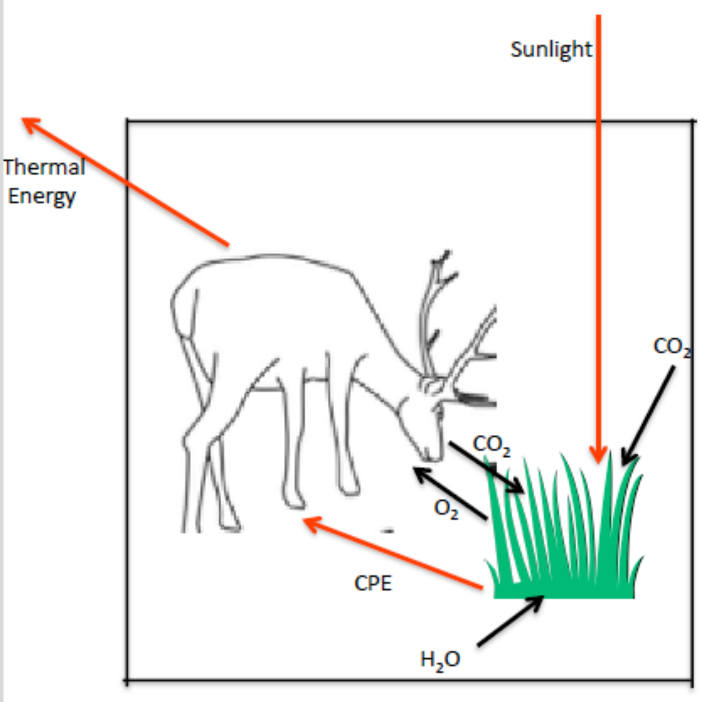


Figure 10: Flows of energy and matter into, within and out of a model of a Deer-Grass System. (Provided by Dr. Art Sussman, courtesy of WestEd)

Engineering design challenge to quantify energy released

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

The activity began with students bringing in food labels. Sharing the food labels with each other, the students raised **questions** and also provided answers about food contents, the meaning of calories, and the connections with chemical reactions and chemical potential energy. The students then worked in groups to design ways they could determine the calories per gram that could be obtained from different foods. They brainstormed a list of major criteria for their design challenge that included safety, cost and accuracy. The accuracy issue involved addressing the problem of maximizing the capture of **energy** that was measured by the device.

The student groups had numerous opportunities to share plans with each other, critique each other's ideas, and refine their plans before getting approval from Mr. G to proceed with the construction and testing of their devices. The class as a whole determined the foods that would be tested, again using the same design criteria but being especially cognizant of the issue of food allergies. Students collaboratively worked on designing the data sheets that they would use, but they did have the choice to customize their group's data sheets. In addition, students had multiple opportunities to iteratively test and improve their device subject to limitations imposed by the teacher and the rest of the class. At the end of the design and testing, student groups developed posters that they shared with each other and with other classes.

As students worked on their calorimeters, Mr. G revised his plans for the next sequences of lessons. He wanted to make sure that students had opportunities to explore the uses of food to build bodies. Students tended to focus on food for growth, but Mr. G wanted them to realize how much biomass is used to keep replacing the cells of our bodies. He also wanted to make sure that he had enough time for the students to investigate in depth the flows of matter and cycles of energy in the rock cycle.

NGSS Connections in the Vignette

Performance Expectations
MS-LS1-6 From Molecules to Organisms: Structures and Processes *Construct a scientific explanation based on evidence for the role of photosynthesis in the cycling of matter and flow of energy into and out of organisms.* **MS-LS1-7 From Molecules to Organisms: Structures and Processes** *Develop a model to describe how food is rearranged through chemical reactions forming new molecules that support growth and/or release energy as this matter moves through an organism.* **MS-PS1-2 Matter and Its Interactions**

Analyze and interpret data on the properties of substances before and after the substances interact to determine if a chemical reaction has occurred.

MS-PS1-5 Matter and Its Interactions
Develop and use a model to describe how the total number of atoms does not change in a chemical reaction and thus mass is conserved.

MS-PS1-6 Matter and Its Interactions
*Undertake a design project to construct, test, and modify a device that either releases or absorbs thermal energy by chemical processes.**

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.

MS-ETS1-3 Engineering Design
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 Engineering Design
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.

Science and engineering practices	Disciplinary core ideas	Crosscutting concepts
Asking Questions and Defining Problems *Define a design problem that can be solved through the development of an object, tool, process, or system that includes multiple criteria and constraints, including scientific knowledge that may limit possible solutions.* **Planning and Carrying Out**	**LS1.C Organization for Matter and Energy Flow in Organisms** *Photosynthesis produces sugars that can be used immediately or stored for growth or later use.* **PS1.A Structure and Properties of Matter**	**Patterns** *Macroscopic patterns are related to the nature of microscopic and atomic-level structure.* *Patterns can be used to identify cause-and-effect relationships.* **Cause and Effect: Mechanism and**

Investigations *Plan an investigation individually and collaboratively.* *Collect data about the performance of a proposed object, tool, process, or system under a range of conditions.* **Developing and Using Models** *Develop and/or use a model to predict and/or describe phenomena.* **Analyzing and Interpreting Data** *Analyze data to define an optimal operational range for a proposed object, tool, process, or system that best meets criteria for success.* **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** *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.*	*Each pure substance has characteristic physical and chemical properties.* **PS1.B Chemical Reactions** *In a chemical process, the atoms that make up the original substances are regrouped into different molecules, and these new substances have different properties from those of the reactants. The total number of each type of atom is conserved, and thus the mass does not change.* *Some chemical reactions release energy; others store energy.* **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.* **ETS1.B Developing Possible Solutions** *A solution needs to be tested, and then modified based on the test results.* **ETS1.C Optimizing the Design Solution**	**Prediction** *Cause and effect relationships may be used to predict phenomena in natural or designed systems.* **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.* **Systems and System Models** *Models can be used to represent systems and their interactions – such as inputs, processes, and outputs – and energy, matter, and information flows within systems.* **Energy and Matter: Flows, Cycles and Conservation** *Matter is conserved because atoms are conserved in physical and chemical processes.* *Within a natural or designed system, the transfer of energy drives the motion and/or cycling of matter.* *The transfer of energy can be tracked as energy flows through a designed or natural system.*

	An iterative process of testing and modifying can ultimately lead to an optimal solution.	
Connections to the CA CCSSM: MP. 3, 7.EE.3–4		
Connections to CA CCSS for ELA/Literacy: RST.6–8.1, 2, 4, 9; WHST. 6–8.1, 7; SL.7.1, 2		
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 introduced phenomena related to physical and chemical changes via a comparison of the changes that had occurred in a river environment after 200 years. Students noticed changes to both the nonliving and living components of the environment. The vignette focuses more on lessons that connect the physical and chemical changes with the life science processes of photosynthesis and respiration. Modeling the photosynthesis reaction was a major highlight that helped students conclude that atoms rearrange in chemical reactions, mass is conserved, and energy can be absorbed or released. In subsequent lessons within Instructional Segment 2, students will reach the same conclusions regarding Earth science processes.

Students also significantly engaged with the engineering design cycle as they optimized ways to quantify the thermal energy released by a chemical reaction. Throughout the vignette learning experiences, students used a wide range of scientific and engineering practices and applied numerous crosscutting concepts as documented in the Table columns above.

Instructional Segment 2 Teacher Background and Instructional Suggestions:

The second half of Instructional Segment 2 involves applying the same physical science concepts explored in the vignette to the cycling of Earth's materials and the ***flows of energy*** that drives these processes (performance expectation MS-ESS2-1). Rocks and minerals make up the vast majority of the planet's mass. They provide homes for organisms, make many of Earth's surface landforms, and provide the basis for all of Earth's soil. Rocks and minerals are both formed by geologic processes. Table 7 summarizes the main differences between rocks and minerals.

TABLE 7: Comparing Minerals and Rocks

Minerals	Rocks
Generally made of a single element or a single compound.	Generally made of one or more minerals but some rocks are made from non-mineral material. Made of multiple elements and/or compounds.
Typically have one specific crystalline structure. Many minerals are examples of "extended structures" described in Instructional Segment 1.	Do not have a crystalline structure but can contain visible crystals as well as particles of sand, other rocks, or shells.
Generally considered as pure substances.	Generally considered as mixed substances.

(Table based on Making Sense of Science *Land and Water* course, courtesy of WestEd)

The geoscience processes that form rocks and minerals include: volcanic eruptions, the heating and compaction of rock deep underground, the cooling of very hot underground rock, the evaporation of mineral-rich water, and the physical and chemical breakdown of surface rock by wind and water. All but the last of these geoscience processes are driven by the transfer of Earth's internal thermal energy. This internal thermal energy resulted from the immense heating of Earth's interior during its cataclysmic formation billions of years ago, the gravitational compaction of Earth in its early history, and the energy released by radioactive decay of buried Earth materials.

Rock at Earth's surface is almost exclusively a solid, except the few locations where it flows as liquid lava. As shown is Figure 9, liquid rock is also located underground, where it is called magma. A significant percentage of the rock underground exists as a plastic solid that is similar in some ways to bouncing putty. Even deeper underground, the immense pressure causes the rock to exist as a solid. Students can be given an unlabeled version of the right side of Figure 11, and asked to label where rock would have the ***pattern*** of existing as solid, plastic, and liquid. The assignment could also include providing the ***cause and effect*** physical science reasoning **explaining** why the rock existed in that particular form in each particular place.

