molecules). If students could take objects from the environment diagram and place them in these devices, they would find that the majority of living things are made of just a few types of atoms. These same types of atoms are common in the nonliving parts of the environment and in synthetic materials as well (MS-PS1-3, assessed in IS3). Teachers can simulate this process using an interactive Web page where students click on objects or use flashcards with object pictures on one side and a simplified molecular and atomic composition of the object on the other side. Exploring this data set, students can identify **patterns [CCC-1]** in the common types of atoms in the natural environment and begin to develop models of how **matter cycles [CCC-5]** in the environment. They will examine these cycles in more detail in IS2.

IS2 Integrated Grade Seven Instructional Segment 2: Matter Cycles and Energy Flows through Organisms and Rocks

Students apply their understanding of materials to the **cycling of matter [CCC-5]** in two different **systems [CCC-4]**, the cycle of rock material in the geosphere and the cycling of biomass between organisms. In each case, the **flow of energy [CCC-5]** within the system is intimately tied to the flow of matter.

INTEGRATED GRADE SEVEN INSTRUCTIONAL SEGMENT 2: MATTER CYCLES AND ENERGY FLOWS THROUGH ORGANISMS AND ROCKS

Guiding Questions

- How do rocks and minerals record the flow of energy and cycling of matter in the Earth?
- How do we get energy from our food?
- How are hot objects different than cold objects? What changes when they heat up or cool down?

Performance Expectations

Students who demonstrate understanding can do the following:

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.*]

INTEGRATED GRADE SEVEN INSTRUCTIONAL SEGMENT 2: MATTER CYCLES AND ENERGY FLOWS THROUGH ORGANISMS AND ROCKS

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.

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

INTEGRATED GRADE SEVEN INSTRUCTIONAL SEGMENT 2: MATTER CYCLES AND ENERGY FLOWS THROUGH ORGANISMS AND ROCKS

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

Highlighted Science and Engineering Practices	Highlighted Disciplinary Core Ideas	Highlighted Crosscutting Concepts
[SEP-1] Asking Questions and Defining Problems [SEP-2] Developing and Using Models [SEP-4] Analyzing and Interpreting Data [SEP-6] Constructing Explanations (for science) and Designing Solutions (for engineering) [SEP-7] Engaging in Argument from Evidence	LS1.C: Organization for Matter and Energy Flow in Organisms PS1.A: Structure and Properties of Matter PS1.B: Chemical Reactions PS3.D: Energy in Chemical Processes and Everyday Life 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	[CCC-1] Patterns [CCC-5] Energy and Matter: Flows, Cycles, and Conservation [CCC-7] Stability and Change

Highlighted California Environmental Principles and Concepts:

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

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

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

CA CCSS Math Connections: 6.EE.9, MP.2, MP.4, 6.SP.4, 5, 7.EE.3, 7.SP.7

CA CCSS for ELA/Literacy Connections: RST.6–8.1, 2, 3, 7, WHST.6–8.2, 7, 8, 9, SL.7.5

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

Students have been investigating the relationships between plants and animals since kindergarten (K-LS1-1), and they supported the claim that plants get the matter they need from air and water in grade five (5-LS1-1), thus tying the biosphere to the rest of Earth systems. The vignette below illustrates one approach to teaching about energy and matter flows in living systems in the middle grades.

INTEGRATED GRADE SEVEN VIGNETTE 5.2: PHYSICAL AND CHEMICAL CHANGES IN ORGANISMS

Performance Expectations

Students who demonstrate understanding can do the following:

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-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.

INTEGRATED GRADE SEVEN VIGNETTE 5.2: PHYSICAL AND CHEMICAL CHANGES IN ORGANISMS

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

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

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

Highlighted Science and Engineering Practices	Highlighted Disciplinary Core Ideas	Highlighted Crosscutting Concepts
[SEP-1] Asking Questions and Defining Problems [SEP-2] Developing and Using Models [SEP-3] Planning and Carrying Out Investigations [SEP-4] Analyzing and Interpreting Data [SEP-6] Constructing Explanations and Designing Solutions [SEP-7] Engaging in Argument from Evidence	LS1.C: Organization for Matter and Energy Flow in Organisms PS1.A: Structure and Properties of Matter PS1.B: Chemical Reactions PS3.D: Energy in Chemical Processes and Everyday Life ETS1.A: Defining and Delimiting Engineering Problems ETS1.B: Developing Possible Solutions ETS1.C: Optimizing the Design Solution	[CCC-1] Patterns [CCC-2] Cause and Effect: Mechanism and Explanation [CCC-3] Scale, Proportion and Quantity [CCC-4] System and System Models [CCC-5] Energy and Matter: Flows, Cycles, and Conservation

Highlighted California Environmental Principles and Concepts:
Principle III Natural systems proceed through cycles that humans depend upon, benefit from and can alter.

