Grade 8 - Middle School Discipline Specific Core Model – Physical Science

From the introduction to the Middle School Physical Sciences Standards in the NGSS:

> The performance expectations in physical science blend the core ideas with scientific and engineering practices and crosscutting concepts to support students in developing useable knowledge to explain real world phenomena in the physical, biological, and earth and space sciences…. The performance expectations in the topic Structure and Properties of Matter help students to formulate an answer to the questions: “How can particles combine to produce a substance with different properties? How does thermal energy affect particles?” by building understanding of what occurs at the atomic and molecular scale…. The performance expectations in the topic Chemical Reactions help students to formulate an answer to the questions: “What happens when new materials are formed? What stays the same and what changes?” by building understanding of what occurs at the atomic and molecular scale during chemical reactions…. The performance expectations in the topic Forces and Interactions focus on helping students understand ideas related to why some objects will keep moving, why objects fall to the ground and why some materials are attracted to each other while others are not. Students answer the question, “How can one describe physical interactions between objects and within systems of objects?”…. The performance expectations in the topic Energy help students formulate an answer to the question, “How can energy be transferred from one object or system to another?”…. The performance expectations in the topic Waves and Electromagnetic Radiation help students formulate an answer to the question, “What are the characteristic properties of waves and how can they be used?” (NGSS Lead States 2013d)

Introduction

Just about every change that you can think of involves a transfer or conversion of ***energy***. This physical science course for 8th grade is organized around the crosscutting concept of ***energy flows, cycles, and conservation***. While the disciplinary core ideas cover physical science, many of the applications are drawn from earth and life sciences such that the course truly serves as a culmination to the middle school science experience.

Each of the units focuses on one form of ***energy***. The instructional segments are sequenced such that the most conceptually simple energy form (kinetic) comes first, with an emphasis on colliding objects due to both the engineering applications and the importance of collisions in thermal energy that will be discussed in a later instructional segment. The exchange between kinetic energy and gravitational potential energy introduces the concept of potential fields and energy conversion. **Investigations** in the next instructional segment explore electric and magnetic fields, and the role these fields play in the conversion and transfer of various types of energy. An instructional segment covering waves, a means to transfer energy, follows because waves and information transfer are often employed in electrical devices. The course returns to kinetic energy as viewed at a different ***scale*** with an instructional segment on thermal energy that emphasizes the view of matter as moving and colliding particles. The final instructional segment then culminates with chemical potential energy as these particles interact through chemical bonding, providing the mechanism for organisms to store and utilize energy, among many other uses.

Energy is a difficult concept to grasp because it is not something tangible (it is not an object that has mass or can be held), yet it appears to come in many different forms. Textbooks often define energy as the "ability to do work" (with the caveat that the term 'work' has a very specific definition in physical science) or "anything that can be converted into heat." An alternative to these technical definitions that may be less precise but very illustrative is that energy is the "ability to cause damage." For example, there are many different ways a person can get hurt, and each process even has a unique descriptive name just like different forms of energy unique names. For example, you can get hurt when something that is moving hits you. We call this a "crash" in everyday language, and when you describe that you were hurt in a crash, other people instantly know that moving objects were involved (kinetic energy). This manner of getting hurt differs from a "burn," a word that communicates that a hot object was involved (thermal energy). A "sunburn" involves rays of ultraviolet sunshine (a form of light energy). You can be "electrocuted" only if there is electricity around (electromagnetic energy), or "poisoned" by exposing yourself to dangerous chemicals (chemical potential energy). There are also some ways of being hurt that only depend on your position, such as having the potential to get hurt by "falling" when you are high above the ground (gravitational potential energy). The different terms for the different forms of energy are an example of how language is used in science. Scientists label complex processes with specific terminology so that they can communicate many aspects of a situation in a single word or phrase. While this analogy of different ways of getting hurt corresponding to different energy forms helps communicate ideas about the nature of energy to students, it has limitations like all analogies. All of the examples above involve people getting hurt when ***energy*** is transferred. Many forms of energy can be associated with objects (but not, for example, light energy), meaning that the objects have energy even when they are not interacting with anything else. Even though it is possible to calculate the energy of an object by itself, it is really only possible to measure this energy by seeing what happens when objects interact and transfer energy. A transfer of energy involves a “force” – an interaction that can change the motion of an object. Thus forces and energy are closely related, and this course discusses forces largely in terms of their relation to the crosscutting theme of ***energy***.

Example Course Mapping for a Physical Science Course

<table>
<tr><td rowspan="6">Instructional segment 1:
Energy of motion</td><td colspan="3">Performance Expectations Addressed</td></tr>
<tr><td colspan="3">MS-PS2-1, MS-PS2-2, MS-PS3-1, MS-PS3-5, MS-ETS1-1, MS-ETS1-2, MS-ETS1-3, MS-ETS1-4</td></tr>
<tr><td>Highlighted SEP</td><td>Highlighted DCI</td><td>Highlighted CCC</td></tr>
<tr><td>• Developing and Using Models
• Planning and Carrying Out Investigations
• Analyzing and Interpreting Data</td><td>PS2.A: Forces and Motion
PS2.B Types of Interactions
PS3.A Definitions of Energy
PS3.B Relationship Between Energy and Force
PS3.B: Conservation of Energy and Energy Transfer
ETS1.A: Defining and Delimiting an Engineering Problem
ETS1.B: Developing Possible Solutions
ETS1.C: Optimizing the Design Solution</td><td>• Cause and Effect
• Scale, Proportion, and Quantity
• Systems and System Models
• Energy and Matter
• Structure and Function
• Influence of Science, Engineering, and Technology on Society and the Natural World</td></tr>
<tr><td colspan="3">Summary of DCI</td></tr>
<tr><td colspan="3">Objects have energy when they are in motion, and changes to their motion require changes to their energy. When two objects collide, push, or pull on one another, each one exerts a force on the other that can cause energy to be exchanged. Students design bumpers to minimize the effect of a collision and then conduct investigations to understand the physical processes that allowed their bumpers to work.</td></tr>
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<table>
<tr><td rowspan="6">Instructional segment 2:
Gravity, Energy related to position</td><td colspan="3">Performance Expectations Addressed</td></tr>
<tr><td colspan="3">MS-PS2-2, MS-PS2-4, MS-PS2-5, MS-PS3-2</td></tr>
<tr><td>Highlighted SEP</td><td>Highlighted DCI</td><td>Highlighted CCC</td></tr>
<tr><td>• Developing and Using Models
• Planning and Carrying Out Investigations
• Using Mathematics and Computational Thinking</td><td>PS2.A: Forces and Motion
PS2.B Types of Interactions
PS3.A Definitions of Energy
PS3.B Relationship Between Energy and Force
PS3.B: Conservation of Energy and Energy Transfer</td><td>• Cause and Effect
• Scale, Proportion, and Quantity
• Systems and System Models
• Energy and Matter
• Influence of Science, Engineering, and Technology on Society and the Natural World</td></tr>
<tr><td colspan="3">Summary of DCI</td></tr>
<tr><td colspan="3">Some types of forces act on objects even when they are not touching. Gravity attracts objects together. Students explore the interplay between gravity and kinetic energy in roller coasters and determine how the strength of gravity’s attraction depends on the mass of objects and their relative position.</td></tr>
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<table>
<tr><td rowspan="6">Instructional segment 3:
Electric and Magnetic energy and interactions</td><td colspan="3">Performance Expectations Addressed</td></tr>
<tr><td colspan="3">MS-PS2-3, MS-PS2-5, MS-PS3-2, MS-ETS1-3</td></tr>
<tr><td>Highlighted SEP</td><td>Highlighted DCI</td><td>Highlighted CCC</td></tr>
<tr><td>• Asking Questions and Defining Problems
• Developing and Using Models
• Planning and Carrying Out Investigations
• Analyzing and Interpreting Data
• Designing Solutions</td><td>PS2.A: Forces and Motion
PS2.B Types of Interactions
PS3.A Definitions of Energy
PS3.B Relationship Between Energy and Force
PS3.B: Conservation of Energy and Energy Transfer
ETS1.C: Optimizing the Design Solution</td><td>• Patterns
• Cause and Effect
• Systems and System Models
• Energy and Matter</td></tr>
<tr><td colspan="3">Summary of DCI</td></tr>
<tr><td colspan="3">Magnets are familiar and yet mysterious. They exert forces without touching, and students explore magnets to ask questions about the factors that affect the strength of these forces. Electricity and magnetism are related and students create an electromagnet and design an electric motor.</td></tr>
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Instructional segment 4: Waves Transmitting Energy and Information	Performance Expectations Addressed		
	MS-PS4-1, MS-PS4-2, MS-PS4-3		
	Highlighted SEP	Highlighted DCI	Highlighted CCC
	• Developing and Using Models • Engaging in Argument from Evidence	PS4.A: Wave Properties PS4.B Electromagnetic Radiation PS3.B: Conservation of Energy and Energy Transfer	• Energy and Matter • Influence of Science, Engineering, and Technology on Society and the Natural World
	Summary of DCI		
	A simple wave has a repeating pattern whose amplitude is proportional to the energy it carries. Waves can be caused by vibrations in matter or by oscillations of electric and magnetic fields. When waves interact with matter, their energy is either absorbed, reflected, or transmitted. Modern technology depends on waves to transmit digital information. Students generate their own waves in ripple tanks in order to develop models of wave motion and use flashlights to explore energy transfer through light waves. They then explore the history of communication using waves and support the argument that digital communication is superior to analog data transmission.		