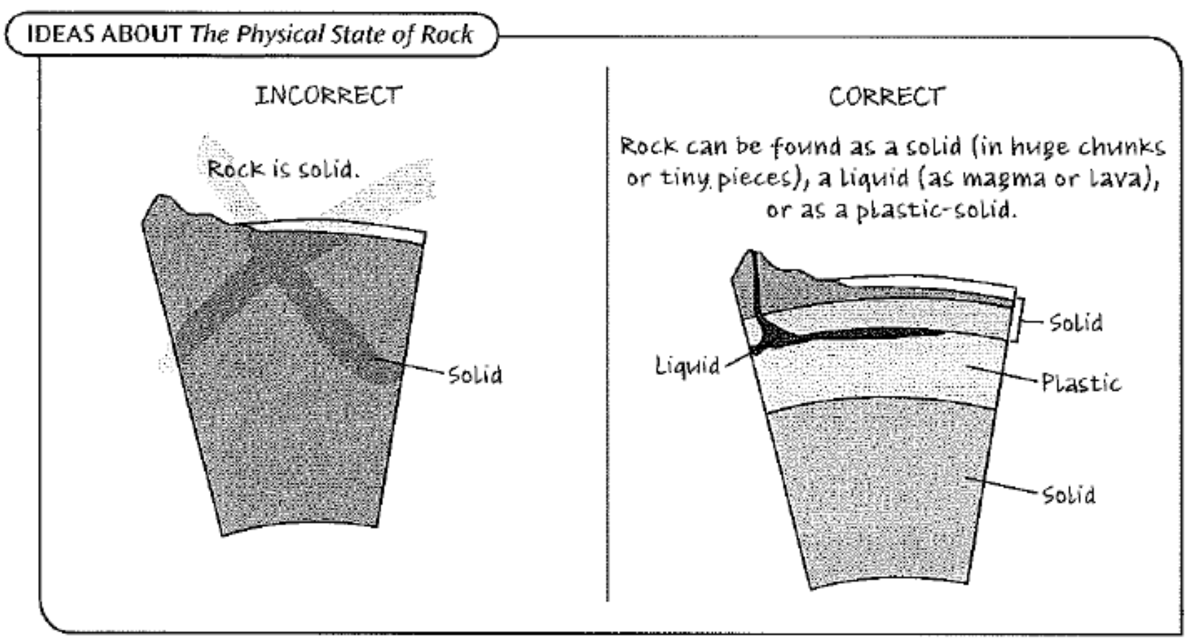


Figure 11: The Earth system has rocks in the solid, liquid and plastic states. (Illustration from Making Sense of Science *Earth Systems* course, courtesy of WestEd)

Many of the changes that happen to the geosphere (Earth's nonliving solid material excluding ice) are due to movement of tectonic plates. As the plates push together, spread apart, and slide against one another, a variety of geologic processes occur including earthquakes, volcanic activity, mountain building, seafloor spreading, and subduction (sinking of a plate into the underlying mantle). All of these geoscience processes change Earth's rock – some form new rock, and others break down existing rock.

Earth's rock is also formed and broken down by interacting with other Earth systems – namely, the atmosphere, hydrosphere (Earth's water including ice) and biosphere (Earth's life). For example, exposure to air, wind, and biological activity all ***cause*** *rock* to weather (change physically or chemically). Chemical weathering by the atmosphere, hydrosphere and biosphere occurs when chemical reactions break down the chemical bonds that hold rocks together. Physical weathering causes rocks to physically break into smaller pieces but does not change the rock's chemical bonds.

Classic Rock Cycle Diagram

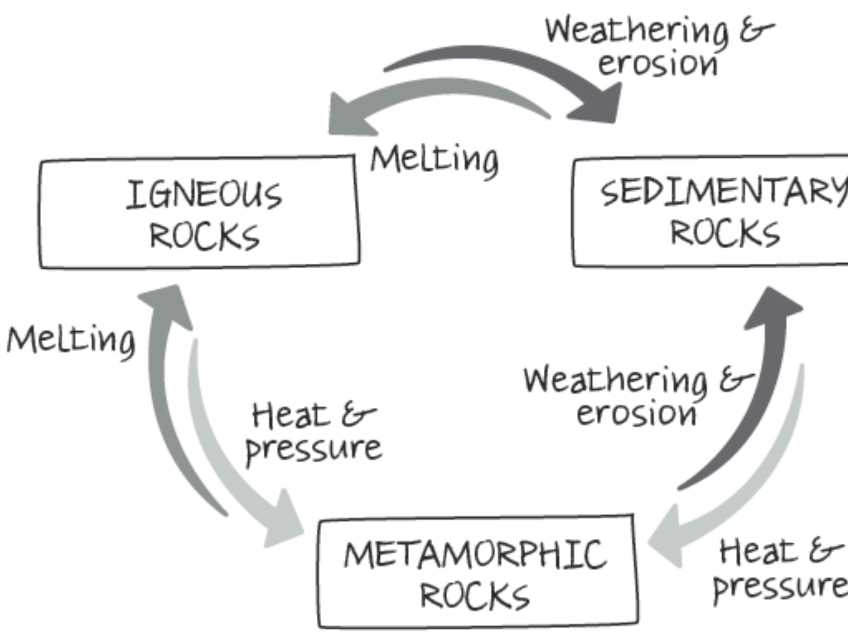


Figure 12: The classic rock cycle diagram summarizes the three types of rocks and a circular pattern of movements of rock materials. (Illustration from Making Sense of Science *Earth Systems* course, courtesy of WestEd)

The atmosphere, hydrosphere, and biosphere also cause rock to erode – that is, move from one place to another. Erosion is a physical change caused by the force of moving water, moving glaciers, moving air, and moving organisms. Gravity also plays an important role in erosion. The constant pull of gravity causes rocks to fall from mountains and sand to settle in the bottom of oceans.

These physical and chemical transformations of rock are often summarized as the rock cycle. Figure 12 shows a classic rock cycle diagram with the three major rock types of igneous (melted in Earth's interior), sedimentary (compacted from broken pieces), and metamorphic (rearranged by Earth's internal pressure and thermal energy).

TABLE 8: Benefits and Limitations of Classic Rock Cycle Diagram

Benefits	Limitations
Good summary of key geosphere interactions.	Does not show the many interactions the geosphere has with other Earth systems.
Easy to read and understand.	Does not show the timeframe for each geologic process, implying that they have similar timeframes.
Shows how each type of rock can become the other types of rock.	Does not show the locations where each geologic process takes place.
Helps dispel the incorrect idea that rock is "steady as a rock" and never changes.	Suggests that rock never leaves the rock cycle. Yet rocks often do leave the rock cycle, such as when they are incorporated into organisms, other Earth systems, and human-made materials.

(Table based on Making Sense of Science *Land and Water* course, courtesy of WestEd)

Students can **evaluate** the benefits and limitations of this classic rock cycle diagram by referencing and discussing the information in Table 8. Students can also research the excellent rock cycle website from the Geological Society in Britain, at: http://www.geolsoc.org.uk/ks3/gsl/education/resources/rockcycle.html. Like most models, the classic rock cycle diagram has inaccuracies and can foster misconceptions. Students can mistakenly surmise that every rock has experienced or will experience the same cycle. However, rock does not move through the "rock cycle" in a specific order, like a product on a conveyor belt moving through a factory. The British rock cycle website is a very useful resource for students, who could then **gather, evaluate and**

communicate information about California examples of the British rocks and landforms cited in the website.

The physical and chemical changes that happen to minerals and rocks reinforce the principle of the conservation of matter. Almost three-quarters of Earth’s crust is made of oxygen and silicon. Just six elements (aluminum, iron, magnesium, calcium, sodium, and potassium) make up practically all the rest of Earth’s crust Atoms of these eight elements combine to form Earth’s rocks and minerals. Throughout all the physical and chemical interactions, none of these atoms are lost or destroyed. The changes that happen to matter in rock material exemplify the principle of conservation of matter.

Table 9 - Grade 7 - Instructional Segment 3

Natural Processes and Human Activities Shape Earth's Resources and Ecosystems

Guiding Questions:

What processes have shaped the distribution of Earth's resources and ecosystems?

How do organisms in ecosystems interact with each other?

How do organisms in ecosystems interact with the physical environment?

What patterns of interactions are common across different ecosystems?

Highlighted Scientific and Engineering Practices

Analyzing and Interpreting Data

Constructing Explanations

Developing and Using Models

Highlighted Crosscutting concepts

Energy and Matter: Flows, Cycles and Conservation

Cause and Effect; Mechanism and Prediction

Systems and System Models

Performance expectations associated with this Instructional Segment:

MS-LS2-1. **Analyze and interpret data to provide evidence for the effects of resource availability on organisms and populations of organisms in an ecosystem.** [Clarification Statement: Emphasis is on cause and effect relationships between resources and growth of individual organisms and the numbers of organisms in ecosystems during periods of abundant and scarce resources.]

MS-LS2-2. **Construct an explanation that predicts patterns of interactions among organisms across multiple ecosystems.** [Clarification Statement: Emphasis is on predicting consistent patterns of interactions in different ecosystems in terms of the relationships among and between organisms and abiotic components of ecosystems. Examples of types of interactions could include competitive, predatory, and mutually beneficial.]

MS-LS2-3. **Develop a model to describe the cycling of matter and flow of energy among living and nonliving parts of an ecosystem.** [Clarification Statement: Emphasis is on describing the conservation of matter and flow of energy into and out of various ecosystems, and on defining the boundaries of the system.] [Assessment Boundary: Assessment does not include the use of chemical reactions to describe the processes.]

MS-ESS2-3. **Analyze and interpret data on the distribution of fossils and rocks, continental shapes, and seafloor structures to provide evidence of the past plate motions.** [Clarification Statement: Examples of data include similarities of rock and fossil types on different continents, the shapes of the continents (including continental shelves), and the locations of ocean structures (such as ridges, fracture zones, and trenches).] [Assessment Boundary: Paleomagnetic anomalies in oceanic and continental crust are not assessed.]