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

CA CCSS Math Connections: MP. 5

CA CCSS for ELA/Literacy Connections: RST.6–8.7, 9; SL.7.1

CA ELD Connections: ELD.PI.6–8.1, 9

Introduction

This vignette illustrates the integration of life and physical science concepts surrounding energy and matter flows [CCC-5] in living systems [CCC-4]. It is designed to illustrate a large section of IS2 within the Integrated Grade Seven course. Instruction spans nearly three weeks, beginning at the scale of entire ecosystems, zooming down to the scale [CCC-3] of individual atoms and molecules, and then returning back to the scale of individual organisms within the ecosystem.

INTEGRATED GRADE SEVEN VIGNETTE 5.2: PHYSICAL AND CHEMICAL CHANGES IN ORGANISMS

Day 1: Classifying changes in a natural environment

Students identify changes that happened over 200 years in a river environment and ask questions about the similarities and differences between these changes.

Day 2: Identifying and Defining Chemical Changes

Students analyze observations of substances before and after they interact to determine features characteristic of chemical changes.

Days 3–4: Models of Photosynthesis

Students engage in a short engineering design challenge to find an effective physical model for atoms and molecules in the photosynthesis reaction.

Day 5: Energy and the chemical reaction of respiration

Students struggle with and discuss how to represent energy using their physical model of the respiration reaction.

Days 6–8: "Energy Love" Investigations

Students explore hands-on stations with different devices that use or give off energy and try to develop a definition of energy (a task as difficult as defining love). When that fails, they resort to categorizing different forms of energy.

Day 9: Models of Energy from Food

Students grapple with models of the flow of energy in a chemical system.

Days 10–13: Engineering design challenge to quantify energy released

Students refine the design of a food calorimeter that converts chemical potential energy into thermal energy.

Day 14: Organism energy/matter system diagram

Students develop a model of the energy flow and matter cycling at the scale of organisms in an ecosystem.

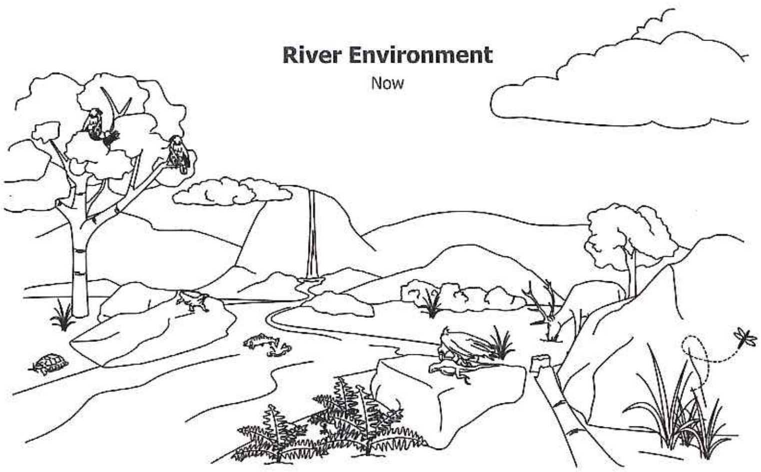
Day 1: Classifying changes in a natural environment

Anchoring phenomenon: Within a river environment, a lot changes in 200 years. Plants and animals live and grow.

In IS1, students noted the kinds of matter that exist in natural environments. They had begun with whole-class discussions focused on a river environment viewed 200 years ago (figure 5.26). To start IS2, Mr. G presented students with a new illustration of the same location today (figure 5.28). What has changed?