<table>
<tr><td rowspan="6">Instructional segment 5:
Thermal Energy and Heat Flow</td><td colspan="3">Performance Expectations Addressed</td></tr>
<tr><td colspan="3">MS-PS1-1, MS-PS1-4, MS-PS3-3, MS-PS3-4, MS-PS3-5, MS-ETS1-1, MS-ETS1-2, MS-ETS1-3</td></tr>
<tr><td>Highlighted SEP</td><td>Highlighted DCI</td><td>Highlighted CCC</td></tr>
<tr><td>• Developing and Using Models
• Planning and Carrying Out Investigations
• Analyzing and Interpreting Data
• Using Mathematics and Computational Thinking</td><td>PS1.A: Structure and Properties of Matter
PS3.A: Definitions of Energy
PS3.B: Conservation of Energy and Energy Transfer
ETS1.A: Defining and Delimiting an Engineering Problem
ETS1.B: Developing Possible Solutions
ETS1.C: Optimizing the Design Solution</td><td>• Cause and Effect
• Energy and Matter
• Stability and Change</td></tr>
<tr><td colspan="3">Summary of DCI</td></tr>
<tr><td colspan="3">Matter is made up of tiny particles that are in constant motion, which means that they have kinetic energy. Particles collide and exchange energy, which is how some heat transport processes work. As temperatures get hotter, the particles move faster and push one another farther apart, which contributes to phase changes. Supported by computer simulations and computational models, students design a vehicle radiator that maximizes the transfer of thermal energy.</td></tr>
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<table>
<tr><td rowspan="6">Instructional segment 6:
Chemical Energy and Reactions</td><td colspan="3">Performance Expectations Addressed</td></tr>
<tr><td colspan="3">MS-PS1-1, MS-PS1-2, MS-PS1-3, MS-PS1-4, MS-PS1-5, MS-PS1-6, MS-ETS1-1, MS-ETS1-2, MS-ETS1-3, MS-ETS1-4</td></tr>
<tr><td>Highlighted SEP</td><td>Highlighted DCI</td><td>Highlighted CCC</td></tr>
<tr><td>• Asking Questions and Defining Problems
• Developing and Using Models
• Planning and Carrying Out Investigations
• Analyzing and Interpreting Data
• Using Mathematics and Computational Thinking
• Constructing Explanations and Designing Solutions
• Engaging in Argument from Evidence
• Obtaining, Evaluating, and Communicating Information</td><td>PS1.A: Structure and Properties of Matter
PS1.B: Chemical Reactions
PS3.A: Definitions of Energy
PS3.B: Conservation of Energy and Energy Transfer
ETS1.A: Defining and Delimiting an Engineering Problem
ETS1.B: Developing Possible Solutions
ETS1.C: Optimizing the Design Solution</td><td>• Patterns
• Cause and Effect
• Scale, Proportion, and Quantity
• Systems and System Models
• Energy and Matter
• Influence of Science, Engineering, and Technology on Society and the Natural World
• Structure and Function
• Stability and Change</td></tr>
<tr><td colspan="3">Summary of DCI</td></tr>
<tr><td colspan="3">Atoms combine together to form molecules. In chemical reactions, the atoms in molecules rearrange to form new molecules with different combinations of atoms. This process can absorb or release energy and causes changes in the properties of materials. Students engineer hand warmers, act out chemical reactions with their bodies, and obtain information about how people use technology to change natural materials into synthetic ones.</td></tr>
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Grade 8 Instructional segment 1: Energy of Motion

Instructional segment 1: Energy of Motion
Guiding Questions: How can understanding energy and forces help make us safer in car crashes? What happens to energy when objects collide or otherwise interact? Why do objects sometimes appear to slow down on their own?
Highlighted Scientific and Engineering Practices: *Developing and Using Models* *Planning and Carrying Out Investigations* *Analyzing and Interpreting Data*
Highlighted Cross-cutting concepts: *Cause and Effect* *Scale, Proportion, and Quantity* *Systems and System Models* *Energy and Matter* *Influence of Science, Engineering, and Technology on Society and the Natural World* *Structure and Function*
Students who demonstrate understanding can: **MS-PS2-1. Apply Newton's Third Law to design a solution to a problem involving the motion of two colliding objects.*** [Clarification Statement: Examples of practical problems could include the impact of collisions between two cars, between a car and stationary objects, and between a meteor and a space vehicle.] [Assessment Boundary: Assessment is limited to vertical or horizontal interactions in one dimension.] **MS-PS2-2. Plan an investigation to provide evidence that the change in an object's motion depends on the sum of the forces on the object and the mass of the object.** [Clarification Statement: Emphasis is on balanced (Newton's First Law) and unbalanced forces in a system, qualitative comparisons of forces, mass and changes in motion (Newton's Second Law), frame of reference, and specification of units.] [Assessment Boundary: Assessment is limited to forces and changes in motion in one-dimension in an inertial reference frame and to change in one variable at a time. Assessment does not include the use of trigonometry.] **MS-PS3-1. Construct and interpret graphical displays of data to describe the relationships of kinetic energy to the mass of an object and to the speed of an object.** [Clarification Statement: Emphasis is on descriptive

	relationships between kinetic energy and mass separately from kinetic energy and speed. Examples could include riding a bicycle at different speeds, rolling different sizes of rocks downhill, and getting hit by a wiffle ball versus a tennis ball.]
MS-PS3-5.	**Construct, use, and present arguments to support the claim that when the kinetic energy of an object changes, energy is transferred to or from the object.** [Clarification Statement: Examples of empirical evidence used in arguments could include an inventory or other representation of the energy before and after the transfer in the form of temperature changes or motion of object.] [Assessment Boundary: Assessment does not include calculations of energy.]
MS-ETS1-1.	**Define the criteria and constraints of a design problem with sufficient precision to ensure a successful solution, taking into account relevant scientific principles and potential impacts on people and the natural environment that may limit possible solutions.**
MS-ETS1-2.	**Evaluate competing design solutions using a systematic process to determine how well they meet the criteria and constraints of the problem.**
MS-ETS1-3.	**Analyze data from tests to determine similarities and differences among several design solutions to identify the best characteristics of each that can be combined into a new solution to better meet the criteria for success.**
MS-ETS1-4.	**Develop a model to generate data for iterative testing and modification of a proposed object, tool, or process such that an optimal design can be achieved.**
Significant Connections to California's Environmental Principles and Concepts: none	

Background and Instructional Suggestions

Imagine a boy standing and reading a book and a girl riding a skateboard down the sidewalk toward him. If they accidentally collide, which person will gain ***energy*** and which person will lose energy? Who will feel a stronger force from the impact? How could this force be minimized so that nobody gets hurt? These are the types of questions that students will be able to answer at the end of this unit.

Engineering Challenge: Reducing the impact of collisions

The unit begins with a design challenge where students use a fixed set of materials to reduce the damage during a collision (*MS-PS2-1*). The classic egg drop could be used, but many of the solutions to that problem involve slowing the egg down before the collision (via parachute). The emphasis for the PE is on applying Newton's Third Law that objects experience equal and opposite forces during collision. A variation where students attach eggs to model cars and design bumpers allows for a consistent theme of car crashes throughout the instructional segment and vehicles in general throughout the course. Students will need to identify the constraints that affect their design as well as the criteria for measuring success (*MS-ETS1-1*). Such a design challenge could be placed at the end of the instructional segment as a culmination where students apply what they have learned from **investigations** throughout the instructional segment, but here the choice is made explicitly to use an engineering task to draw attention to the variables of interest in the problem. By identifying the common features of successful models (*MS-ETS1-3*), they can identify the physical processes and variables that govern the process. Students will then investigate these variables more systematically throughout the rest of the instructional segment. At the end of the instructional segment, they return to their design challenge and **explain** why certain choices they made actually worked and then use their more detailed models of the ***system*** to refine their design.

In the design challenge, there are objects in motion and interactions between the objects that cause them to change their motion. Different design elements reduce the impact of the collision, despite the fact that all the objects have the same initial motion. Why? Students begin a systematic **investigation** using objects such as toy cars or marbles on a track. They start by experimenting with what it takes to get the object to move, **asking questions** about their observations. Does pushing a car work different than pulling it? (It should not make a difference if their pushes and pulls are identical, though students often pull upward along with forward. Why would that make a difference?). If they push the car gently, does it behave differently that if they push it harder? Does the car behave differently if a human pushes it versus if it is pushed by another car?