MS-ESS3-1. **Construct a scientific explanation based on evidence for how the uneven distributions of Earth's mineral, energy, and groundwater resources are the result of past and current geoscience processes.** [Clarification Statement: Emphasis is on how these resources are limited and typically non-renewable, and how their distributions are significantly changing as a result of removal by humans. Examples of uneven distributions of resources as a result of past processes include but are not limited to petroleum (locations of the burial of organic marine sediments and subsequent geologic traps), metal ores (locations of past volcanic and hydrothermal activity associated with subduction zones), and soil (locations of active weathering and/or deposition of rock).]

MS-PS1-2. **Analyze and interpret data on the properties of substances before and after the substances interact to determine if a chemical reaction has occurred.** [Clarification Statement: Examples of reactions could include burning sugar or steel wool, fat reacting with sodium hydroxide, and mixing zinc with hydrogen chloride.] [Assessment Boundary: Assessment is limited to analysis of the following properties: density, melting point, boiling point, solubility, flammability, and odor.]

MS-PS1-5. **Develop and use a model to describe how the total number of atoms does not change in a chemical reaction and thus mass is conserved.** [Clarification Statement: Emphasis is on law of conservation of matter and on physical models or drawings, including digital forms that represent atoms.] [Assessment Boundary: Assessment does not include the use of atomic masses, balancing symbolic equations, or intermolecular forces.]

Connections to the CA Environmental Principles and Concepts:

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

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

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

Instructional Segment 3 Teacher Background and Instructional Suggestions:

In the early 1900's, Alfred Wegener, a German meteorologist, proposed that all of Earth's continents had been connected together millions of years ago and subsequently moved to their current locations. His theory, known as "Continental Drift," was based on substantial evidence.

Fossil Evidence of Continental Drift

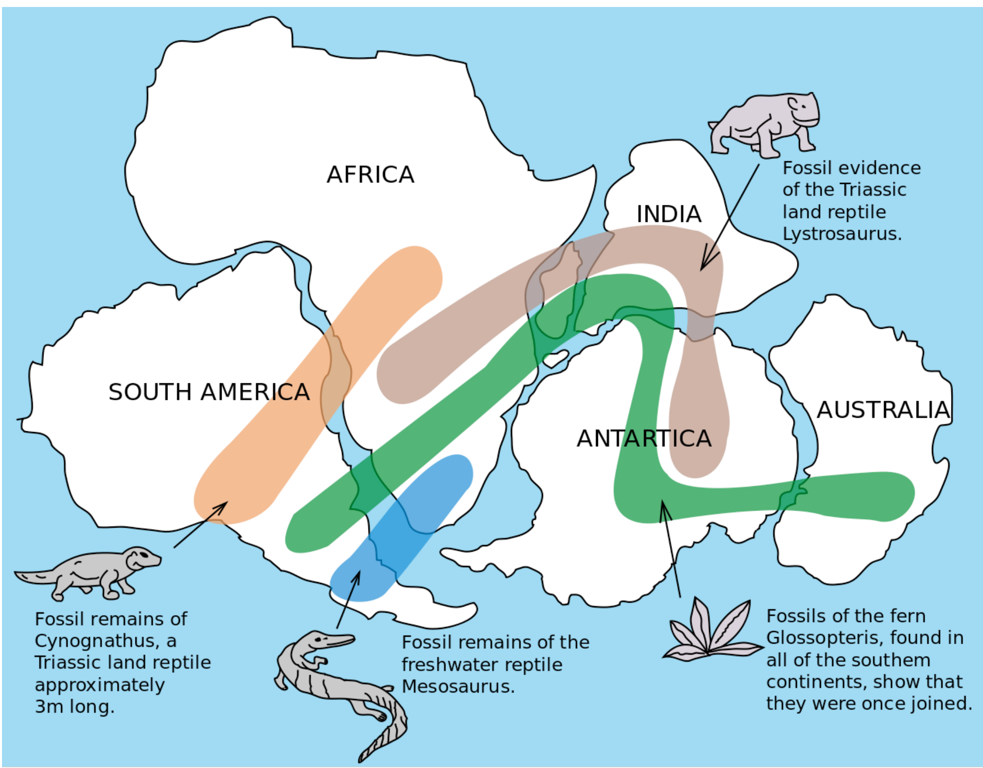


Figure 13: A summary of Wegener's fossil evidence that Southern Hemisphere continents were once joined together. (Wikibooks 2015)

Some of this evidence came from using maps to show how well the continents fit together, especially including the submerged continental shelves in aligning the continents, and most obviously with South America and Africa (Figure 13). Fossils and rocks provided even more persuasive evidence. Using source information such as

Figure 13, students can make jig-saw type **models** that include coding of different fossil locations, and then challenge each other to assemble a map that shows how the continents were connected in a large land mass before they moved apart. They can then **explain** using evidence that the overlap of fossil locations help indicate not only that these continents were joined together, but also specifically that the connection points match those predicted by matching the outlines of the continents. Their **explanation** should include that there is no other plausible mechanism to account for the existence of these same fossil types in such widely separated locations.

Wegener also traced the past positions and motions of ancient glaciers based on grooves cut by those glaciers in rocks, and also by rock deposits that the glaciers left on different continents. His evidence indicated that if the continents had been in their current locations, the glaciers would have formed very close to the equator, an extremely unlikely situation. If the continents moved as he hypothesized, those glaciers would have formed much closer to the South Pole.

Despite the evidence that he compiled, Wegener's theory was not accepted and was generally forgotten. While Wegener was using traditional Science Practices of **analyzing data and constructing explanations** based on evidence, the other geologists were viewing his claims through the lens of the crosscutting concept of ***cause and effect: mechanism and explanation***." Wegener could not propose any possible mechanism that would cause continents to plow through the ocean over great distances. In the absence of a mechanism to cause the proposed movements of continents, the geologists of his time rejected Wegener's claims.

Technological developments approximately 50 years later resulted in new information that supported Wegener's claims and also provided the missing mechanism. Results from submarine explorations revealed that the largest mountain ranges actually exist below the ocean. For example, the Mid-Atlantic Ridge rises about 3 km in height above the ocean floor and has a length of about 10,000 km running from a few degrees south of the North Pole to an island at a latitude of 54^0S. Even more profound was the discovery that the ocean floor is actually spreading from these mid-ocean ridges causing the ocean to grow in size. The spreading sea floor and increasing ocean size made it easier to understand a cause and effect mechanism that resulted in continents moving away from each other.

Two Perspectives of Earth's Layers

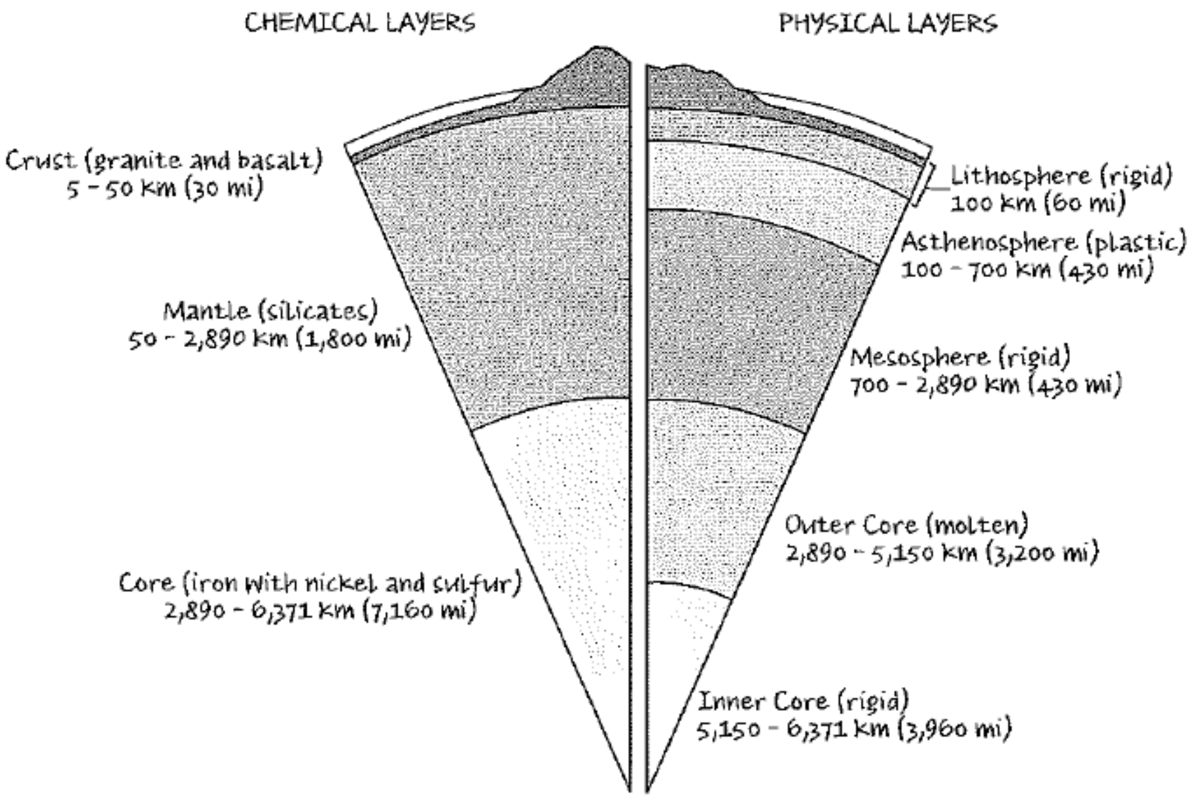


Figure 14: Two complementary models of Earth's layers juxtaposed next to each other. (Illustration from Making Sense of Science *Earth Systems* course, courtesy of WestEd)

These and other discoveries provided critical evidence leading to today's well-accepted theory of plate tectonics. Wegener's continental drift theory can be viewed as a precursor to plate tectonics, which is a much more complete and robust explanation. Plate tectonics is best viewed in conjunction with a description of our planet's layered structure. As shown in Figure 14, geoscientists describe Earth's layers from two perspectives. The more familiar perspective of Earth having three main layers (crust, mantle and core) is based on chemical composition. The crust and mantle are both mostly silicate rock, but the mantle rock has more magnesium and iron. In contrast, the core is made mostly of iron and some nickel.