INTEGRATED GRADE SEVEN VIGNETTE 5.2: PHYSICAL AND CHEMICAL CHANGES IN ORGANISMS

Figure 5.28. River Environment



The previously viewed river environment 200 years later. *Source:* From Making Sense of SCIENCE: Earth Systems (WestEd.org/mss) by Daehler and Folsom. Copyright © 2013 WestEd. Adapted with permission.

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.

After the whole class shared and reached 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 [SEP-1]** about the changes that had happened in the natural environment. In the subsequent whole-class discussion, 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 [SEP-7]** 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.

INTEGRATED GRADE SEVEN VIGNETTE 5.2: PHYSICAL AND CHEMICAL CHANGES IN ORGANISMS

Day 2: Identifying and Defining Chemical Changes

Investigative phenomenon: When substances mix, sometimes unusual things happen and sometimes they don't.

When students mixed substances together in grade five, they found that sometimes new substances formed and sometimes they did not (5-PS1-4). Mr. G set up a similar series of **investigations [SEP-3]** to pinpoint 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. They **analyzed [SEP-4]** the results of their investigations by organizing their observations and looking for **patterns [CCC-1]** in what they saw, heard, smelled, or felt (MS-PS1-2). Students liked the idea that the changes in physical properties were similar to clues in a mystery story or crime scene investigation. The investigation included some examples that appeared to be chemical changes (gas bubbling out of a soda can) but were really *just* physical changes. This emphasis on the word "just" helped students 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." Lorena was particularly troubled by this phrase and asked, "How do these substances magically appear?" Mr. G encouraged Lorena and Juanita to repeat several of the investigations in a sealed bag so that no matter could enter or leave and watch to see if the mass changed. As they found in grade five (5-PS1-2), the mass remained the same after each change. "See, whatever stuff starts in the bag stays in the bag," gloated Lorena. Juanita recognized that her words were misleading and erased them to read, "Old substances change into new substances." Mr. G highlighted the new phrase to the class and asked students to work in teams to rewrite Juanita's idea using the terms *atoms* and *molecules*. After students shared their ideas, Mr. G introduced the new term, *chemical bond* to describe how the atoms stay together as molecules. "What exactly is a chemical bond?" asked Pedro.

Days 3–4: Models of Photosynthesis

Investigative phenomenon: Trees grow using air and water

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. Mr. G asked

INTEGRATED GRADE SEVEN VIGNETTE 5.2: PHYSICAL AND CHEMICAL CHANGES IN ORGANISMS

students to call out what plants need to grow. He pointed out that air and water are both made of molecules. Within the plant, these substances change into new substances. Mr. G rewrote the needs as chemical formulas and then wrote out the rest of the balanced equation for photosynthesis on the board. He emphasized that the arrow in the chemical equation represented the chemical change. He then provided interconnecting plastic toy bricks to students and instructed them to create a **model [SEP-2]** of that reaction. Each group of students had a variety of colorful toy bricks that they could assemble in their work areas.

Marco, the reporter for one student group, described how they used a different type of toy brick for each molecule. Most of the other student groups had used a similar type of modeling. Marco explained how their **model [SEP-2]** represented carbon dioxide with the small black brick ("just like coal"), water with the small blue brick ("just like the ocean"), glucose with the big white brick ("just like a sugar cube"), and oxygen with the small red brick ("just like fire"). Kelly, another member of the same student group, proudly added that they had used six of each type of brick except for only one white brick 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 [SEP-7]**."

Juanita and Alex called everyone's attention to their group. Alex explained that they had tried to use models where each type of toy brick 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 [SEP-2]** 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 students presented their ideas, Mr. G emphasized that the class was engaging in a simple engineering design problem. This prompted them to discuss the problem in terms of the criteria and constraints. They noted one constraint was that they could only use inexpensive materials. One significant criterion was that there needed to 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 (figure 5.29). Students also wanted to use a smaller size sticky note to represent hydrogen since they knew that it was the smallest atom.

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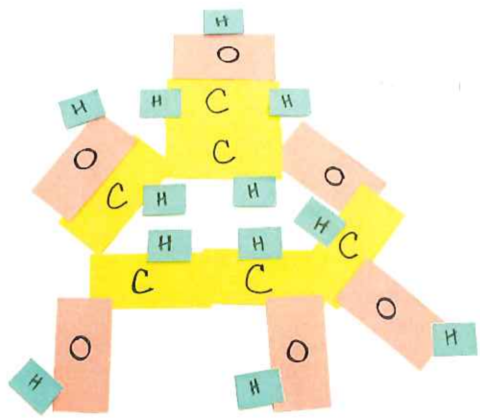
Figure 5.29. Classroom Model of a Glucose Molecule



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.