In order to talk in detail about the similarities and differences in the motion of an object, students need to be able to make specific measurements of the motion. The word 'motion' in the *CA NGSS* implies both the object's speed and its direction of travel. However, all work in this instructional segment is done in one dimension and the focus is on speed; the distinction between the technical definitions of 'velocity' and 'speed' is not essential (the assessment boundaries of PE's for 8th grade clearly state that assessment is restricted to forces that are aligned or to ***systems*** of only two objects. In high school, students will extend this understanding into two and three dimensions). Speed is the ratio of a distance and a time, allowing students to easily conduct **investigations** that measure both ***quantities***. Manual measurements of time in tabletop experiments using stopwatches are prone to large error, so there are several alternatives: students can pool multiple measurements using collaborative online spreadsheets and take the average, use an app to calculate speed from video clips[42], or use a motion sensor probe.

Students often harbor the preconception that objects will naturally stop when they run out of 'inertia' or when the force given to them 'runs out.' This idea is based on abundant personal experience with moving objects that do indeed stop 'automatically' because of friction, a force that can be reduced or increased by design measures. Understanding why objects slow down requires thinking about motion in terms of ***energy***. Students build on their **explanation** of the relationship between these ideas from 4th grade (*4-PS3-1*) and their model for the ***conservation of energy*** from 5th grade (*5-PS3-1*). An object retains its kinetic energy until it transfers it to another object or converts the energy to another form, which is the conceptual model that explains Newton's First Law that an object in motion tends to stay in motion while an object at rest tends to stay at rest unless unbalanced forces act upon it. Students can create a

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

diagrammatic **model** of the ***flow of energy*** within ***systems*** as shown in Figure 25. This simple diagram is a model because it includes components (an energy source and receiver), an understanding of the way these objects will interact based on the laws of physics (energy is conserved, with one object decreasing in energy that will be transferred to the other object), and it can be used to predict the behavior of the ***system*** (the object that decreases in kinetic energy slows down while the object that increases in kinetic energy should speed up). Students can use these types of diagrammatic models to illustrate energy transfer throughout[43] the course.

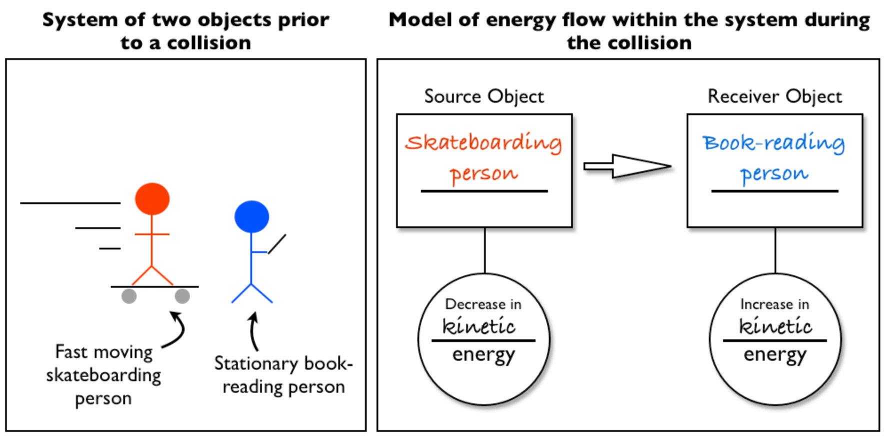

Figure 25. Model of energy flow within a system during a collision. Image credit: M. d'Alessio, released to the public domain.

The force of friction is an interaction in which ***energy*** is transferred. Students must **plan investigations** to explore the effects of balanced and unbalanced forces on the motion of objects (*MS-PS2-2*). One such investigation could involve measuring the velocity of model cars with different amounts of friction by attaching sticky notes to the front and sides of the car to vary the amount of friction. Students should notice that when they push the car, they apply a force in one direction while friction is a force working in the opposite direction. The overall change in motion (and therefore change in energy) depends on the total sum of these forces. Using an energy source/receiver

[43] Diagrams based on those introduced in Physical Science of Everyday Thinking by Goldberg et al.

diagram to model the situation helps draw attention to the fact that some of the energy must go somewhere because the cart clearly decreases in energy but that means another component of the ***system*** must increase in energy (**Figure 26**). With some simple analogies to the friction of hands rubbing together, students can accept that the energy is likely converted into thermal energy, which will be discussed in more detail in instructional segment 5. When rubbing hands together, both hands warm up even when one hand remains stationary. This observation gives rise to two modifications to the simple energy source/receiver diagram of Figure 25 that are depicted in **Figure 26**: 1) there can be multiple energy receivers in a ***system*** from a single energy source; and 2) an object can be both the source and the receiver of energy if that energy converts from one form to another. Students will revisit this idea in instructional segment 2, but the remainder of this instructional segment emphasizes the transfer of energy between two distinct objects.

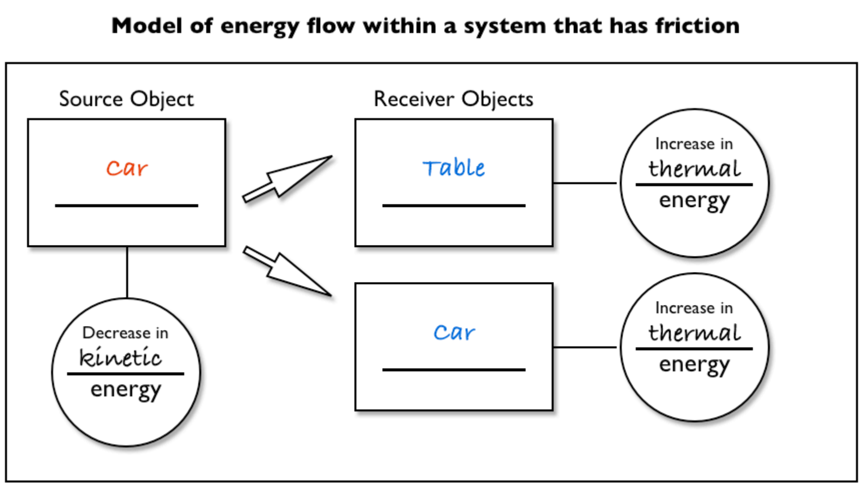

Figure 26. Model of energy flow within an experimental system of a tabletop car with realistic friction. Image credit: M. d'Alessio, released to the public domain.

During an interaction when a force acts on an object, that object will gain kinetic energy. How much will the object's motion change during this interaction? Students asked similar **questions** in 4th grade (*4-PS3-3*), and now they will begin to answer them. The answer depends strongly on the object's mass. This principle becomes easily apparent in collisions. Students can perform **investigations** into colliding a given object with objects of different masses that are otherwise identical (for example glass versus steel marbles of different sizes, cars with or without fishing weights attached, etc). In order to measure consistent ***patterns***, students will need to **plan their investigation** (*MS-PS2-2*) such that the source object has a consistent speed (by rolling down a ramp of a fixed distance, for example). This will ensure that the initial kinetic energy of the object is the same and lead to a consistent force during the collision interaction, if all other factors remain constant. Students can vary the mass of the target object and see how its speed changes as a result of the impact, plotting the results to look for a consistent pattern. This graphical representation should lead them towards a discovery of Newton's Second Law that relates the change in an object's motion ('acceleration') to the force applied and the mass of the object. *MS-PS2-2* does not require that students have a mathematical understanding of acceleration, it instead focuses on the ***proportional*** relationship of motion changes and force.

When the objects have equal masses and collisions transfer all of the ***energy*** from source to receiver, the speed of the target object should be similar to the speed of the source object, which can be seen clearly in billiards when the cue ball comes to a complete stop after hitting another ball. Observations such as these provide evidence to make the **argument** that as one object loses kinetic energy during the collision, another object must gain energy, and vice-versa (*MS-PS3-5*).

In each collision so far, the target object always receives the same amount of ***energy*** from the source object (the model in Figure 25 illustrates that energy transfer does not depend on the object’s mass). The effect of this energy transfer on the target object's speed, however, does depend on its mass. This observation is the basis for understanding more about kinetic energy. Energy transfers can be thought of as analogous to transfers of money, such as winning the lottery. If a single person buys a lottery ticket alone and wins, he or she will have a big change in bank account and lifestyle. If a group of people get together to buy the ticket, the jackpot is split amongst them and the change in each person's lifestyle will be smaller. To relate the analogy to the collision, the same amount of energy must go into changing the speed of a larger amount of mass. Students can explore this idea further by changing the kinetic energy of the source object. Keeping the target object constant, groups of students can be assigned to vary either the source object's mass or its speed to see how the changes impact the speed of the target.