The other perspective of Earth's layers is based on physical properties. The outermost layer, called the lithosphere, consists of the crust and the topmost portion of the mantle. Its physical characteristics are that it is hard and rigid, and somewhat elastic but brittle. Movements of the lithosphere often result in fractures or faults. Earth's lithosphere is divided into huge chunks, and each of those chunks is a tectonic plate. Plates can include both oceans and continents, or more specifically oceanic crust (denser) and continental crust (less dense). Continents are the uppermost parts of plates, so if a plate is moving, then the continent simply moves along with the plate as a whole and does not have to plow through the oceans.

Directly below the rigid lithosphere, the asthenosphere is the semi-plastic, bendable and "flowable" layer of the mantle. Its plasticity helps cause the plate movements. The other three physical layers (the lower rigid part of the mantle, the liquid outer core and the solid inner core) do not play such direct causal roles in plate tectonics.
At their boundaries, plates bang into, dive under, split further apart, or slide along each other (like the San Andreas Fault in California). The highest continental mountain range, the Himalayas, results from the collision of two continental plates. All these movements can ***cause*** earthquakes, and as a result, plate boundaries have the most earthquakes and volcanoes.

Volcanoes emit lava and build mountains at locations where plates diverge, such as the mid-ocean ridges, and also where the less dense oceanic plate subducts (dives under) other crust, usually continental. The South American Andes and the North American west coast Cascades are continental examples of a volcanic mountain range resulting from an oceanic plate subducting under a continental plate (Figure 15).

Example of Subduction

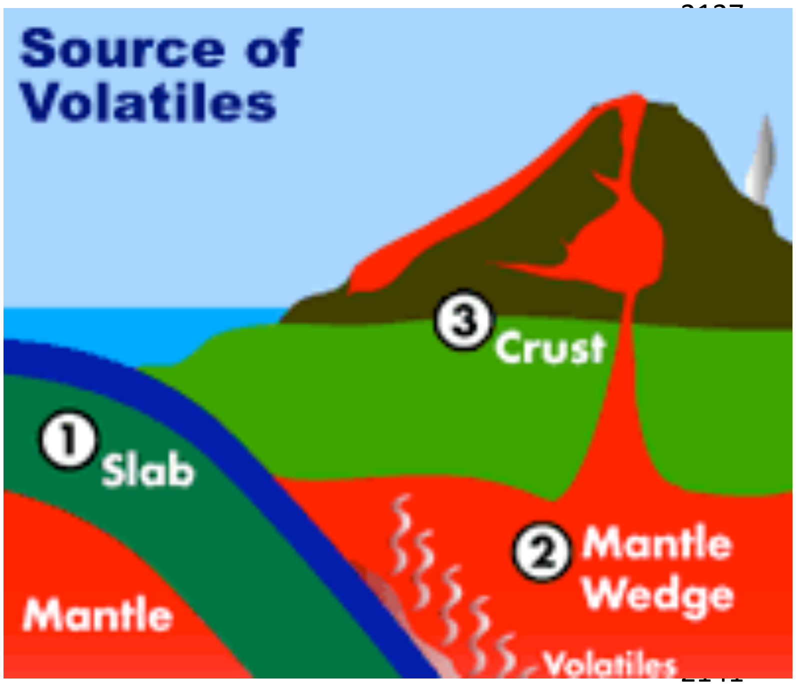


Figure 15: Subduction of an oceanic plate under a continental plate can result in volcanic coastal mountains such as the Cascade mountain range. (Illustration from *"Volcano Expedition" website of Scripps Institute of Oceanography at* http://ucsdnews.ucsd.edu/archive/newsrel/science/Hilton%20Science%20Volcano.htm

Students can create a digital or physical **model** of an oceanic plate subducting under a continental plate, and resulting in a volcanic mountain. In Figure 15 the darker green represents a slab of subducting marine crust (labeled number 1). This marine crust slab includes sediments (dark blue) that have lots of water and carbonates. Chemical reactions break down the carbonates and release carbon dioxide. These sediments are particularly volatile, and they release steam and carbon dioxide as they contact the very hot mantle that is wedged between the subducting marine crust and the more dense oceanic crust (lighter green). This mantle wedge itself also releases volatiles (labeled number 2). The rising melted rock can also create more steam and carbon dioxide to form in the oceanic crust (labeled number 3). The result can be an explosive or slow release of lava, either building a mountain or blowing its top off. Some of the same processes happen when marine crust subducts in ocean trenches, such as the famous Mariana Trench.

In high school Earth science, students delve deeper into the evidence and mechanisms of plate tectonics. The middle school introduction to plate tectonics provides background that helps **explain** many of Earth's landscape features. The forces of weathering and erosion would make Earth very flat, and it is plate tectonics that ***results*** in the continuing creation and existence of beautiful mountains that play important roles in biology, climate and human cultures.

Plate tectonics is also one of the geoscience processes that play an important role in the uneven distribution of Earth's natural resources (performance expectation MS-ESS3-1). This performance expectation very broadly addresses Earth's mineral, energy and groundwater resources. Each of those three categories (minerals, energy, groundwater) can provide multiple examples. From an instructional perspective, each category provides opportunities for students to engage with the science and engineering practices to pose questions, gather information, develop and use models, analyze and interpret data, use mathematical and computational thinking, construct explanations, argue from evidence, and communicate information.

With respect to energy resources, plate tectonics is most directly involved with geothermal sources. The thermal energy at plate boundaries can be used to generate electricity and as a source of energy for heating buildings and commercial purposes. Volcanic and uplift processes can bring important minerals on or near the surface where they can be profitably mined. For example, most copper mines are located near plate boundaries. The prospector's shout that "there's gold in them thar hills" directly connects gold distribution with the plate tectonics that created them thar hills.

Fossil fuel distribution is one the most politically important uneven distributions of natural resources. The Middle East has about 2/3 of the world's proven reserves of crude oil. Petroleum and natural gas are generally associated with sedimentary rocks. These fuels formed from soft-bodied sea organisms whose remains sank to the ocean floor, decomposed in the relative absence of air, and were further transformed by heat and pressure deep underground.

Coal, the most abundant fossil fuel, was created 300 to 400 million years ago during the Carboniferous period that had a generally warm and humid climate. Tropical swamp forests of Europe and North America provided much of the organic material that was buried and compressed in sediments to form coal. Locations, such as today's Appalachian Mountain region, that supported these Carboniferous swamp forests have more of the unevenly distributed coal.

The distribution of groundwater is most directly related to the amount of precipitation and to the permeability of the soil and rocks. Groundwater is not like an underground lake or river. Instead groundwater is simply the water under the surface that can fully saturate pores or cracks in soils and rocks. Sedimentary rocks such as sandstone tend to hold more water. Groundwater needs to be replenished since it can be depleted by plants, evaporation and human uses. The uneven distribution of groundwater strongly correlates with the regional latitude and geographic conditions that determine the amount of precipitation.

Water and other natural resources provide a strong link with the Instructional Segment 3 life science ecosystem performance expectations and disciplinary core ideas. MS-LS2-3, one of the central Instructional Segment 3 performance expectations, states, "**Develop a model** to describe the ***cycling of matter and flow of energy*** among living and nonliving parts of an ecosystem." Student teams have been gathering **information** about cycles of matter and flows of energy from the perspectives of organisms and of ecosystems. Using environment diagrams, they have shared their ideas and evidence, and are now primed to create more complex models that address this performance expectation.

Figure 16 illustrates some of the instructional issues that arise in this modeling. The model needs to identify forms of matter that are biomass. The biomass molecules have the complex carbon molecules that organisms can use as building blocks to manufacture, replace, and repair their internal structures. The biomass molecules also have significant stored chemical potential energy that organisms can use in their biological activities and processes. In the Figure 16 model, a black arrow with a reddish interior signifies the coupling of biologically useable matter and energy in the form of biomass, and the transfer of that coupled matter and energy through the eating of food. Simple black arrows represent transfers of matter that are not biomass, and that cannot provide calories to organisms. Examples are water, carbon dioxide, and the simple minerals that decomposers such as microorganisms release to the soil. Note that this model uses these simple black arrows to represent the respiration flows of carbon dioxide out of plants and animals back into the local environment. These black arrows help to emphasize the recycling of carbon atoms.