At the start of the next day, each group gathered supplies of sticky notes and began to assemble them to **model [SEP-2]** photosynthesis. 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 the model as **evidence to explain [SEP-6]** that in the reaction none of the atoms had disappeared, and that there were also no new atoms in the products (MS-PS1-5). 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. Students inquired if physical changes also featured this rule of conservation of matter. After some discussion and additional modeling, they agreed that all changes followed this rule.

Days 5: Energy and the chemical reaction of respiration

Investigative phenomenon: Animals can get their energy from eating plants.

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 noted that back in grade six they had learned that respiration happened in both plant cells and in animal cells, so plants must do respiration, too.

Following that introduction, Mr. G challenged the students to use the sticky notes to **model [SEP-2]** 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. While his comment was sarcastic, Mr. G recognized that he had not always spent so much time on topics before moving on in the past. He went on to explain that practicing their skills and applying them to new situations is what leads to effective learning.

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 [SEP-7]** that in chemical reactions the atoms changed their

INTEGRATED GRADE SEVEN VIGNETTE 5.2: PHYSICAL AND CHEMICAL CHANGES IN ORGANISMS

connections and that the amount of mass remained constant. Students knew that plants get energy from photosynthesis and animals get energy from plants, so they asked Mr. G about how they should 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 [SEP-1] 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 [SEP-7] 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 [CCC-5] during chemical reactions.

Days 6–8: "Energy Love" Investigations

Investigative phenomenon: (Students investigate a range of devices that use or give off energy.)

Mr. G set up stations around the room for students to explore different forms of energy. Each station had cryptic labels and instructions such as a ball labeled "Drop me," a bowl of fresh fruit with the label "Eat me," and a radio playing music with the label "Dance with me." On the board, Mr. G had written the instructions, "Describe how each station relates to energy." As the students circulated between the stations, they discussed everything they knew and wondered about energy from their previous science classes and real-world experiences. Mr. G helped them develop and compare Frayer diagrams about the concept of energy. In the end, they 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."

Over the next several days, Mr. G referred to the different stations and subsequent hands-on experiences as their "energy love" investigations. Mr. G then asked the students to categorize the investigations based on patterns [CCC-1] they noticed. After some discussion, the class settled on two categories and developed a summary table 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.

INTEGRATED GRADE SEVEN VIGNETTE 5.2: PHYSICAL AND CHEMICAL CHANGES IN ORGANISMS

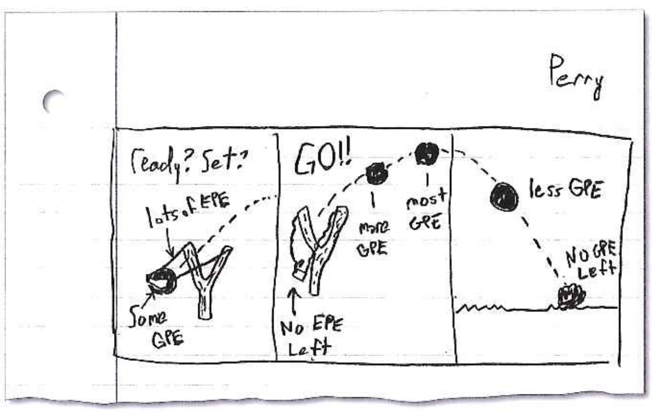
ENERGY OF MOTION Energy due to the motion of matter	**ENERGY OF POSITION** Energy due to the relative positions of matter
Kinetic Energy	Gravitational Potential Energy
Thermal Energy "often called Heat Energy"	Elastic Potential Energy
Light Energy	Chemical Potential Energy
Sound Energy	Magnetic Potential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

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

Investigative phenomenon: Pulling back a slingshot just a few inches can launch a walnut all the way across the schoolyard.

In the final investigation of the "energy love" series, students **modeled [SEP-2]** the changes in potential energy when using a slingshot to propel a walnut across the schoolyard (employing appropriate safety precautions). The prompt involved listing examples of three forms of potential energy (elastic, gravitational, and chemical), and the changes in those forms of potential energy. Perry's diagram was typical for the class (figure 5.30).