Common Core Connection

Each group should graph their findings and report to the class their interpretation of the relationship between kinetic energy and their variable (*MS-PS3-1*). Students should notice that the two graphs have very different forms. One is linear while the other has a curved shape that can be described by a square root (*CA CCSSM 8.EE.2*). They can be given the challenge of finding different combinations of source object speed and mass that all result in the target object going the same speed.

Students are now ready to return to their design challenge of reducing the impact of a collision. They should be able to use their models of ***energy*** transfer and kinetic energy to make an **argument** about why their original design solution worked. Two different processes help bumpers reduce damage during collisions: 1) they absorb some of the energy so that less of it gets transferred to kinetic energy in the target object (the absorbed energy gets converted to heat); and 2) they make the collision last longer, so that the transfer of energy occurs over a longer time interval (since speed changes at a slower rate, Newton's laws tell us that a smaller force is exerted on the cars). Students should be able to create energy source/receiver diagrams such as Figure 25 to describe the energy flow during a collision that includes a bumper and begin to **ask questions** about where the energy actually "goes" during the interaction. They should also be able to propose improvements to their bumper (*MS-ETS1-2, MS-ETS1-4*) using the results of a more sophisticated testing regime and their enhanced understanding of the physical processes.

Grade 8 Instructional segment 2: Gravity, Energy Related to Position

Instructional segment 2: Gravity, Energy Related to Position
Guiding Questions: What affects the strength of the force of gravity? How do roller coasters get the energy to go so fast? Do heavy objects fall faster than lighter ones?
Highlighted Scientific and Engineering Practices: *Developing and Using Models* *Planning and Carrying Out Investigations* *Using Mathematics and Computational Thinking*
Highlighted Cross-cutting concepts: *Cause and Effect* *Systems and System Models* *Energy and Matter* *Influence of Science, Engineering, and Technology on Society and the Natural World*
Students who demonstrate understanding can: **MS-PS2-2. Plan an investigation to provide evidence that the change in an object's motion depends on the sum of the forces on the object and the mass of the object.** [Clarification Statement: Emphasis is on balanced (Newton's First Law) and unbalanced forces in a system, qualitative comparisons of forces, mass and changes in motion (Newton's Second Law), frame of reference, and specification of units.] [Assessment Boundary: Assessment is limited to forces and changes in motion in one-dimension in an inertial reference frame and to change in one variable at a time. Assessment does not include the use of trigonometry.] **MS-PS2-4. Construct and present arguments using evidence to support the claim that gravitational interactions are attractive and depend on the masses of interacting objects.** [Clarification Statement: Examples of evidence for arguments could include data generated from simulations or digital tools; and charts displaying mass, strength of interaction, distance from the Sun, and orbital periods of objects within the solar system.] [Assessment Boundary: Assessment does not include Newton's Law of Gravitation or Kepler's Laws.] **MS-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.] [Assessment Boundary: Assessment is limited to electric and magnetic fields, and is limited to qualitative evidence for the existence of fields.]
MS-PS3-2.	**Develop a model to describe that when the arrangement of objects interacting at a distance changes, different amounts of potential energy are stored in the system.** [Clarification Statement: Emphasis is on relative amounts of potential energy, not on calculations of potential energy. Examples of objects within systems interacting at varying distances could include: the Earth and either a roller coaster cart at varying positions on a hill or objects at varying heights on shelves, changing the direction/orientation of a magnet, and a balloon with static electrical charge being brought closer to a classmate's hair. Examples of models could include representations, diagrams, pictures, and written descriptions of systems.] [Assessment Boundary: Assessment is limited to two objects and electric, magnetic, and gravitational interactions.]
Significant Connections to California's Environmental Principles and Concepts: none	

Background and Instructional Suggestions

Some interactions happen even when objects are not touching, and the most familiar of these involve gravity. Gravity is one of only four fundamental forces in the Universe, and it attracts literally all objects with mass in the Universe together. The Golden Gate Bridge pulls on the Hollywood sign (and every student in the state) just like the Moon pulls on the Earth. The reason we don't notice this pull is that it is so weak compared to the attraction towards Earth itself. That is because the planet has so much more mass than the Hollywood sign or even the Golden Gate Bridge. Since all mass is attracted to all other mass in the Universe, it is also true that the Sun itself pulls on every student in the class. The star Alpha Centauri is many times more massive than the Earth, so why don't students fly up in the sky towards that star or any of the others? The answer is that the strength of the gravitational force also depends on the relative position of the two objects (i.e., the distance between them). Gravity on Earth is usually thought of as pulling objects towards 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 rock directly beneath his or her feet exerting the strongest pull and the rock on the opposite side of the planet having the weakest because of its distance away. Just like students investigated the sum of forces when objects are touching in instructional segment 1 (*MS-PS2-2*), the overall change in motion is ***caused*** by the sum of all the forces. The Earth is a sphere, so there is approximately the same amount of rock to the north, south, east, and west of a person and the overall effect is a downward pull towards the center of the planet. With very careful measurements, however, scientists can measure slight differences in the direction and strength of the pull of gravity at different locations on Earth. For example, if an underground aquifer is full of water or a volcano magma chamber fills with magma, the extra mass will pull slightly harder on objects than if the aquifer was dry or the magma chamber empty. This pull can even be measured by satellites orbiting the planet that provide valuable data for monitoring global water supplies and volcanic hazards.[44]

Students conduct **investigations** into gravitational interactions on Earth to create a mental **model** of the relationship between the concepts of gravity, force, and energy. Their investigation could include letting cars roll down ramps or dropping balls and recording their speed at different points in time with a sensor probe or frame-by-frame video analysis app. For this particular investigation, students should explicitly **evaluate** the experimental design, which might include the teacher providing students with a cookbook-style procedure with an intentional flaw in it that students must correct before collecting valuable data. They notice a change in motion, which must be caused by a force that exists even though the objects are not touching (*MS-PS2-5*; even though assessment on this PE is restricted to electric and magnetic fields, the same principle applies to gravitational fields). By noticing that the speed of the object changes, they infer that the kinetic energy of the object is increasing (assuming that its mass doesn't change). If an object increases in ***energy***, that energy must come from some sort of

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

interaction. The inevitable conclusion is that there must be some sort of energy associated with gravity, and scientists refer to it as gravitational potential energy. The everyday language use of the word ‘potential’ applies fairly well in this situation in that there is energy ready to be unleashed with the capability to do work because the force of gravity is always acting on the object. The moment that this force acts unbalanced on an object, there will be a net transfer of energy and the potential energy will convert to motion or vice versa (*MS-PS2-2*; **Figure 27**). Other forces for which the energy change depends only on the final position of the object (as opposed to the path it took to reach that position) are also said to be associated with potential energies (such as electric forces discussed in instructional segment 3 and the elastic forces in springs and other materials).

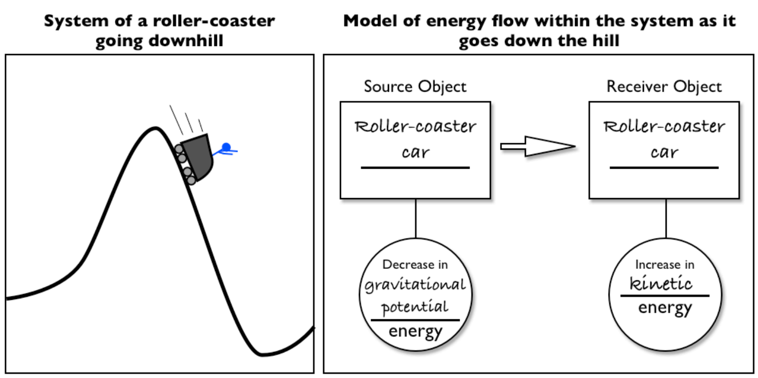

Figure 27. Schematic diagram and model of energy flow within a system of a roller coaster going downhill. Note that the source and receiver objects are the same but the type of energy has changed.

Students can extend their **investigation** to include the interplay between gravitational potential and kinetic energy by predicting an object’s speed as it moves between different heights (by creating a roller coaster, marble track, or simply throwing a ball upwards and recording its speed at points moving upward and downward). They can use their roller coaster to **develop a model:** changes in the position of the object affect the amount of gravitational potential ***energy*** it has (*MS-PS3-2*). This model should allow them to predict how high a car will go on a ramp when released at different heights or how its speed will change as it moves from one height to another. Their model can be refined by interacting with a computer simulator of a roller coaster or skate park[45].