Ecosystem Cycles of Matter and Flows of Energy

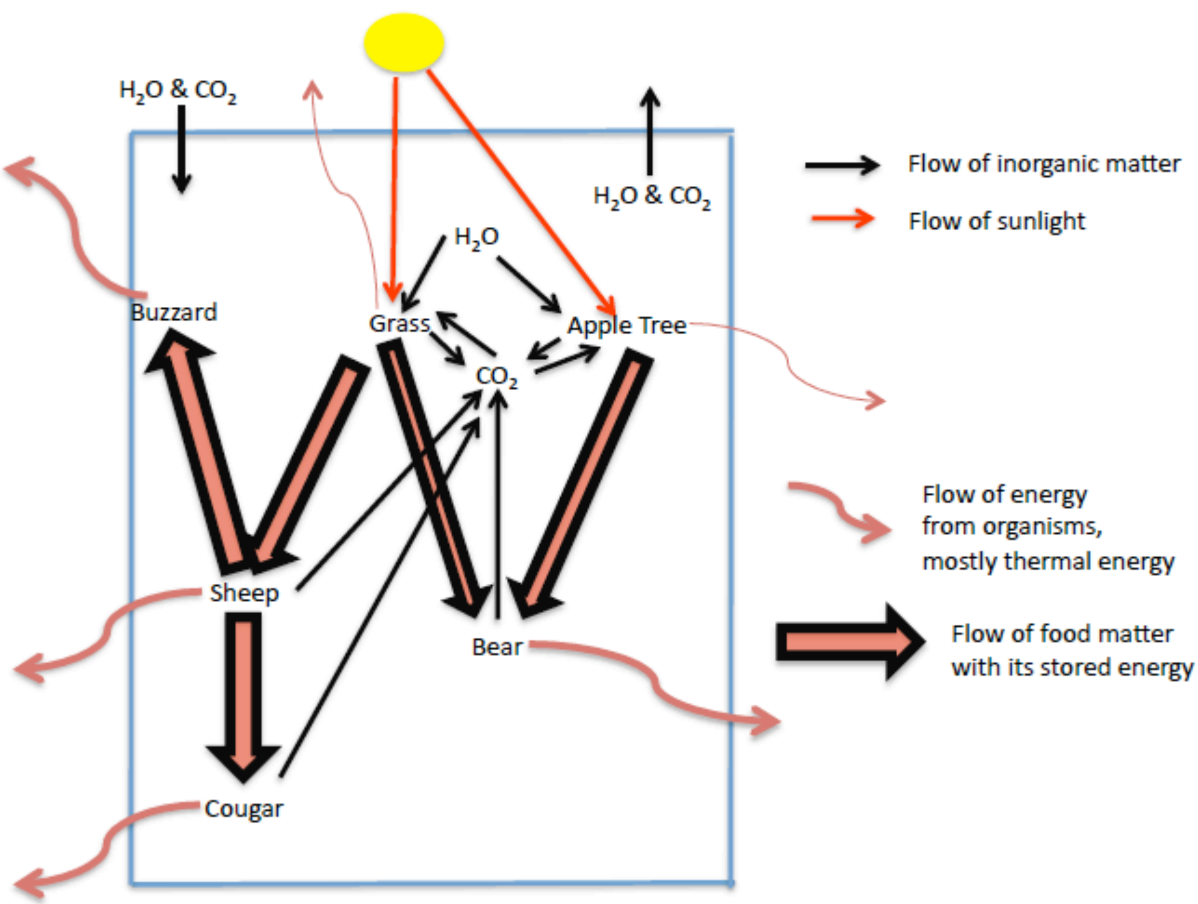


Figure 16: A model of the flows of energy and matter into, within and out of a simplified ecosystem. The wider arrows represent transfers of matter and energy coupled together in biomass. (Illustration from Dr. Art Sussman, courtesy of WestEd)

Similarly, the model needs to distinguish between different ***flows of energy***. The straight red arrows represent the input of sunlight energy via photosynthesis. Producers transform the input energy and matter into biomass (food). This biomass is then available to the producers themselves and all the consumers, and they release and obtain that energy via respiration. The pinkish interior of the food arrows represents the transfer of the biomass chemical potential energy.

The wavy red arrows represent the dissipation of much of the biomass energy that inevitably transfers to “waste heat” that escapes and leaves the system. Everything that an organism does dissipates some form of energy out of the system. The plants have the most food energy available to build their bodies. The herbivores have significantly less food energy available to them, and the carnivores have much less than the herbivores. One important result of this dissipation is the “energy pyramid,” a common graphic representation that the amount of biomass decreases markedly at each step going from producers to primary consumers to higher-level consumers and to decomposers.

A model such as Figure 16 can become much more complex if the developer of the model chooses to increase the kinds of ***flows of matter and energy*** and/or the number and types of organisms that are included. This complexity can pose a problem, but it can also provide great learning opportunities in situations where productive academic discourse flourishes.

Students should be **asking** themselves and their peers about which features are important to display in the model and why? The crosscutting concept of ***system models*** teaches that, “Models are limited in that they only represent certain aspects of the system under study.” The students get to choose what features to include, but they need to provide **evidence-based explanations** for why they have included those features. A necessary part of gaining proficiency in the science and engineering practice of **developing and using models** involves learning to wisely choose and omit features in order to hit the sweet spot of detail complexity.
One criterion for evaluating a **model** representing “ecosystem cycles of matter and flows of energy” is whether it helps distinguish why we use that phrase instead of “cycles of energy and flows of matter.” Figure 16 clearly has many more energy arrows going into and out of the system (flowing) compared with the preponderance of matter

arrows that remain within the system (cycle). This particular model includes two black arrows to indicate that no ecosystem is a closed system for matter. There are flows of matter, such as carbon dioxide and water in the air, that move into and out of ecosystems. Was that too much detail or still within the sweet spot of complexity? It depends on the goals of the modeler and on the nature of the audience.

Instructional Segment 3 performance expectations MS-LS2-1 and MS-LS2-2 introduce phenomena related to the ways that ecosystem populations change and the ***patterns*** of organism interactions across ecosystems. For these phenomena, would it be better to use a model like Figure 16 or a more traditional food web model? Students can evaluate and compare types of models, and discuss the advantages and disadvantages of each. Ideally, they would design and then use and refine their own models to help understand and explain these phenomena.

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Table 10: Grade 7 Instructional Segment 4

Sustaining Biodiversity and Ecosystem Services in a Changing World

Guiding Questions:

What services do ecosystems provide?

What is biodiversity and why is it important?

What natural processes and human activities threaten biodiversity and ecosystem services?

How can people help sustain biodiversity and ecosystem services in a changing world?

Science and Engineering Practices:

Obtaining, Evaluating and Communicating Information

Constructing Explanations and Designing Solutions

Engaging in Argument from Evidence

Crosscutting concept:

Stability and Change

Connections to Engineering, Technology and Applications of Science

Stability and Change Cause and Effect: Mechanism and Explanation

MS-LS2-4. **Construct an argument supported by empirical evidence that changes to physical or biological components of an ecosystem affect populations.** [Clarification Statement: Emphasis is on recognizing patterns in data and making warranted inferences about changes in populations, and on evaluating empirical evidence supporting arguments about changes to ecosystems.]

MS-LS2-5. **Evaluate competing design solutions for maintaining biodiversity and ecosystem services.*** [Clarification Statement: Examples of ecosystem services could include water purification, nutrient recycling, and prevention of soil erosion. Examples of design solution constraints could include scientific, economic, and social considerations.]

MS-ESS2-2. Construct an explanation based on evidence for how geoscience processes have changed Earth's surface at varying time and spatial scales. [Clarification Statement: Emphasis is on how processes change Earth's surface at time and spatial scales that can be large (such as slow plate motions or the uplift of large mountain ranges) or small (such as rapid landslides or microscopic geochemical reactions), and how many geoscience processes (such as earthquakes, volcanoes, and meteor impacts) usually behave gradually but are punctuated by catastrophic events. Examples of geoscience processes include surface weathering and deposition by the movements of water, ice, and wind. Emphasis is on geoscience processes that shape local geographic features, where appropriate.]

MS-ESS3-2. Analyze and interpret data on natural hazards to forecast future catastrophic events and inform the development of technologies to mitigate their effects. [Clarification Statement: Emphasis is on how some natural hazards, such as volcanic eruptions and severe weather, are preceded by phenomena that allow for reliable predictions, but others, such as earthquakes, occur suddenly and with no notice, and thus are not yet predictable. Examples of natural hazards can be taken from interior processes (such as earthquakes and volcanic eruptions), surface processes (such as mass wasting and tsunamis), or severe weather events (such as hurricanes, tornadoes, and floods). Examples of data can include the locations, magnitudes, and frequencies of the natural hazards. Examples of technologies can be global (such as satellite systems to monitor hurricanes or forest fires) or local (such as building basements in tornado-prone regions or reservoirs to mitigate droughts).]

MS-PS1-3. Gather and make sense of information to describe that synthetic materials come from natural resources and impact society. [Clarification Statement: Emphasis is on natural resources that undergo a chemical process to form the synthetic material. Examples of new materials could include new medicine, foods, and alternative fuels.] [Assessment Boundary: Assessment is limited to qualitative information.]

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.

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.

Grade 7 Instructional Segment 4 Vignette:

Ecosystems Services and Biodiversity in California Ecosystems

The vignette presents an example of how teaching and learning may look in a 7th-Grade 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.

The vignette focuses on only a limited number of performance expectations. It should not be viewed as showing all instruction necessary to prepare students to fully achieve these performance expectations or complete the instructional segment. Neither does it indicate that the performance expectations should be taught one at a time.

The vignette uses specific classroom contexts and themes, but it is not meant to imply that this is the only way or the best way in which students are able to achieve the indicated performance expectations. Rather, the vignette highlights examples of teaching strategies, organization of the lesson structure, and possible students' responses. Also, science instruction should take into account that student understanding builds over time and that some topics or ideas require activating prior knowledge and extend that knowledge by revisiting it throughout the course of a year. In the first series of lessons, Mr. R. has chosen to focus on:

- the "ecosystems services" that sustain an ecosystem and help humans;
- how changes to physical and biological components of ecosystems affect populations and thereby influence biodiversity; and
- how people can design solutions to help maintain biodiversity and reduce the damaging impacts of human activities on ecosystems.