Figure 5.30. Student Diagram of Changes in Potential Energy



Student diagram of changes in potential energy accompanying the propulsion of a walnut by a slingshot. EPE was the abbreviation the class used for elastic potential energy and GPE for gravitational potential energy. *Source:* From Making Sense of SCIENCE: Energy (WestEd.org/mss) by Daehler, Shinohara, and Folsom. Copyright © 2011a WestEd. Reproduced with permission.

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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 chemical potential at all. Perry defended his diagram by saying, "We did elastic and gravitational, but there is no food in this diagram so we did not include chemical."

After Marco pointed out that the walnut is food, Perry replied, "Okay, the walnut is food and has chemical potential energy, but that energy didn't change in the experiment. We didn't eat or burn the walnut."

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

Day 9: Models of Energy from Food

Everyday phenomenon: We get hot when we exercise.

After all this "energy love," Mr. G returned to the question, "How do we get energy from our food?" and asked students to draw or write a response for their warm-up. Most students chose to write a response, and most included the phrase, "Chemical potential energy gets converted into kinetic energy." While they all had "correct" answers, Mr. G pointed out that most of the class used the passive voice that energy "gets converted." What does the converting? How does that happen? Trying to convey enthusiasm about a new unexplained challenge, Mr. G said, "I think that we still don't have a good **model [SEP-2]** of what **causes [CCC-2]** that energy conversion. If we did, more of you would have drawn that model." Mr. G next provided students a clue—he cited the everyday phenomenon that people get all hot and sweaty when they exercise. Why do we get hot? Mr. G reminded students where they left off yesterday that **all** materials have chemical potential energy stored in their bonds. The students worked in teams to refine their model of the changes in energy that go into cells as food and then molecules get rearranged during cellular respiration (MS-LS1-7). During whole-class discussion, teams held up molecules from their sticky note models of respiration and said that the chemical energy in the products (water and carbon dioxide) must be smaller than the total chemical energy of the reactants (glucose and oxygen) because energy left the **system [CCC-4]** as thermal energy or kinetic energy when the atoms got rearranged into new molecules. Mr. G then asked them if they could imagine a situation where a system would get cooler because of a chemical reaction, and they replied that energy would have to come into the system to make the energy of the products greater than the energy of the starting reactants. They discussed the chemical reactions in a first aid cold pack (figure 5.31).

INTEGRATED GRADE SEVEN VIGNETTE 5.2: PHYSICAL AND CHEMICAL CHANGES IN ORGANISMS

Figure 5.31. Two Different Categories of Chemical Reactions

Energy-Releasing Actions	Energy-Absorbing Actions
Total Energy of Reactants > Total Energy of Products	Total Energy of Reactants > Total Energy of Products
	

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.

Days 10–13: Engineering design challenge to quantify energy released

Investigative Problem: How do we capture as much of the energy as possible in a calorimeter so that we can measure the chemical potential energy in food?

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 the CA NGSS professional development and planning with his middle grades 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 simply 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 [SEP-1]** and also provided answers about food contents, the meaning of calories, and the connections with chemical reactions and chemical potential energy. Mr. G then showed the students a prototype calorimeter made out of a soda can. Students would refine this device to convert the chemical potential energy in the food to thermal energy (MS-PS1-6) that they can use to determine the number of calories of a food sample. The calculations were advanced for his middle grades students (they would complete this activity in the high school Three Course Model Chemistry in the Earth System course), but but Mr. G had set up an interactive spreadsheet where all they do is enter their measurements

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and they get the estimate of the food's calorie content. Mr. G wanted the students to optimize this prototype so that it created more accurate estimates. Students brainstormed a list of major **criteria [SEP-1]** for their design challenge that included safety, cost, and accuracy (MS ETS1 1). To make the device more accurate, they needed to capture as much of the **energy [CCC-5]** from the food as possible. Safety concerns placed constraints on the types of materials they could use (they must be non-flammable).