Common Core Connection

One of the things students may notice in either physical or computer simulations is that the mass of the object does not affect its speed as an object's ***energy*** converts back and forth between gravitational potential and kinetic energies. This observation will likely surprise many students who harbor the common preconception that heavier objects fall faster. Students' mental model of forces should include the idea that objects with more mass require a stronger force to speed up and slow down. The force of gravity pulls harder on heavier objects. This stronger gravitational pull is exactly balanced by the greater inertia of massive objects such that all objects end up falling at the same speed on planet Earth. Students should use evidence (likely from computer simulations) to construct an **argument** that gravitational interactions attract objects together and depend on the mass of the object (*MS-PS2-4*). To **communicate** their argument, students may construct fact sheets that include charts showing the relative strength of different interactions (such as Earth-Moon, Earth-Sun, Jupiter-Sun, Earth-student, or even student-student interactions). CA NGSS explicitly states that students will not be assessed on using the formula for Newton's Law of Gravitation, but students can use the equation to apply scientific notation to a real-world problem (*CA CCSSM 8.EE.4*). Regardless of their ability to do the calculations themselves, they should be able to represent the relative magnitudes (i.e., ***scale and proportion***) of these forces using scientific notation (*CA CCSSM8.EE.3*). Students can also use this sort of **mathematical thinking** to **evaluate the claims** of astrology by examining the relative strength of the force of gravity between themselves and each of the planets. How do these magnitudes compare to the scale of other gravitational forces such as the force between the student and the desk they are sitting at or the textbook they are reading? Are they large enough to ***cause*** major changes to interactions on Earth?

[45] PhET, Energy Skate Park: https://phet.colorado.edu/en/simulation/energy-skate-park

3773 **Grade 8 Instructional segment 3: Electric and Magnetic Interactions and Energy**

Instructional segment 3: Electric and Magnetic Interactions and Energy
Guiding Questions: How do electric motors work to convert electricity into motion? How does a compass needle move?
Highlighted Scientific and Engineering Practices: *Asking Questions and Defining Problems* *Developing and Using Models* *Planning and Carrying Out Investigations* *Analyzing and Interpreting Data* *Designing Solutions*
Highlighted Cross-cutting concepts: *Patterns* *Cause and Effect* *Systems and System Models* *Energy and Matter*
Students who demonstrate understanding can: **MS-PS2-3. Ask questions about data to determine the factors that affect the strength of electric and magnetic forces.** [Clarification Statement: Examples of devices that use electric 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 strength of an 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-PS2-5. 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.] [Assessment Boundary: Assessment is limited to electric and magnetic fields, and is limited to qualitative evidence for the existence of fields.] **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.]
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.**
Significant Connections to California's Environmental Principles and Concepts: none	

Background and Instructional Suggestions

More and more vehicles are using electric motors that use electricity and magnets to push against one another. Electric car motors are big and expensive, but students can disassemble smaller electric motors from old fans or other electronics to look inside (donated by parents or purchased cheaply at local thrift stores). As they open them up, they will encounter wires carrying electricity and magnets[46]. How do these interact with one another to push a car?

Electricity and magnetism are grouped together in physics courses because they are ultimately driven by the same fundamental force, and they can interact with one another. Both are, like gravity, examples of forces that act on objects even when the objects are not touching, and both are associated with a potential ***energy***. Unlike gravitational fields around stars and planets that are hard to visualize, students can easily investigate magnetic fields with simple bar magnets and iron filings (*MS-PS2-5*).

[46] Arizona Science Lab, All About Electric Motors, http://www.azsciencelab.org/All_About_Electric_Motor.php and https://youtu.be/PdqOgUtl3WM

Placing the iron filings on top of a thin, flat piece of clear plastic, students can place various magnets and magnetic objects beneath the screen. They should begin to **ask questions** about the spatial ***patterns*** they see (*MS-PS2-3*). What happens if two magnets are placed end-to-end versus side-by-side? Does the pattern change as a magnetic object is held in between? The iron filings also tend to concentrate in areas where the magnetic force is strongest. Does the location of strong magnetic field change in any situations? Can they arrange the magnets so that they create a stronger force?

While many teachers are familiar with thinking about magnetic forces, what is the relationship between magnets and ***energy***? Magnetic fields are 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. This is the basic principle behind electric motors. By **analyzing data** from frame-by-frame video analysis of a compass needle, students can determine the conditions that cause the needle to gain the most kinetic energy. They use these observations to support their **model** that the arrangement of objects determines the amount of potential energy stored in the ***system*** (*MS-PS3-2*).

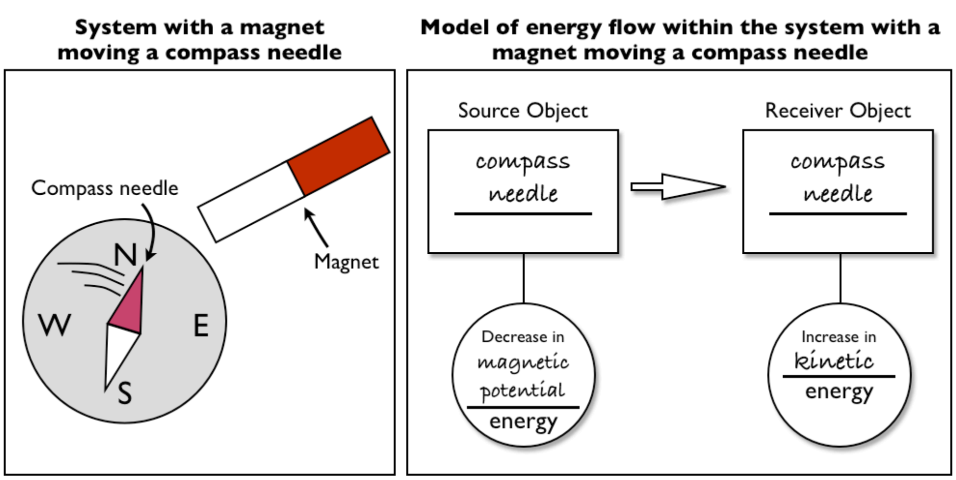

Figure 28. Schematic diagram and model of energy flow within a system of a magnet moving a compass needle. Note that the energy source/receiver model is very similar to the roller coaster being pulled by gravity in **Figure 27**.

Students then **investigate** electromagnets using iron filings to see that they create magnetic fields with similar spatial ***patterns*** to permanent magnets. Students can be given a challenge to create the strongest electromagnet, allowing different groups to **ask questions** about the factors that affect magnetic strength such as the number or arrangement of batteries, number of turns of the coil, or material inside the coil (*MS-PS2-3*). They can compare their results from this investigation to a computer simulator that also visualizes the magnetic fields[47].

They can then apply their knowledge to electric cars by creating a small electric motor using just a battery, a magnet, and magnet wire[48]. What approach will create the motor that spins fastest? (*MS-PS2-3*). Students present their designs and each group must refine its motor, potentially integrating successful design elements from other groups (*MS-ETS1-3*). Like all engineering design, they will need to figure out a way to measure and compare the performance of different designs. For example, they could slowly step through a video recording of their motor to count the number of turns their motor completes in 5 seconds. Students can create a graph comparing this ***quantification*** of motor speed to the initial length of wire used in the motor coil, the number of loops of wire in the coil, or other factors. Two students might have used identical wires for the coil but their motors perform differently, so students can focus in on what differences there might be between the two designs or how carefully they were constructed. Students then return to the motor that they dissected at the beginning of the instructional segment and compare it to their simple motor. Why is the real motor designed the way it is?

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[47] PhET, Magnets and Electromagnets, https://phet.colorado.edu/en/simulation/magnets-and-electromagnets

[48] Museum of Science and Industry, Build an Electric Motor, http://www.msichicago.org/online-science/activities/activity-detail/activities/build-an-electric-motor/browseactivities/0/

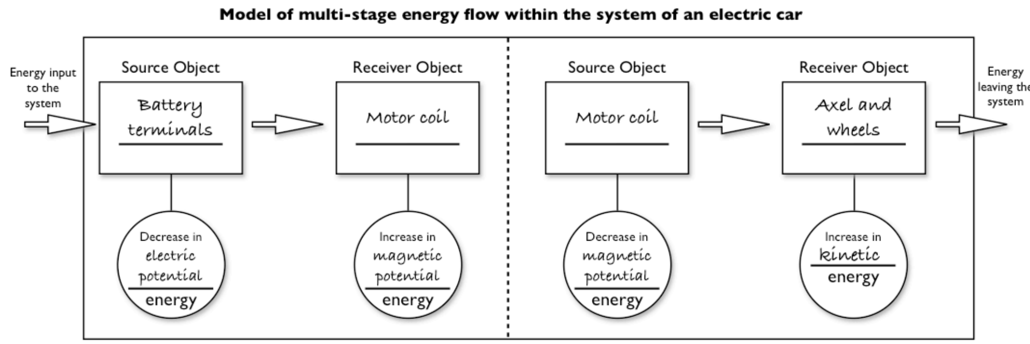

Figure 29. Model of multi-stage energy flow within the system of an electric car. Note that the energy chain continues on both sides of the chosen system (energy must come from somewhere outside the system and will eventually leave the system.