Mr. R has decided to begin this instructional segment with materials from a California EEI Curriculum unit, *Responding to Environmental Change*, and three EEI maps: *Natural Regions, Political,* and *Biological Diversity*.

The day after students had visited a local nature center, they discussed in teams the ecosystems that they had seen. These had included a wetland, a grassy meadow, a river, and a forested area. For each ecosystem, they listed the plants and animals they had seen.

After sharing their lists as part of a whole class discussion, several students mentioned that the part of the visit they most enjoyed was learning about the "natural processes" (e.g., carbon, nitrogen, oxygen, and water cycles) that are important to the functioning of these ecosystems. Other students said that they hadn't previously been aware of the idea of "ecosystem services," which they had learned about from the naturalist. They had not considered pollination, decomposition, or erosion control as a service from the ecosystem that directly benefits humans. Mr. R posted in their Word Chart area the definition from the EEI Curriculum, "Ecosystems services: The functions and processes that occur in natural systems, such as pollination, that support or produce ecosystem goods and help sustain human life, economies, and cultures."

Following the discussion of ecosystem services, another team began expressing their concerns about the health of these ecosystems. Their naturalist guide had taken them to visit areas at the site where they saw signs of human activities. They had also briefly discussed both the ***causes and effects***, including: a road by the side of the wetland that seemed to have caused erosion; and another location which it seemed that local people were using as a dump. One student put these ideas together and predicted that if people change an ecosystem, then some of the ecosystem services might be lost. Several students reminded the class that the naturalist had also pointed out some areas where habitat was being restored to more “natural” conditions.

Many students began to talk about working on a habitat restoration project. Mr. R explained that to be effective with habitat restoration they needed to learn more about the ecosystems. He asked the class, “How would we begin a scientific study of our local ecosystems so we learn enough to work on a restoration?” Students responded that the best way to begin an investigation was to **ask scientific questions**. Following up on these comments, students began writing questions about local ecosystems at the nature center or that they had experienced in other ways. Soon the teams had numerous questions to share so they began posting them on their team flipcharts. While the teams were writing their questions, Mr. R visited and guided their discussions, as needed.

With all the questions posted, Mr. R asked the students if they noticed any ***patterns*** among the questions. Several pointed out that some of the questions seemed to focus on the plants and animals, and others were more focused on things like the soil, rocks, water, and other parts of the physical surroundings. Mr. R asked the students to return to their flipcharts and put a big P next to questions that involved physical components and a big B next those that involved the biological components of ecosystems.

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

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

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

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

Mr. R. posted both the *Natural Regions* map and the *Political* map side-by-side on the wall. A student put a pin at the school's location on the *Political* map. Another student then put a pin at the location of the school on the *Natural Regions* map. Using the map key, the students determined in which natural region their school is located. Another student identified some of the plants and animals found in their region. Students eagerly shared names of plants and animals that they had seen that matched what the map indicated.

The students asked Mr. R if he could arrange for the class to conduct their investigation at the nearby nature center so that they could visit it with enough time to collect all the data they wanted and eventually develop their own habitat restoration project. They knew that Mr. R had a close relationship with the staff of the nature center. He knew that the nature center director wanted to get more involved with schools and the community. When he shared the scientific questions that the students had developed and were seeking to answer during their investigation, the nature center director agreed to allow the class to work there and even offered to support the students with some of his staff and resource materials.

Mr. R recognized during the class discussions that the students needed to have a deeper understanding of how changes to the physical and biological components of an ecosystem can affect populations. Some students were not familiar with that term, so one student posted a definition: “Population: The number of individuals of a species in an area.”

Mr. R organized a lesson about “*The Coyote Success Story*” from the EEI *Responding to Environmental Change* curriculum unit. After distributing copies of the informational text, Mr. R explained that, while reading, the students should highlight examples of changes to the physical and biological components of the coyote’s environment and identify how the coyotes’ population changed in response. He also asked them to think about what happened to other species in these ecosystems.

Once they finished reading, the students reported what they had learned. For example, some students mentioned that coyotes: are related to wolves and foxes; are some of the most adaptable mammals in North America; live in residential neighborhoods, outskirts of cities, and rural areas; coyote populations boomed when the human population boomed after World War II. Others pointed out that, as a result of human activities, there have been many changes to the ecosystems where coyotes and other animals live. One student mentioned that he had noticed an example of an ecosystem service that the coyotes provide humans—they kill rodents and they control the population of smaller predators.

Mr. R had selected the story about coyotes because he wanted to challenge the students' thinking, helping them realize that not all changes to ecosystems are detrimental to all species and populations. In order to help students recognize this idea, he challenged them with two questions first, "How and why did the coyote population change in response to the effects of human activities on their ecosystems?" (The coyote population increased because they can eat many different kinds of foods and they can survive in a wide variety of ecosystems.) Secondly, he asked, "How and why did the population of other species in these ecosystems change in comparison to coyotes?" (The population of some other species decreased because they could not survive the effects of human development.)

The following day, Mr. R started a class discussion by asking students to think about the types of data they would need to answer the questions they developed the previous day. The students regrouped into their teams and began a discussion. Following the discussion, each team reported their ideas and Mr. R recorded them on a flipchart. There were many interesting ideas shared by the teams, but before asking them to vote on which data to collect, Mr. R reminded them that they should focus on collecting data that would help them answer their questions. He also, mentioned that there was limited time for the study and they should be realistic about what information they could gather.

Once the students decided on the data they needed to gather they summarized their plans for collecting data at both the disturbed and undisturbed study sites as follows:

- one-half of the students spending the morning gathering data in the undisturbed study site and the other half at the disturbed site, then trading off in the afternoon;
- using a form based on the nature center's drawings and checklists of plants and animals, and adding a column for the number of each plant and animal they observed; and,
- creating two simple data sheets with two columns each for collecting data on each study site, with space for gathering the specific information needed. Including some sample answers (Figure 17)

Sample Data Sheets

Undisturbed Ecosystem

Biological Components Observed Trees, shrubs, vines, grasses, worms, insects, six species of birds, two species of mammals, nests, animal burrows, decomposing tree trunks, etc.	**Physical Components Observed** Clear water in the creek, water flowing in the creek, sunlight, rocks, soil, sand, shady areas, etc.
Natural Processes Water flowing through the area as part of the water cycle Trees and small plants gathering sunlight and producing nutrients for animals	**Ecosystem Services** Bees pollinating plants Grasses and trees holding the soil and stopping erosion Predators controlling the population of mice Water purification Decomposition and recycling of nutrients
Human Activities Hiking Bird watching Picnicking	**Effects on the Ecosystem** Hiking path caused erosion Holes from signs along the trail Litter and waste bins

Disturbed Ecosystem

Biological Components Observed Grasses, worms, insects, one species of birds, one species of mammals, animal burrows, decomposing tree trunks, etc.	**Physical Components Observed** Muddy water in the pond, dry creek bed, sunlight, rocks, soil, eroded hillside, large sandy area, etc.
Natural Processes Water flowing through the area as part of the water cycle Small plants gathering sunlight and producing nutrients for animals	**Ecosystem Services** Bees pollinating plants Grasses holding the soil and stopping erosion Decomposition
Human Activities Building a dirt road through the area Cutting of most trees Dumping of waste and littering	**Effects on the Ecosystem** Erosion along the road Hot and sunny in most of the area Few trees Very few animal homes Accumulating litter

Figure 17: Sample data sheets based on undisturbed and disturbed ecosystems. (Courtesy of Dr. Gerald Lieberman)

Prior to the visit to the nature center Mr. R and the center staff reviewed the students' data collection questions and recording instruments. He asked the staff to identify two examples of a particular ecosystem, one relatively undisturbed and another substantially disturbed by human activities. The staff met this criterion by locating two forested areas, one which had not been cut in over 150 years and another that was cut 10 years prior. They designated these sites as the areas where the student teams would focus their investigations.

At the nature center before the teams went out to collect data, the nature center director explained the rules for visiting and conducting their investigations. Parent volunteers and school aids accompanied and assisted each team during their investigations. After the introduction, the “young scientists” broke off into their teams to begin their investigations. Following their naturalist guides, the teams hiked to their assigned locations, carrying their data recording forms, clipboards, paper and writing tools, cameras, and binoculars. The teams had 90 minutes to gather data at their morning study site, making observations, jotting notes on their forms, taking photographs, and drawing maps. When their time in the field was over, the student teams returned to the nature center where they had 30 minutes to finish making notes on their forms. After a lunch break, the teams repeated this process focusing their investigations on the other study site. At the end of the day, with their forms complete for both the disturbed and undisturbed ecosystems, the students returned to school. (Note: Using this team-based data collection strategy resulted in everybody in the class participating in **collecting empirical evidence**. This process gave students of all ability levels an opportunity to make a meaningful contribution to the investigation.)

The following day Mr. R kicked off a class discussion by asking students to share their initial ideas about how the disturbed area compared to the undisturbed study site. They mentioned that the undisturbed area looked healthier than the disturbed area, because in the disturbed area “there were fewer plants and animals,” “the water in the pond was muddier,” “weeds were more common,” “soil had eroded at the side of the road,” and “it was hotter because so many trees had been cut down.”

Mr. R took this discussion as an opportunity to focus attention on the crosscutting concept of ***stability and change,*** as well as helping students further develop their understanding of California Environmental Principle IV Concept c, "*the capacity of natural systems to adjust to human-caused alterations depends on the nature of the system as well as the scope, scale, and duration of the activity and the nature of its byproducts*." He decided to use Lesson 5, "*Human-Caused Change in Ecosystems*", from EEI Curriculum unit, *Responding to Environmental Change* to focus the students on this topic. In this lesson students read about three California ecosystems and located them on a *Biological Diversity* map.