The student groups had numerous opportunities to share plans with each other, critique each other's ideas (MS-ETS1-2), 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. 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 (MS-ETS1-4). During each test, students used the same food with a known calorie content and checked to see how well their device reproduced the known value and identified design elements of the calorimeters that worked best (MS-ETS1-3). At the end of the design and testing, students could use their calorimeter to measure the calorie content of other foods. Groups then shared posters that **communicated [SEP-8]** their design to their peers. They included diagrams with annotations that described how the different **structures [CCC-6]** and materials helped make the device meet the design criteria. Mr. G ensured that students made the connection that the transfer of energy from the food to the calorimeter was analogous to the energy transferred from food to animals as they eat and digest their food.

Day 14: Organism energy/matter system diagram

Investigative Phenomenon: Animals survive and grow by eating food.

Mr. G wanted the students to think about the food and calorimeter as a system, so he elicited from the students what they knew about **systems and system models [CCC-4]** 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. The students began by drawing a simple diagram of the energy transfer in their food calorimeter. Then, Mr. G told the class they were going to "zoom out" to **cycles of matter and the flows of energy [CCC-5]** in a larger system.

Returning to the river environment diagram, students worked in pairs and developed a system model to illustrate the **flows of matter and energy [CCC-5]** into and out of the deer and also into and out of the grass (MS-LS1-6). The class developed a consensus diagram (figure 5.32) after students worked on their separate team diagrams, critiqued each other's diagrams, iteratively improved them, and then finalized the diagram after whole-class discussion.

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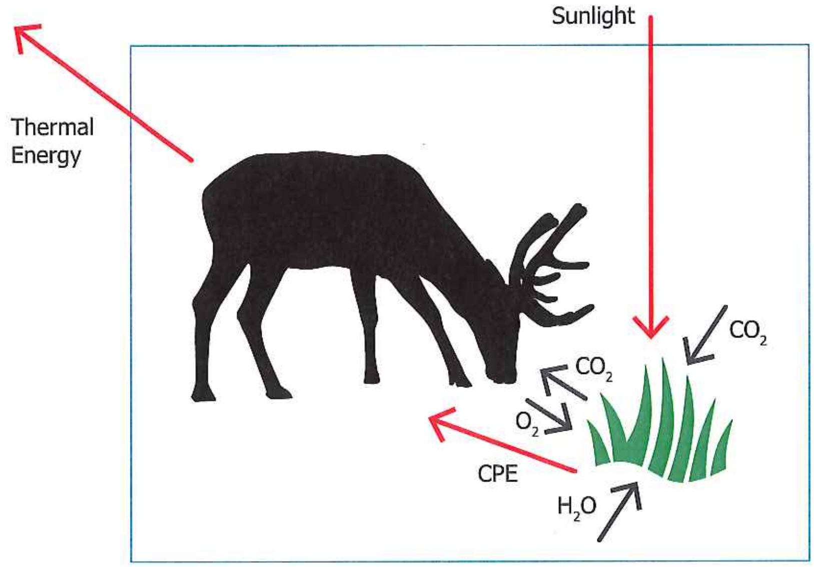
Figure 5.32. System Model to Illustrate Flows of Matter and Energy



Flows of energy and matter into, within, and out of a model of a Deer-Grass System. Thin red arrows represent energy and thick gray arrows represent matter. CPE is chemical potential energy. Provided by Dr. Art Sussman, courtesy of WestEd.

Vignette Debrief

In this vignette, the teacher introduced phenomena related to physical and chemical changes using 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 focused more on lessons that connected 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 IS2, students will reach the same conclusions regarding Earth science processes.

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

SEPs. Students focused on **developing models [SEP-2]** throughout this vignette, by spending all of days 3-4, 8, 9, and 14 grappling with phenomena and trying to model them. These modeling experiences were not designed as assessments of learning at the end. Instead, Mr. G used these modeling opportunities to motivate and frame the learning—students recognized limitations and missing pieces in their understanding when they built the

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models. For example, the "Energy Love" investigations on days 6–8 were included because students did not know how to represent energy in their models because they didn't understand enough about energy yet. On days 1–2, students analyzed data [SEP-4] in the sense that they looked for patterns [CCC-1] in their qualitative observations and made categories based on those patterns. Mr. G chose to introduce the distinctions of "physical versus chemical change" by having students discover the categories themselves and then refine their labels to reflect the current state of scientific vocabulary, rather than beginning with definitions of the scientific terminology.

