Grade 7 Instructional Segment 2

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

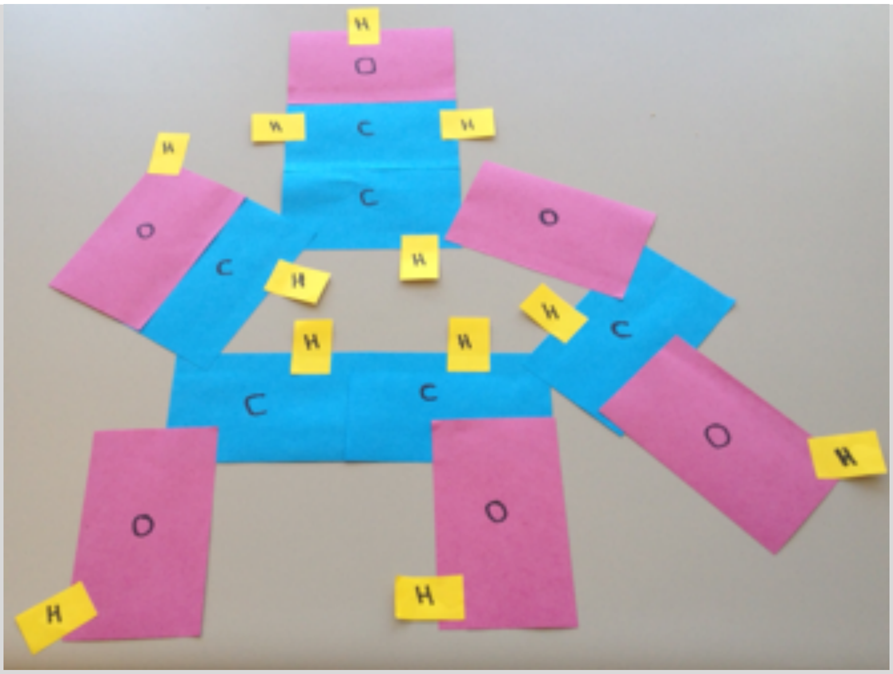

Figure 7: A model of a glucose molecule with different colors representing carbon (C), oxygen (O) and hydrogen (H). (Provided by Dr. Art Sussman, courtesy of WestEd)

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

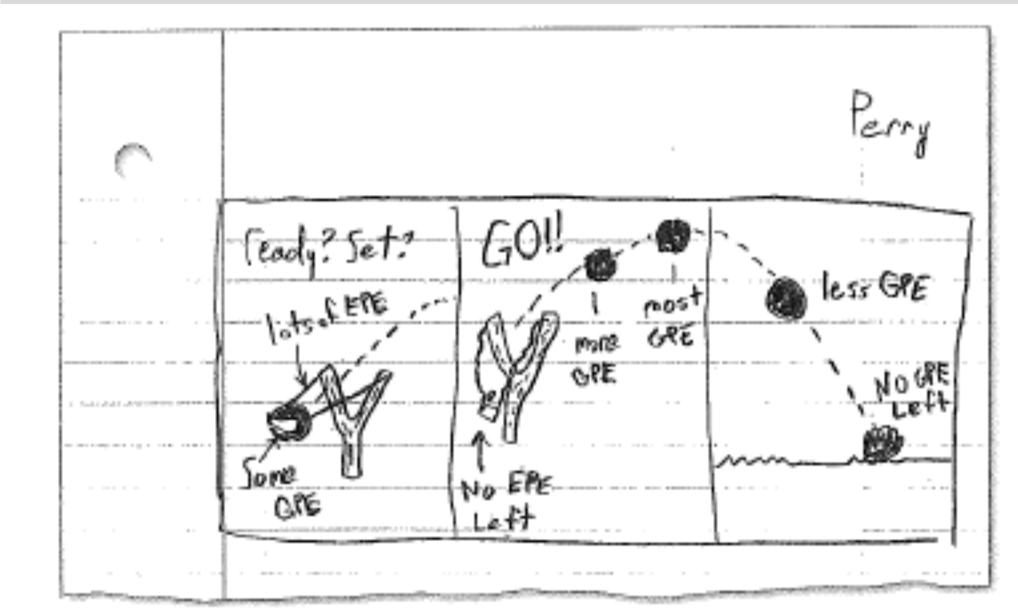

Figure 8: Student diagram of changes in potential energy accompanying the propulsion of a walnut by a slingshot. (Illustration from Making Sense of Science *Energy* course, courtesy of WestEd)

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

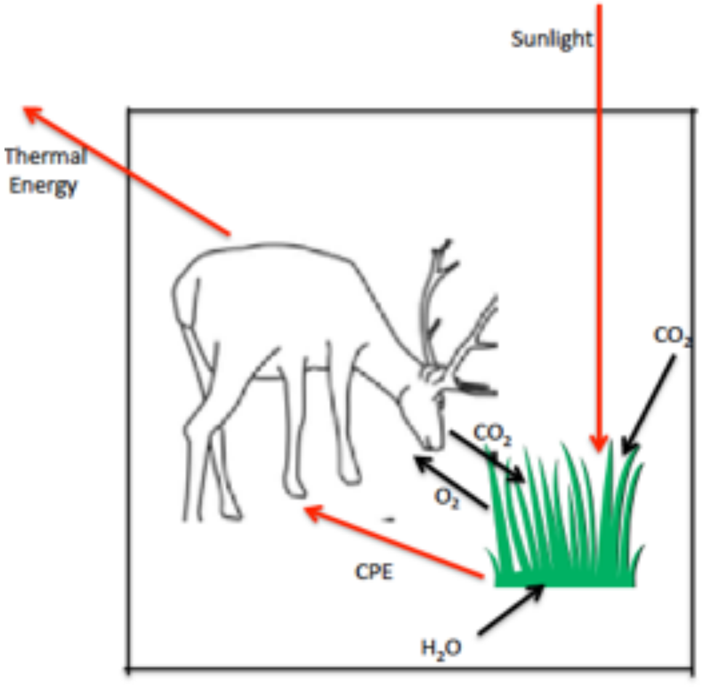

Figure 10: Flows of energy and matter into, within and out of a model of a Deer-Grass System. (Provided by Dr. Art Sussman, courtesy of WestEd)

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

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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,

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.