Several students mentioned that they didn't understand the term "biodiversity" so Mr. R asked the class to break the word apart. One student guessed that "bio" referred to the word "biology," the study of living things. Another said she was familiar with the term "diversity" and it refers to having many different types in a group like, a classroom with students from many cultures. Mr. R explained that the term "biodiversity" combines these two ideas. He then posted and had one of the students read the definition from the EEI Curriculum, "Biodiversity: A measure of the number of different species of organisms in a specific area."

Students then prepared for playing the *Changes in Ecosystems* board game by reading about several threatened California ecosystems and locating them on the Biodiversity map. Using the informational text, they played and answered questions about how human activities in California ***caused and resulted*** in changes to ecosystems. This provided students the background they needed to **analyze their data** about human activities and prepared them for more in-depth discussions.

Mr. R asked the students to think about how they could **analyze and interpret the data** from their investigation. Several students brought up the idea of using a Venn diagram to compare the data they had collected from the disturbed and undisturbed study sites for each of their five questions. After further class discussion the students designed an analysis tool and then made one for each of the questions (Figure 18).

Venn Diagram Templates

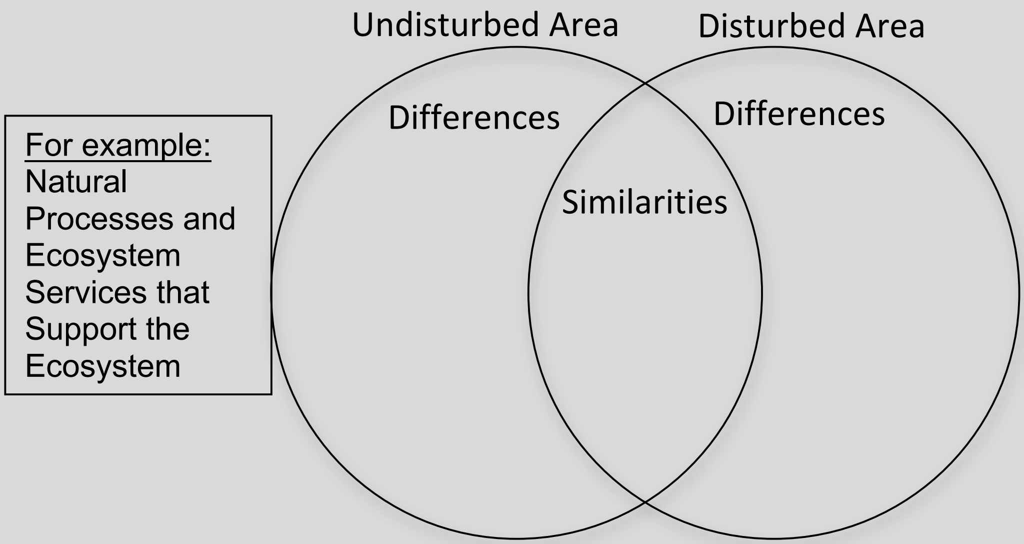

Figure 18: Venn Diagram templates for comparing undisturbed and disturbed areas. (Courtesy of Dr. Gerald Lieberman).

Each student in a team completed the Venn diagram for one of their five original questions. This process resulted in each team having a complete set that they could share and use for further analysis.

During the next class session, Mr. R explained that working in teams they would use their Venn diagrams to compare and **interpret their data** from the disturbed and undisturbed study sites to **provide evidence** related to the following statements:

- some kinds of organisms survive well, some survive less well, and some cannot survive at all after human activities change an ecosystem; and
- changes to ecosystems which affect populations and biodiversity can influence humans' resources, such as food, energy, and medicines, as well as ecosystem services that humans rely on—for example, water purification and recycling.

Each team had a piece of flipchart paper on which to list their evidence and write responses to the statements above. Two of the teams asked to share their evidence and conclusions.

By the end of the team presentations, Mr. R noticed a great deal of excitement among the students. Some mentioned that, having seen the disturbed ecosystem and learned how the disturbance affected the plant and animal populations, they were becoming concerned about how human disturbances affect biodiversity. They wondered out loud if there was anything they could do about this problem. One of the students suggested that they could contact staff at the nature center to find out how they could help. Another student mentioned that her parents were active members of a local conservation group. Yet, another suggested that they could contact the biology department at the local college.

Various students offered to contact individuals from these different groups and organizations. Mr. R suggested that they might want to invite these local experts to come to class and guide the students in identifying a project where they could work together as a class to apply what they had been learning to a local problem, perhaps even the habitat damage they had seen at the nature center.

The following week, representatives from the local natural history museum, nature center, and watershed management agency, arrived at the school to join in a student-led discussion of local biodiversity issues. At first, the students reported to the guests about their observations at the nature center and shared their conclusion. The local experts brought up several similar issues, but mentioned that there were some significant problems in a particular wetland in the nearby San Francisco Bay. Much to Mr. R's surprise, the environmental experts challenged the students to get involved in studying the area and designing solutions for maintaining biodiversity and ecosystem services in this small part of the bay. The students and Mr. R simply couldn't pass up this exciting challenge. By the end of the meeting, working with the local experts the students began identifying next steps. They laid out a simple plan that involved 10 steps:

1. Visit the wetland to learn more about its overall biodiversity, and the plants and animals that live there.
2. Identify the major physical and biological components of the wetland.
3. Describe the natural processes and cycles (***patterns***) that occur in the wetland and the ecosystem services they provide.
4. Determine which of the services support the ecosystem itself and which benefit humans.

5. Investigate the wetland site for signs of human disturbances and determine which were caused by human activities and how those changes influenced the plants and animals living there (***cause and effect***, ***stability and change***).
6. **Define the design problem** associated with maintaining the health of the wetland.
7. **Design engineering solutions** to reduce the problems.
8. **Establish criteria to evaluate competing design solutions** and try to optimize them.
9. Conduct small-scale tests to **evaluate their competing design solutions**.
10. **Analyze and interpret data** from their tests to identify the best characteristics of each proposed solution that can be combined into a new solution to better meet the criteria for success.

Over the next several weeks, with guidance from scientists from the college and nature center the students began implementing their 10-step plan. They visited the wetland on several occasions, following the same data gathering steps they had used when they investigated the ecosystems at the nature center, e.g., identifying the plants and animals, and the major physical and biological components of the ecosystem. The students, with the help of one of the college professors, created a ***system model*** of the wetland which included graphs with population data about locally endangered species and showed connections to the natural processes and cycles that they observed. The model identified ecosystem services as outputs from the wetland and indicated how those services benefited the ecosystem itself and the local community. They used diagrams as part of their systems map to indicate how human disturbances and activities influenced the plants and animals living in the wetland.

Having completed the first five steps of their plan, the students started analyzing their data to answer more of their own questions, including: “What activities were most harmful to the wetland?”, “Which of these activities could they have any control over directly (e.g., pollution from school or home)?”, “Which issues could they only influence indirectly by working with the local community, businesses, and government agencies?”, and ultimately, “How could they make a significant difference and help to sustain the biodiversity and ecosystem services in the wetland?”

They used the results of their analysis to state their design problem, “reduce the effects of human activities on biodiversity and ecosystem services in the wetland.” With this as the focus, they began to design different engineering solutions that would help reduce the effects of human activities at the wetland.

As the students began to consider criteria for evaluating their competing design solutions they discussed several other considerations, including: indicators of success; additional information they needed in order to make wise decisions; how much time it would take to implement their plan; who could help them implement their plans; and, how they could inform their peers and community decision makers about threats to local biodiversity and the importance of the ecosystem services wetland provided to their community.

Ultimately, the students divided themselves into two groups, a “Wetland Teaching Team” (WTT) that wanted to share what they had learned with others and a “Restoration Challenge Team” (RCT) group that wanted to get directly involved with a habitat restoration project in the wetland. Each group wanted to see how effective their plan would be so they developed criteria for measuring their success. The WTT members decided to measure their results by counting the numbers of different audiences that they presented to. The RCT members decided to count the number of wetland plants they were able to plant in a damaged part of the wetland. They planned to compare their results after completing their work in six weeks.

Mr. R offered to act as an advisor to the WTT, but suggested that the RCT might want to ask somebody experienced with restoration work should advise them. His advice to the WTT included presenting their empirical evidence about the changes to physical or biological components of the wetland and how those changes affected populations of plants and animals. The students had already decided to identify, describe, and quantify the human disturbances they had observed in the wetland. Mr. R suggested that they might also want to describe **patterns they found in their data**. The students thought that the audience would need something to take away with them and decided to create an informational brochure about the importance of the wetland to the people and the community.

The WTT developed a three-part presentation about their investigation and conclusions about the wetland work. They asked to make a presentation to the other seventh-grade students at the school and did such a good job that the principal invited them to present at an assembly. One of the student's mothers was on the city council and so the WWT was invited to make a presentation to the council. The interest and excitement about their work grew and they received invitations to speak to the PTA, several local services clubs, and finally at the nature center. By the end of their six-week service-learning project, the WTT had presented to over 650 people including other students and community members.

The RCT contacted one of the scientists who had helped them plan their investigation to guide them with their restoration work. Meeting with their scientific advisor at the wetland site two times allowed the students to develop a specific plan for which species of plants they would use, exactly where they should plant, and how they would care for and monitor their plantings. As they worked through their planning, the students decided on six species of plants that they could readily obtain, plant, and easily care for. The wetland managers identified a 100 square meter area where the RCT could go to do their restoration project. By the end of their six-week restoration project, the RCT had planted over 4,000 young plants, 95% of their plants survived the first heavy storm, convincing the students that their work had, at least initially, been successful.