DCIs. Chemical reactions (PS1.B), the energy in chemical reactions (PS3.D), and energy and matter flow in organisms (LS1.C) were the common thread through the entire lesson. Students extended their understanding of matter made up of atoms and molecules (PS1.A) through their physical modeling on days 3–5 and 9. On days 6–8, students grappled with the definitions of energy (PS3.A). The engineering challenge on days 10–13 allowed students to focus on all aspects of engineering design (ETS1) and they even briefly addressed these core ideas on day 3 when they tried to find the best way to represent molecules using a physical model.

CCCs. Student models focused on the exchange of energy and matter [CCC-5] between components of chemical systems (days 3–5), macroscopic physical systems (days 6–8), a calorimeter system (days 10–13), and a small section of an entire ecosystem (day 14). While students had tracked the flow of matter in elementary school, tracking energy as it changed between various forms was the key addition to understanding CCC-5 at the middle grades level (see the progressions in appendix 1 of this framework). While systems [CCC-4] were inherent in the modeling, very little discussion in the vignette, as written, was explicitly devoted to thinking of these situations as system. That explicit discussion would be done as part of the classroom discourse not captured in this vignette.

EP&Cs. As written, Mr. G did not explicitly address any of the EP&Cs, though the skills students developed discussing the cycling of matter in their modeling were crucial for understanding EP&C IV ("The exchange of matter between natural systems and human societies affects the long-term functioning of both"). Mr. G easily could have extended this vignette another day to fast forward into the future with another environment diagram showing human impacts from pollution, or by tracking toxins in the day 14 diagrams that show matter exchanged between organisms.

CA CCSS Connections to English Language Arts and Mathematics. Students engage in structured discourse (SL.7.1) with teams throughout the vignette, including evaluating and reviewing the ideas of their peers on days 2, 3–4, during the engineering design challenge on days 10–13 and again on day 14. The students calculate the calories in food samples using an interactive spreadsheet (MP.5).

Resources:

Daehler, Kirsten, and Jennifer Folsom. 2013. *Making Sense of SCIENCE: Earth Systems*. San Francisco: WestEd.

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

Rock Cycles and Earth's Energy Flows

The second half of IS2 involves applying the same physical science concepts explored in the vignette to the **cycling of Earth's materials [CCC-5]** and the **flows of energy [CCC-5]** that drive these processes (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. Students return to the environment diagram of figure 5.28 and focus on the rocks. Can they identify evidence of places where rocks are forming or changing? The class makes a list of all the different things they can think of that can happen to rocks: eroded by the river, erupted from a volcano, buried at the bottom of a landslide, broken up by roots, eaten as a speck of soil on a piece of grass, dust blown by the wind, etc. Students engage in a jigsaw where different students read a short article about a particular location on Earth that exemplifies one transformation in the rock cycle. The articles have pictures of rocks and the locations where they were found that highlight the evidence for the change (i.e., a volcanic rock has holes in it that are evidence of gas bubbles, and it came from a long outcrop that heads straight downhill providing evidence that the material once flowed as a liquid at the surface). Students then come together for a "rock summit" to describe the possible events that can befall a piece of rock.

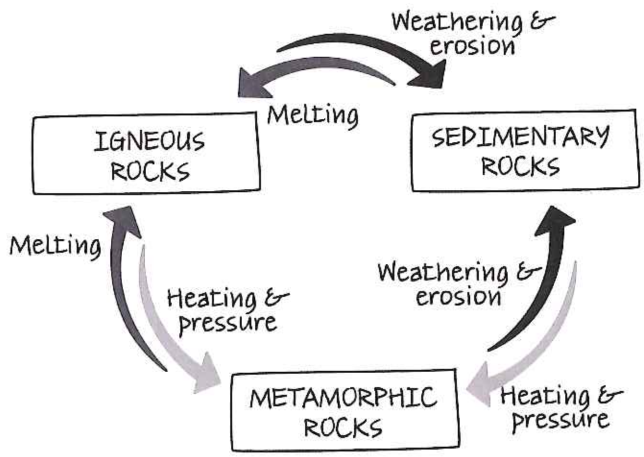
Students write a fictional short story tracing the path of one rock through many adventures. As an illustration for this piece, they depict the path of their imaginary rock on a flowchart. As students compare their flowcharts, they see that no two rocks follow the same path. This idea is critical because it counters the preconception that many students have when they read materials about the "rock cycle"—since these materials are written on a page they have a linear flow that implies there is only one path. Next, students work in groups to create a physical model of one rock story using crayons or sugar cubes. Both these materials can be melted, solidified, broken apart, dissolved (for sugar), pressed together (for crayons). Students will record the process in a video that captures how their rock changes. They start by making a storyboard to plan the physical processes they will depict in each scene and also their narration for that scene. In the narration, they must emphasize where the **energy [CCC-5]** comes from that drives the transformation in each scene. They discuss both the energy in the physical model as well as where the energy source would be in the real Earth system. If students have uncertainty about where the energy comes from in the Earth system, they return to the jigsaw articles or the teacher can engage in whole-class discussions and provide additional information. The paragraphs below provide some of this background for teachers, and curriculum developers can find excellent examples within California and beyond of case studies that exemplify and describe these processes and the evidence for them.