Grade 8 Instructional segment 4: Waves Transmitting Energy and Information

Instructional segment 4: Waves Transmitting Energy and Information

Guiding Questions:

How do waves interact with different objects?

How are waves used to move energy and information from place to place?

Highlighted Scientific and Engineering Practices:

Developing and Using Models

Engaging in Argument from Evidence

Highlighted Cross-cutting concepts:

Energy and Matter

Influence of Science, Engineering, and Technology on Society and the Natural World

Students who demonstrate understanding can:

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

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

MS-PS4-3. Integrate qualitative scientific and technical information to support the claim that digitized signals are a more reliable way to encode and transmit information than analog signals. [Clarification Statement: Emphasis is on a basic understanding that waves can be used for communication purposes. Examples could include using fiber optic cable to transmit light pulses, radio wave pulses in wifi devices, and conversion of stored binary patterns to make sound or text on a computer screen.] [Assessment Boundary: Assessment does not include binary counting. Assessment does not include the specific mechanism of any given device.]

Significant Connections to California's Environmental Principles and Concepts:
Principle IV - There are no Permanent or Impermeable Boundaries that Prevent Matter from Flowing Between Systems

Background and instructional Suggestions

Electricity and magnetism work together to transmit another type of ***energy***, 'electromagnetic radiation' which manifests itself as light, radio waves, microwaves, and x-rays, among others. Learning how to convert electricity to electromagnetic radiation has allowed engineers to design all sorts of technology, especially ***technology*** to help communicate voices, images, and data. In this instructional segment, students make simple models of how waves travel and how they can be used to transmit information.

Even though radio waves used for communication are invisible oscillations of electromagnetic fields, they share a lot in common with waves in the ocean and other examples of 'mechanical waves.' Mechanical waves involve the back-and-forth motion of physical materials instead of the oscillations of invisible fields, but the idea of repeated oscillatory movement is common between them. In fact, waves share several common features: 1) They are repeating quantities; 2) They interact with materials by being transmitted, absorbed, or reflected; 3) They can transfer ***energy*** over long distances without long distance movement of matter; 4) They can be used to encode information.

Over the course of this instructional segment, modeling activities should begin with mechanical waves propagating in a matter medium that is visible (such as water waves), then waves that propagate through a matter medium that is invisible (such as sound waves moving through air), and finally wave models of light. **Investigations** with real-world objects can be complemented with technology. Computer or smartphone apps provide interactive simulations of simple waves[49], ripple tanks[50] or even display

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

the waveforms of sound recorded by microphones so that students can use their personal technology as an oscilloscope to visualize waveforms of noises in the room.

Students begin instructional segment 4 by **investigating** a variety of waves they can generate and observe in a flat-bottomed water container (ripple tank). Students observe and discuss general properties of waves as observed including reflection and reflections from a barrier, transmission of one wave through another, transmission of a wave past a row of posts, and even addition of multiple waves to make complex waveforms. Placing floating objects at the surface and drops of colored dye below the surface allow students to track the motion of particles within the tank. All of these observations of phenomena should provoke students to **ask questions** about some of the unique wave behaviors. Each group of students could use a digital camera to create a short video clip of a surprising or exciting observation that they would like to understand further. These questions can form the organizing ***structure*** for the instructional segment, and teachers can revisit them often.

Waves are part of so many different physical processes, but these all share some common aspects related to the shape, direction of their motion, and how this motion changes over time. To help discuss these common elements, scientists often use a diagrammatic representation of a “typical” wave shape as a regularly spaced series of peaks and valleys (**Figure 30**), and have developed a common set of vocabulary to describe key aspects of this shape and its change over time. By illustrating simple waves on a stretched rope or spring, students should be able to describe a wave’s amplitude, wavelength, frequency, wave speed. They can also apply these terms to describe things they saw in their ripple tank investigation.

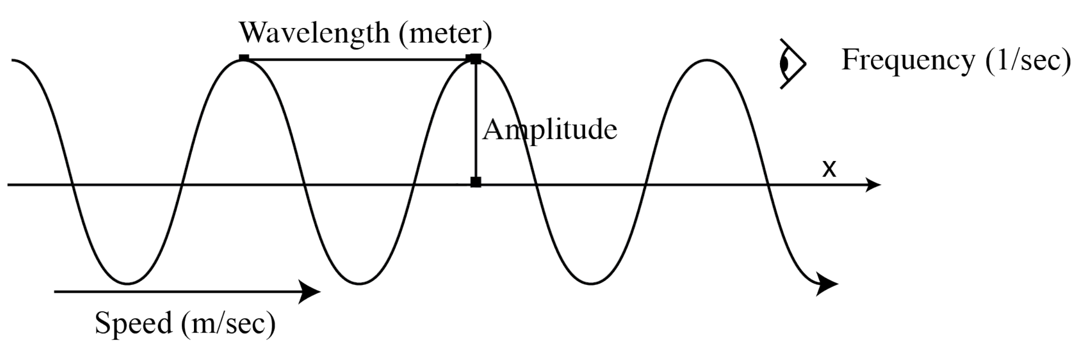

Figure 30. Diagrammatic representation of a wave.

Having become familiar with the properties of waves and developed ways to represent and describe travelling waves, students are ready to think about and model waves and/or wave pulses as carriers of ***energy*** and of information. They can readily recognize that a wave or wave pulse of water in the open ocean transmits energy (in the form of motion of the medium): they can see the motion of the water up and down by observing a boat bobbing at the surface (motion = kinetic energy) and they know that the wave will eventually crash into the shore and transfer this energy. They can also see that more of this up and down motion results in a higher amplitude, thus qualitatively connecting the growth in amplitude of the wave to an increase in the energy it transmits (*MS-PS4-1*). Students can make this representation quantitative by dropping different size objects into a tank and measuring the height of waves generated (perhaps with the aid of digital photography to allow more precise measurements of the fast-moving waves).

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

Using students' **models** of wave motion, amplitude, and ***energy*** allows students to come up with an **explanation** for why waves break at the beach (allowing for California's famous surfing and other beach play). Surfers know that the water in a breaking wave is moving toward the beach (which pushes their surfboard forward), but out beyond the breakers, it is not! They wait beyond the breakers and bob up and down until a good wave arrives and then they paddle forward into the location where waves begin to break. When the water gets shallow enough, there is not enough room for the wave to move up and down over its full amplitude without pushing against the sand below. The wave can no longer continue to have all its kinetic energy as up and down motion, and some of the energy gets transferred into forward motion that begins to 'tip the wave over' and cause it to 'break'. Students can explore this phenomenon in a ripple tank by introducing a sloping bottom spanning about a third of the tank length and driving waves by moving a flat object up and down at the other end of the tank. They can observe the relationship between the location where the sloped bottom begins and where waves begin to break, and vary the slope angle to measure its effect on the waves.

While water waves are easily recognizable as waves, students need evidence to believe that light and sound are waves. Since students' models of waves include motion, they may wonder what is moving in the sound wave or the light wave. For sound, students can readily feel the movement as sound passes through a solid and **develop a model** of back and forth motion of the solid material. This model is then readily generalized to a model for sound travelling through a gas, where this motion cannot be directly observed. Eventually this work must link to particulate models of solids and gases developed later in instructional segment 5 and the way the particles in the medium move as sound travels through it to develop a model of a sound wave. Students can observe the driving energy of sound by observing the vibrations of speakers using slow motion video clips or by simply placing paper scraps on top of a large speaker. Students should be able to draw diagrams relating the driving motion from the speaker to the driving motion in the ripple tank in order to **communicate** their **model** of waves. Sound exhibits other key aspects of waves: two sounds from different sources can pass through one another and emerge undisturbed, sound waves reflect or are absorbed at various surfaces or interfaces and they can be described by frequencies (pitch) and amplitudes (loudness).

For middle grade students, the idea that light is also a wave phenomenon can best be developed by the fact that it shows all the behaviors of waves (reflection, absorption, transmission through a medium such as glass, carrying ***energy*** and information from place to place, MS-PS4-2). Different frequencies of the wave manifest themselves as different colors, and the wave's amplitude is observed as light's brightness. The obvious question, "what is the moving medium in a wave pattern for light?" is difficult to answer at this grade level. In light, the 'movement' is actually the changing pattern of electric and magnetic fields travelling across space or through some forms of matter. Students will explore the nature of light more in the high school physics course and detailed understanding of electromagnetic waves should probably be saved until then.