After seven weeks, when both teams had finished their projects, Mr. R gave them class time to share their results and discuss both their successes and the challenges they had faced. After the students had completed their presentations, he reminded them of the criteria they had established and asked them to think about what they had accomplished. That was when it dawned on the students that both of their projects had been successful; however it wasn't realistic to compare the results of their very distinctive projects.

In subsequent lessons, Mr. R had plans to use similar strategies for active science learning through which his students could further explore the short- and long-term natural processes and human activities that change Earth's surface, as well as how people can predict and mitigate those changes.

NGSS Connections in the Vignette

Performance Expectations
MS-LS2-4. Ecosystems: Interactions, Energy, and Dynamics *Construct an argument supported by empirical evidence that changes to physical or biological components of an ecosystem affect populations.* **MS-LS2-5. Ecosystems: Interactions, Energy, and Dynamics** *Evaluate competing design solutions for maintaining biodiversity and ecosystem services.** **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 solutions.*

Science and engineering practices	Disciplinary core ideas	Crosscutting concepts
Engaging in Argument from Evidence *Construct 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.* *Evaluate competing design solutions based on jointly*	**LS4.C Adaptation** *For any particular environment, some kinds of organisms survive well, some survive less well, and some cannot survive at all.* **LS2.C: Ecosystem Dynamics, Functioning and Resilience** *Biodiversity describes the variety of species found in Earth's terrestrial and*	**Patterns** *Patterns can be used to identify cause-and-effect relationships.* **Cause and Effect** *Cause-and-effect relationships may be used to predict phenomena in natural or designed systems.* **Stability and Change**

developed and agreed-upon design criteria. **Asking Questions and Defining Problems** *Define a design problem that can be solved through the development of an object, tool, process or system and includes multiple criteria and constraints, including scientific knowledge that may limit possible solutions.* **Developing and Using Models** *Develop a model to predict and/or describe phenomena.*	*oceanic ecosystems. The completeness or integrity of an ecosystem's biodiversity is often used as a measure of its health.* **LS4.D: Biodiversity and Humans** *Changes in biodiversity can influence humans' resources, such as food, energy, and medicines, as well as ecosystem services that humans rely on—for example, water purification and recycling.* **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 that are likely to limit possible solutions* **ETS1.B: Developing Possible Solutions** *There are systematic processes for evaluating solutions with respect to how well they meet the criteria and constraints of a problem.* *Sometimes parts of different solutions can be*	*Small changes in one part of a system might cause large changes in another part.*

	combined to create a solution that is better than any of its predecessors. **ETS1.C: Optimizing the Design Solution** *Although one design may not perform the best across all tests, identifying the characteristics of the design that performed the best in each test can provide useful information for the redesign process—that is, some of those characteristics may be incorporated into the new design.*	

California's Environmental Principles and Concepts

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

Concept a. *Direct and indirect changes to natural systems due to the growth of human populations and their consumption rates influence the geographic extent, composition, biological diversity, and viability of natural systems.*
Concept c. *The expansion and operation of human communities influences the geographic extent, composition, biological diversity, and viability of natural systems.*

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

Concept c. *the capacity of natural systems to adjust to human-caused alterations depends on the nature of the system as well as the scope, scale, and duration of the activity and the nature of its byproducts.*

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

Concept a. *the spectrum of what is considered in making decisions about resources and natural systems and how those factors influence decisions.*

CA CCSS for ELA/Literacy: RST.6–8.1, 4, 8; WHST.6–8.2, 7, 8, 9; SL.7.1, 4

Connection to CA ELD Standards:

ELD.PI.6-8.1, 9
Connections to CA CCSSM:
7.SP.1–4

Instructional Segment 4 Teacher Background and Instructional Suggestions: Instructional Segment 4 is titled, “Sustaining biodiversity and ecosystem services in a changing world.” Building on integrated science concepts and practices that they have learned in the prior three Instructional Segments, students apply and deepen their understandings by exploring ***societal*** challenges and designing solutions for those challenges.

Natural resources and ecosystems provide the materials that human communities need. Phrases such as “the Stone Age,” “hunter/gatherers,” ‘the Bronze Age,” “Agricultural Revolution,” “watershed,” and “fishing village,” all highlight the dependence of human communities on natural materials and on the food and water from ecosystems.

Performance expectation PS1-3 calls students’ attention to the synthetic materials that play huge roles in the modern world. A new integrated area of research and development known as *Materials Science and Engineering* has emerged to enable scientists and engineers to efficiently innovate and coordinate across traditional disciplines. Materials scientists and engineers design, create, and apply existing and new kinds of synthetic materials.

Plastics top the list among the current synthetic materials. Plastics have replaced many natural materials such as stone, wood, paper, metal and glass. Our packages, containers, cars, buildings, electronic devices, furniture, toys, and clothing either entirely or substantially consist of plastic materials. Plastics and other synthetic materials are themselves made from natural resources, frequently nonrenewable petrochemicals.

Two key societal challenges relate to the abundance of synthetic materials in our environments: health effects and garbage. Chemicals in these synthetic materials can harm the health of humans and other organisms. Many of these materials break down very slowly and accumulate in the environment. Having been made by humans rather than nature, synthetic materials are generally not part of Earth’s natural cycles of matter.

Chlorofluorocarbons (CFCs) provide a particularly informative example. These relatively simple chemicals consist of carbon, fluorine, and chlorine. They tend to not react chemically and are therefore remarkably stable. Due to their low reactivity, CFCs do not readily catch fire and they are nontoxic. In addition, their physical properties make them very useful as the principal cooling agent in refrigeration and air conditioning, and also as a propellant in spray cans. As a result, the CFCs replaced other more reactive chemicals in home and commercial appliances.

In 1960, independent scientist James Lovelock invented a very sensitive device that could measure very small amounts of chemicals in gases. Using this detector, he became the first person to detect CFCs in the atmosphere. Because these chemicals are so stable that they are not broken down in the lower atmosphere, CFCs can reach the stratosphere and accumulate there. Ultraviolet (UV) radiation in the stratosphere can break the CFC chemical bonds, and release chlorine. Unfortunately, the released chlorine atoms chemically react with and destroy ozone molecules in the upper atmosphere. These reactions have reduced the amount of ozone in the stratosphere, and thereby enable increased amounts of dangerous UV radiation to reach Earth’s surface. After scientists were able to conclusively prove these ***cause and effect*** relationships, governments agreed internationally to strictly reduce the manufacture and uses of CFCs. As a result, Earth’s stratospheric ozone layer is recovering.

The issue of CFCs illustrates that humans now impact the environment at the scale of the planet as a whole. Students in Integrated Grade 6 analyze evidence that human activities, especially combustion of fossil fuels, have caused global temperatures to increase over the past century. When the students are learning Integrated Grade 8, they will explore planetary impacts resulting from increasing human populations and increasing per capita consumption of resources.

Designing and testing these kinds of environmental challenges require a different kind of Engineering Design. Students' prior experiences with engineering design probably focused on specific devices, such as the calorimeter highlighted in Instructional Segment 2. At the middle grade level, the challenges can be at a higher level of generality, and also more strongly connected with personal and societal values. In challenges involving protecting biodiversity and ecosystem services (MS-LS2-5), some of the criteria, evaluations and decisions will inevitably be strongly influenced by ethical, economic and cultural valuations.

California's Environmental Principles and Concepts (EPC) can provide guidance in implementing these design challenges. All five of the Environmental Principles apply to the performance expectations bundled in Instructional Segment 4. Students can refer to these general principles and the specific concepts associated with each principle as part of their analyses, evaluations and argumentation. Having extensively investigated ***cycles of matter*** and ecosystem processes, students are primed to apply California's EPCs. For example, the three Concepts associated with Principle III are:

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

The ***systems*** thinking ***and modeling*** embedded within Integrated Grade 7 provide a scientific framework for these design challenges. Figure 16 in Instructional Segment 3 illustrates that matter cycles within an ecosystem, energy flows into and out of the ecosystem, and the organisms interact with each other and with the cycling matter and flowing energy.

The same generalizations (cycling of matter, flowing of energy and webbing of life) apply at the global level with one significant difference. At the ecosystem level, some matter (e.g., carbon dioxide and water) enters and leaves the ecosystem. In contrast, at the level of the planet, matter essentially does not leave or enter. All of Earth's ecosystems are linked with each other through their sharing of the atmosphere and the hydrosphere. Each of the elements that is vital for life exists on Earth in a closed loop of cyclical changes. At our time scale, Earth is essentially a closed system for matter.

While matter cycles within the Earth system, ***energy flows*** through it. Energy in the visible range of electromagnetic radiation (sunlight) enters the Earth system, and energy at a longer electromagnetic wavelength (infrared radiation) leaves the Earth system. Thus, like its component ecosystems, Earth is an open ***system*** with respect to energy.

Again analogously with the web of organism relationships with ecosystems, the planet as a whole features a web of life. All of Earth's organisms are intimately interlinked with each other and with the planet's cycles of matter and flows of energy. Earth is a networked system with respect to life.

The environmental human impacts that students explore throughout middle school ultimately relate to the effects of human activities on Earth's cycles of matter, flows of energy and web of life. In some challenges, such as habitat destruction or introduction of exotic species, the main direct impacts are on the local web of life. This local web of life is also often impacted by pollution. Essentially all pollution issues, such as the accumulation of CFCs in the upper atmosphere, result from activities that contaminate or disrupt Earth's natural cycles of matter.

Student design challenges will reveal criteria and constraints that are associated with the complexities of environmental issues. A ***systems-***based approach can help frame the analyses. At the appropriate scale (local, regional and/or global), students can analyze how the specific issue involves changes to the cycles of matter, flows of energy, and the web of life. That systems analysis can then inform the specific criteria and constraints, and also help provide a consistent design approach.