Many rock changes 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. Rocks can melt as they move closer to Earth's hot interior, and molten rock can solidify as it rises towards Earth's surface where temperatures are cooler. The movement of rocks upward and downward is often related to the motions of plate tectonics. 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.

Near the surface, rocks also form and break 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 [CCC-2]** 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. Energy that drives these surface processes comes from the Sun (which provides thermal energy that drives chemical reactions and also causes the movements of wind and water in the atmosphere and biosphere), gravity (and its constant downward pull on air, water, and rock), and the chemical potential energy within the biosphere (which ultimately comes from the Sun).

After students have explored and modeled these processes, they can label them with scientific terms. Observation and explanation of phenomena drive instruction in the CA NGSS, not terminology. With this terminology, students can develop something like figure 5.33, 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). Students can **evaluate [SEP-8]** the benefits and limitations of this classic rock cycle diagram (table 5.9).

Figure 5.33. Classic Rock Cycle Diagram



The classic rock cycle diagram summarizes the three types of rocks and a circular pattern of movements of rock materials. *Source:* From Making Sense of SCIENCE: Earth Systems (WestEd.org/mss) by Daehler and Folsom. Copyright © 2013 WestEd. Reproduced with permission.

Table 5.9. Benefits and Limitations of Classic Rock Cycle Diagram

BENEFITS	LIMITATIONS
Provides a 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

Source: From Making Sense of SCIENCE: Land and Water (WestEd.org/mss) by Folsom and Daehler. Copyright © 2012 WestEd. Adapted with permission.

The physical and chemical **changes [CCC-7]** that happen to minerals and rocks reinforce the principle of the **conservation of matter [CCC-5]**. Almost three-quarters of Earth's crust is made of oxygen and silicon (students encountered this information at the end of IS1 when they simulated data collection of materials in the environment diagram of the river). 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 the vast majority of Earth's rocks and minerals. Throughout all the physical and chemical interactions, none of these atoms are lost or destroyed. Even as the appearance and behavior of the rocks change [CCC-7], their overall composition remains relatively stable [CCC-7].

IS3 Integrated Grade Seven Instructional Segment 3: Natural Processes and Human Activities Shape Earth's Resources and Ecosystems

When students look out on a landscape, they might see trees in some places but not others and a gold mine on one hill but not another. In this instructional segment, students focus on explaining why things are located where they are, including organisms within an ecosystem and resources and hazards on the planet. In both cases, interactions within and between different Earth systems determine these distributions. Humans both depend on these distributions and can dramatically alter them. The goal of integrating these topics is that the questions students learn to ask about the distribution of resources on the planet can serve as a template for understanding the relationships between organisms in an ecosystem, and vice versa.

INTEGRATED GRADE SEVEN INSTRUCTIONAL SEGMENT 3: NATURAL PROCESSES AND HUMAN ACTIVITIES SHAPE EARTH'S RESOURCES AND ECOSYSTEMS

Guiding Questions

- How can we use interactions between individual rocks or individual organisms to understand systems as big as the whole geosphere or whole ecosystem?
- How can we use patterns in geosphere interactions to predict the location of resources?
- How can we use patterns in ecosystem interactions to predict how organisms compete and share resources?

Performance Expectations

Students who demonstrate understanding can do the following:

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.]