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

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

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

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

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

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

INTEGRATED GRADE EIGHT INSTRUCTIONAL SEGMENT 2: NONCONTACT FORCES INFLUENCE PHENOMENA

Guiding Questions

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

Performance Expectations

Students who demonstrate understanding can do the following:

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

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

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

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

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

INTEGRATED GRADE EIGHT INSTRUCTIONAL SEGMENT 2: NONCONTACT FORCES INFLUENCE PHENOMENA

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

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

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

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

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

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

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

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

Figure 5.43. Interacting Galaxies Demonstrate Attraction

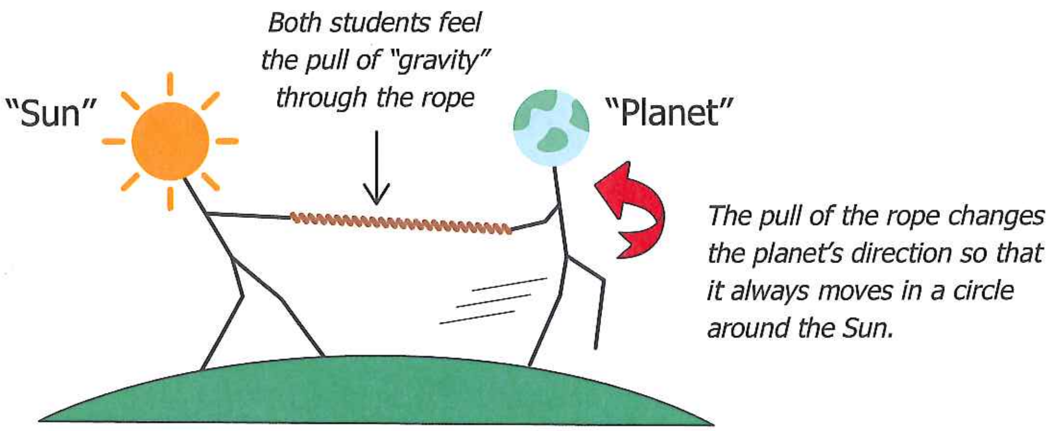
Galaxy pair Ar271. *Source:* Gemini Observatory 2008

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

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

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

Figure 5.44. Kinesthetic Model of an Orbit



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

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

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

Explaining Motion in the Solar System

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

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

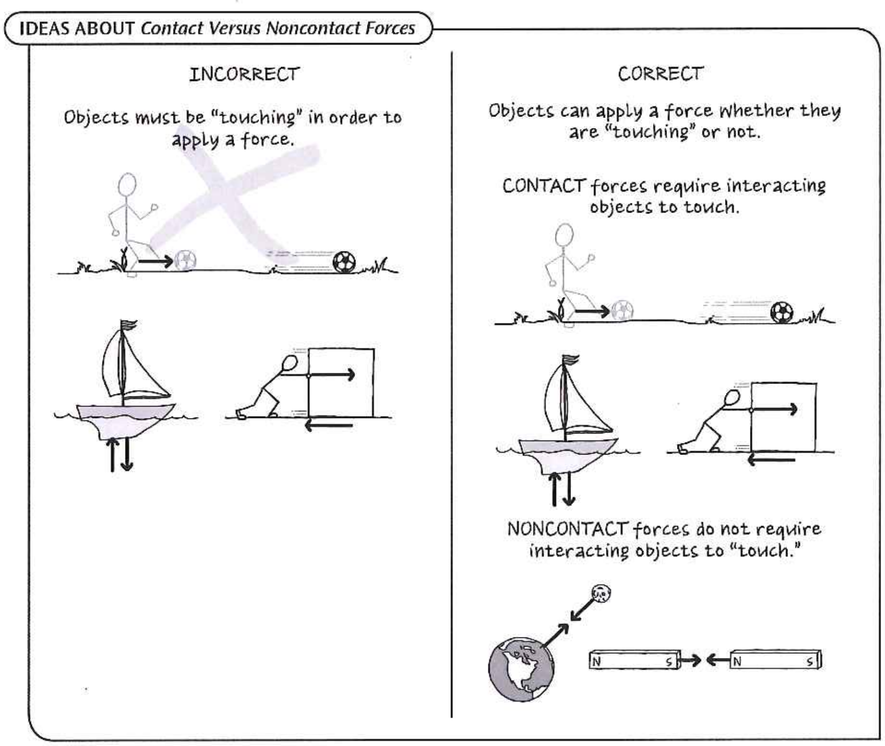
Factors Controlling the Effects of Gravity

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

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

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

Figure 5.45. Contact Forces and Noncontact Forces



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

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

Opportunities for ELA/ELD Connections

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

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

CA ELD Standards: ELD.PI.6–8.9

Similarities Between Gravity and Magnetism

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

Noncontact Forces and Energy

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

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

Table 5.10. Forms of Energy

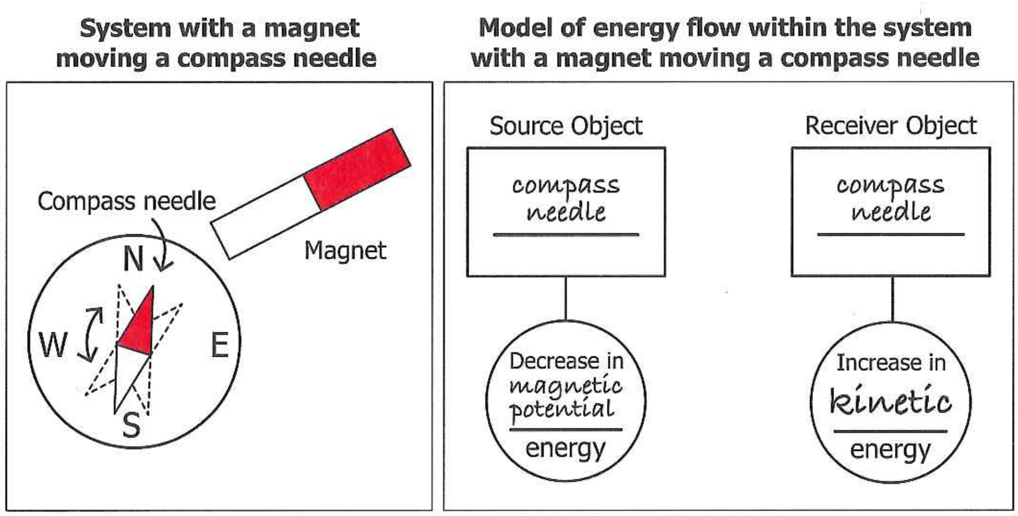
ENERGY OF MOTION **Energy due to the motion of matter**	**ENERGY OF POSITION** **Energy due to the relative positions of matter**
Kinetic Energy	Gravitational Potential Energy
Thermal Energy (often called Heat Energy)	Elastic Potential Energy
Light Energy	Chemical Potential Energy
Sound Energy	Magnetic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

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

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

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

Figure 5.46. A Magnet Moving a Compass Needle



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

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

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

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

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

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

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

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

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

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

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

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

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

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

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