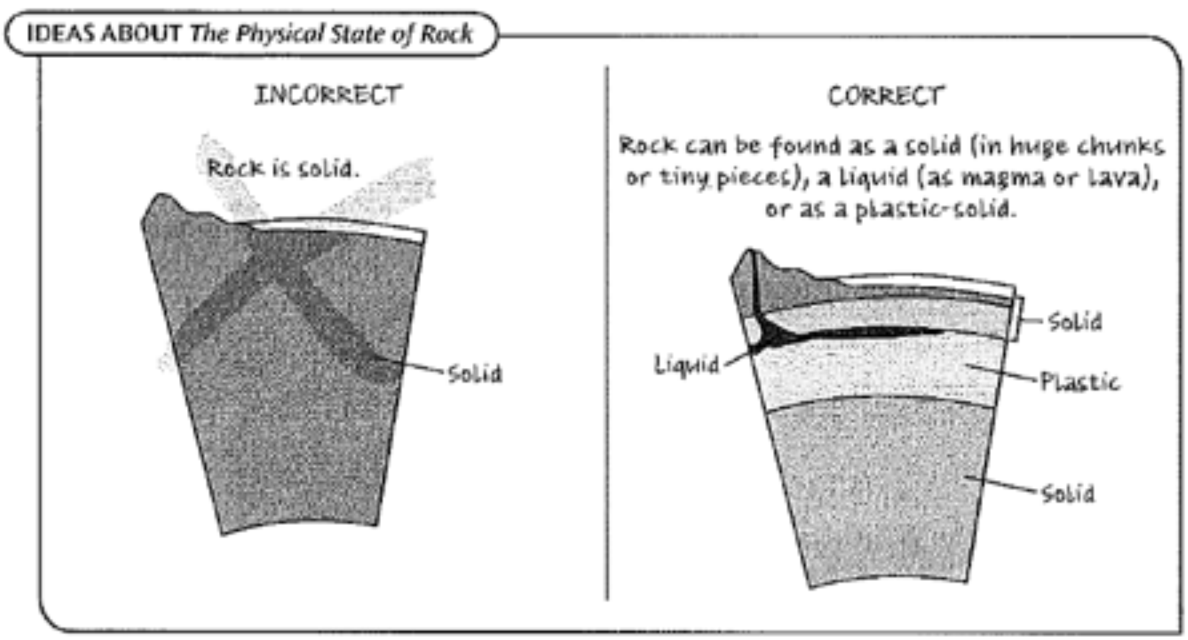

Figure 11: The Earth system has rocks in the solid, liquid and plastic states. (Illustration from Making Sense of Science *Earth Systems* course, courtesy of WestEd)

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

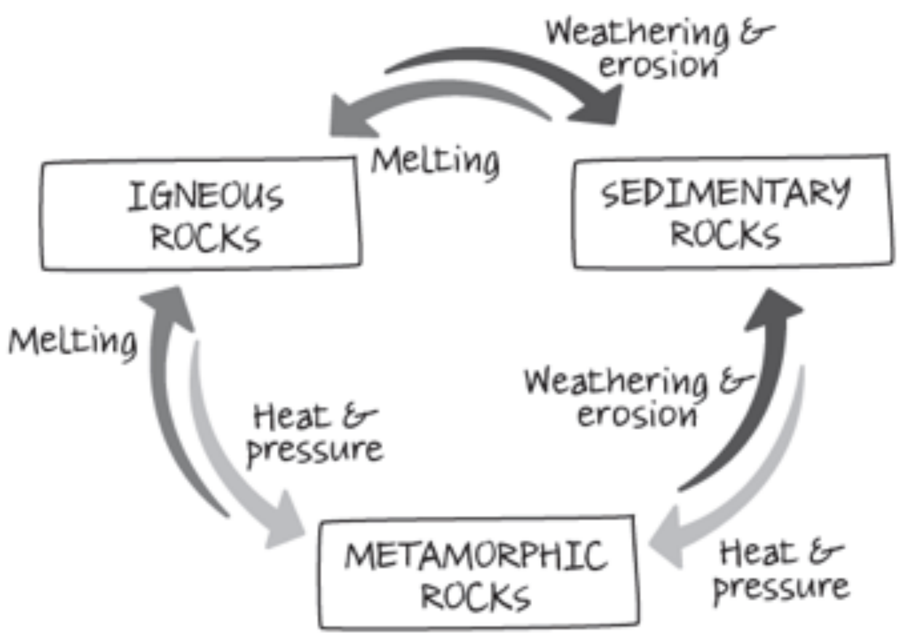

Figure 12: The classic rock cycle diagram summarizes the three types of rocks and a circular pattern of movements of rock materials. (Illustration from Making Sense of Science *Earth Systems* course, courtesy of WestEd)

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.