Light is an ideal platform for investigating the reflection, absorption, and transmission of waves because students can literally see these processes in action Students can perform **investigations** to compare the different effect of mirrors and different color paper on the path of light. Students can draw diagrams to **model** each situation, tracing the path of light and how ***energy*** is transferred to different objects based upon the interaction between each the light and the materials (*MS-PS4-2*; **Figure 31**). In fourth grade, students already began developing a model of how light allows objects to be seen (*4-PS4-2*), and teachers should connect to that learning experience to emphasize that reflection is crucial because we only see objects after they reflect light back to our eyes. White paper reflects light and most reams of paper have a label that the paper industry calls the paper's 'brightness', but this is really related to percentage of light reflected by the paper (measured in a specific frequency range). A '96 bright' paper reflects about 96% of the incident light, which is actually more efficient than many mirrors. How can this be since light reflected off mirrors seems so much brighter? The answer is that paper is rough at the microscopic level, so the light is reflected in all directions instead of concentrated in one place like it is when light bounces off a smooth mirror. So the total reflection of white paper and mirrors are often comparable, but people only observe a small portion of the paper's reflection from one location. Shining a light on some shockingly bright fluorescent colored paper appears to reflect more than 100% of the visible light energy, in apparent violation of ***conservation of energy***. What is the source of this 'extra' energy? In fact, these papers contain dyes that absorb invisible ultraviolet energy and re-emit that energy as visible light that gets added to the total visible light reflected off the paper. Some white papers as well as many laundry detergents also include these dyes that increase the apparent brightness of surfaces. Unfortunately, these dyes can decrease the recyclability of paper and are another chemical going down the drain for laundry detergents (*EP&C Principle IV*).

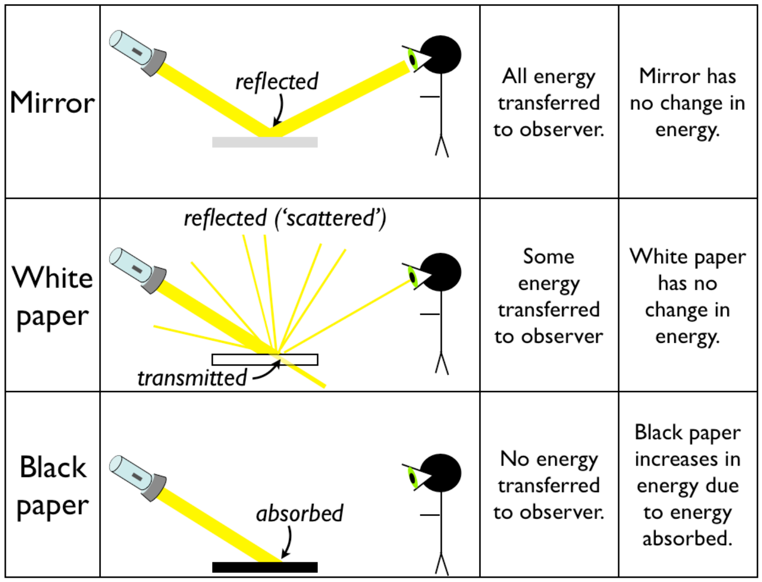

Figure 31. A pictorial model of the interactions between light waves and different ideal materials.

In earlier grades students have developed an understanding of how humans and other animals use light and sound to gain information about the world around them and transmit information to others. In this instructional segment the emphasis shifts to the use of technology to greatly expand our ability to transmit information encoded as waveforms or wave pulses over large distances. For example, converting sound to electromagnetic signals that are transmitted over a distance and converted back to sound at a receiver (telephone, radio). Historical examples of encoded information in wave pulses such as drum or smoke signals, the invention of Morse code and early telegraph systems, can be helpful to develop both the idea of information in a waveform and the idea of encoding information. Finding out about and understanding the difference between an am and an FM radio signal may provide an interesting activity. Understanding how fiber optics technology allows us to transmit light signals over similarly large distances and around corners The idea of noise that can confuse the transmitted signal can be developed with little distortion, or investigating what is wifi provides more modern examples The notion that signals are degraded by noise can first be introduced with activities with sound such as the game of telephone (a whispered message passed from student to student rarely emerges unchanged). The idea of noise must be generalized from that of random sounds to that of random signals of the type being transmitted. The teacher can then introduce design challenges related to how best to avoid the degradation of information in a long range communication system. Teachers can challenge their students to investigate ways to overcome or minimize this problem and ensure that the signal is encoded in a way that the information is less readily destroyed or corrupted when some low level of noise is added to the signal. Students should be able to engage in an **argument** about the benefits of digital encoding over analog encoding of information (*MS-PS4-3*).

The purpose of this last part of the instructional segment is not to develop detailed understanding of the functioning of all the relevant technology, but simply to begin to recognize that engineers utilize an understanding of how sound and electromagnetic waves are produced or absorbed to design all of our modern communication and computation technologies.

Grade 8 Instructional segment 5: Thermal Energy and Heat Flow

Instructional segment 5: Thermal Energy and Heat Flow
Guiding Questions: How can we represent matter at the microscopic level? When an object is hot, how is it different from when it is cold? What happens when hot objects and cold objects interact? What happens to the kinetic energy of an object when it crashes or collides with the ground and stops?
Highlighted Scientific and Engineering Practices: *Developing and Using Models* *Planning and Carrying Out Investigations* *Analyzing and Interpreting Data* *Using Mathematics and Computational Thinking*
Highlighted Cross-cutting concepts: *Cause and Effect* *Energy and Matter* *Stability and Change*
Students who demonstrate understanding can: **MS-PS1-4. Develop a model that predicts and describes changes in particle motion, temperature, and state of a pure substance when thermal energy is added or removed.** [Clarification Statement: Emphasis is on qualitative molecular-level models of solids, liquids, and gases to show that adding or removing thermal energy increases or decreases kinetic energy of the particles until a change of state occurs. Examples of models could include drawings and diagrams. Examples of particles could include molecules or inert atoms. Examples of pure substances could include water, carbon dioxide, and helium.] **MS-PS3-3. Apply scientific principles to design, construct, and test a device that either minimizes or maximizes thermal energy transfer.*** [Clarification Statement: Examples of devices could include an insulated box, a solar cooker, and a Styrofoam cup.] [Assessment Boundary: Assessment does not include calculating the total amount of thermal energy transferred.] **MS-PS3-4. Plan an investigation to determine the relationships among the energy transferred, the type of matter, the mass, and the change in the average kinetic energy of the particles as measured by the**

	temperature of the sample. [Clarification Statement: Examples of experiments could include comparing final water temperatures after different masses of ice melted in the same volume of water with the same initial temperature, the temperature change of samples of different materials with the same mass as they cool or heat in the environment, or the same material with different masses when a specific amount of energy is added.] [Assessment Boundary: Assessment does not include calculating the total amount of thermal energy transferred.]
MS-PS3-5.	**Construct, use, and present arguments to support the claim that when the kinetic energy of an object changes, energy is transferred to or from the object.** [Clarification Statement: Examples of empirical evidence used in arguments could include an inventory or other representation of the energy before and after the transfer in the form of temperature changes or motion of object.] [Assessment Boundary: Assessment does not include calculations of energy.] Revisited from instructional segment 1.
Significant Connections to California's Environmental Principles and Concepts: none	

Background and instructional Suggestions

What is heat? Is it something you can hold? Does it have mass? While the word 'heat' is a noun, it may be better to think of the adjective form as a description of matter: 'hot stuff.' Even as far back as ancient Greece, Democritus made the statement that "opinion says hot and cold, but the reality is just atoms and empty space." The goal of this instructional segment is to help students understand what is meant by that statement and how it relates to car crashes and ***conservation of energy***.

In grade 4, students observed that heat flow is a mechanism to transfer ***energy***, but they did not make any quantitative measurements or come up with a model to **explain** what heat is or how it can be transferred. To set the stage, students should be given a challenge question for formative assessment (Keeley, Eberle, and Farrin 2005). A person has two identical thermometers and places one inside a mitten and the other on the table just beside the mitten. After a few hours, what will happen to the temperature shown on the two thermometers? Many students will incorrectly say that the thermometer inside the mitten will heat up, but there is no energy source such as a human body to cause this increase. As long as one object is hotter than objects or its surroundings, it will serve as an energy source that transfers energy to its surroundings (**Figure 32**). A mitten serves as an insulator that reduces some of this energy transfer between the hand and the cold air. By thinking about how their own bodies are hotter than their surroundings, students are ready to **conduct a detailed investigation** into the factors that affect heat transfer between objects at different temperatures (*MS-PS3-4*). Their goal is to determine how factors such as the amount of material they use, the temperature difference at the start of the investigation, and the type of material affect the transfer of ***energy*** between two objects (PS3.B). There is a lot of flexibility in the experiment students choose and it is difficult to investigate all the factors in a single, simple experiment. *MS-PS3-4* assesses whether or not students can identify a specific sub-question related to heat transfer and design an experiment that collects evidence that will help answer that question. To ensure that students see the role of each factor, student groups **communicate** the results of their experiment to the entire class.

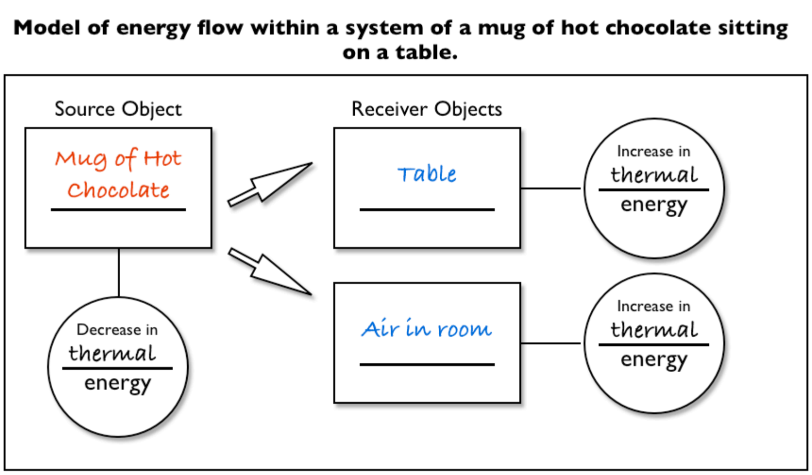

Figure 32. Model of energy flow within a system of a mug of hot chocolate sitting on a table.

Students began to develop a **model** of matter as a collection of tiny particles in 5th grade (*5-PS-1*) that is useful in understanding heat transfer. Teachers can activate student thinking about this model by asking students to, "Draw the air inside a syringe.

How will you represent it?" Then, to elicit the importance of the space between particles, students can be prompted to draw how the ***system*** changes when the syringe is sealed and compressed without air being allowed to escape. Students then need to be introduced to evidence that these particles are in constant motion. Video clips of soot or dust particles settling show that these big, macroscopic particles seem to be pushed randomly left, right, and even upward as they drift slowly downward[51]. The best **explanation** is that gases consist of tiny particles that are moving around and crashing into one another randomly. Since these particles have mass and a speed, they must have kinetic energy that gets transferred as they collide. The models that students constructed to describe the transfer of kinetic energy in car crashes can help students **explain** heat flow and thermal energy. It allows them to explain why objects eventually reach the same temperature as they thermally interact (both objects have the same average kinetic energy, so neither of them has any additional energy to ‘give’ to the other). This model is also the first stage in understanding how atoms combine into molecules during chemical reaction (*MS-PS1-1*). The vignette below illustrates how this model can be developed further within a classroom.

Middle School Vignette

Developing and Using Models to Understand Properties of Gases

(Adapted from NGSS Lead States 2013a – Case Study 1)

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

[51] FranklyChemistry, A Smoke Cell demonstrating Brownian Motion in Air: https://youtu.be/ygiCHALySmM

the topic in the unit. In particular, this vignette illustrates one approach to instruction that blends *MS-PS1-4* with *MS-ETS1-1*, *MS-ETS1-2*, and *MS-ETS1-3*.

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

The vignette uses specific classroom contexts and themes, but it is not meant to imply that this is the only way or the best way in which students are able to achieve the indicated performance expectations. Rather, the vignette highlights examples of teaching strategies, organization of the lesson structure, and possible students' responses.

Also, science instruction should take into account that student understanding builds over time and that some topics or ideas require activating prior knowledge and extend that knowledge by revisiting it throughout the course of a year.

Introduction

The students in Ms. S.'s eighth grade classroom are **investigating *structure*** and properties of ***matter***. They are challenged to be precise with their scientific language and revise their conceptual **models** as new evidence is produced through the classroom's **investigations** or presented by the teacher. The students gain experience with some of the practices and core ideas of the NGSS over 14 school days of science instruction the students in Ms. S.'s class built on their prior knowledge of the particle nature of matter to further explore the behavior of atoms and molecules. The learning outcomes of the instructional segment included the concept that matter, specifically a gas, is composed of particles called molecules that move faster or slower, depending on the temperature of the gas. In addition, the students extended their learning to incorporate a relationship between the relative speed of the particles in a ***system*** and the pressure exerted on the sides of the container.

The teacher promoted student learning through real life examples and student-constructed models. She enabled the students to develop their own conceptual models, use the models in predicting relationships between the model components, and evaluate the models for their explanatory power (**developing and using models**). As the students gained understanding of the core ideas through use of the additional NGSS practices of **planning and carrying out investigations and obtaining, evaluating, and communicating information**, they addressed the limitations presented in the different **models** and worked together to revise the models as new evidence came to light.

Day 1 - Developing an initial conceptual model.

Ms. S. started a instructional segment on matter and its interactions that involved analysis of the forces between atoms and molecules, but first wanted to find out if her students had an understanding of the molecular nature of matter. She used a whole class discussion to bring out students' prior knowledge. They reviewed phase change and molecular movement in relation to temperature. Based on this informal assessment, she learned that some of the class remembered previous experiences with phase changes that occur with water.

The teacher began by asking the class to describe what they already knew about how gases behave. This allows her to build new learning on their prior knowledge and choose questioning and **investigations** more appropriate for her students. "We looked at air, carbon dioxide, and water vapor. What do you know about the molecules of a gas? How do they move? What affects their movement? What is a gas?" As students volunteered, she wrote down several students' responses on a chart paper, for example, "Gases expand when heated." "As a liquid evaporates, it becomes a gas and the molecules move rapidly." "There is a difference in density." "Gas is a phase."

"Molecules are small for gas and large for solid," Canyon offered. Ms. S. asked Canyon if he had any examples of his idea and he said, "No examples." She stated, "That's a question," and wrote Canyon's words on the question side of the chart paper. She added, "Does anyone want to comment on Canyon's remark?" Lorenzo contributed that he thought molecules stay the same size and that as molecules heat up, they move faster. After listing many student responses, Ms. S. asked the driving question, “How do gases and their behavior affect matter?”

The students then **evaluate information** about a real world scenario, using photographs and video. In the video, a railroad tank car (tanker) was washed out with steam and then all the outlet valves were closed. The video revealed the tanker dramatically imploding the next day. After watching the video twice, the students began to speculate why the tanker crushed. They thought that the car froze, exploded, or compressed, and the steam caused the tanker to collapse inward. An understanding of the ***cause and effect*** concept helped students make sense of this phenomenon.

Rick called out, “Okay, that’s crazy!” Ms. S. asked the class to write in their journals their descriptions of why the tanker was crushed. “Do you want to guess?” she asked. “I have no idea,” one student replied. The teacher encouraged the class by asking them to continue to think and work in their regular discussion groups. Each group’s task was to decide on one **model** to **explain** why the tanker imploded, making sure the drawings included molecules and arrows indicating the direction of the overall forces they apply to the tanker. Ms. S. circulated among the students and asked guiding questions, such as, “What happens when water vapor turns into liquid?” She directed students to include their ideas in the models they were creating. The students were drawing and discussing their models in their groups. “Steam inside is moving fast.” “Maybe it was cold.” “Didn’t explode; it imploded,” clarified a student. “Big, but sealed. Nothing in it but air and steam in there,” said another.

Lorenzo decided that there was a tornado inside. Ms. S. directed the group to review what happens when steam turns into a liquid. She reminded students of a previous balloon experiment where they had identified a pressure difference and asked, “What would ***cause*** pressure or a pressure difference?” She also encouraged students to incorporate the observation that heating a substance adds more pressure. Circulating among the four groups, she asked students about their drawings, “Why did the tanker crush the next day? How do temperature changes affect molecules? Is there pressure against the walls? Why?” Cristiano answered, “Pressure in air is more than inside,” and his partner Jasmine offered, “The steam inside turned to liquid.” Ms. S. redirected their conversation with a new question, “Why would it implode?” Jasmine answered immediately, “Heat expands molecules!” “The molecules are getting smaller,” contradicted Cristiano. After thinking a moment, he said, “They *don’t* do that, do they?”

Ms. S. asked the group about the air pressure arrows at the top of the tanker, “Why only at the top of the tanker?” Cristiano ventured, “There’s more air on top, not at the bottom.” Al added, “Molecules combine to take up less space.” Ms. S. emphasized, “When molecules combine, they make new substances.” Jasmine reminded the group that temperature has to do something. Ms. S. moved over to another group that had just broken into laughter and asked what was so funny. Rick related, “I see smashed cans all the time. I think an airfoot stomped the tanker down. And the molecules transformed into a molecule foot.” Ms. S. asked, “What is this imaginary foot?” Latasia answered, “Air.” Ms. S. guided the students, “Let’s add that idea to the model.”

As the discussions continued, several students began making connections between the steam turning to liquid overnight and the resulting changes in collisions of molecules with the walls inside and outside of the tanker. Through further questioning and reminders of previous learning that contradicted students’ claims, Ms. S. pressed the students to prioritize evidence while, at the same time, allowing them to generate their own incomplete conceptual model. Ms. S. was well aware that she needed to allow her students to construct an understanding of phenomena by putting their ideas together. She also knew that through guided experiences and meaningful dialogue students would adapt their model and demonstrate authentic learning.

Day 2 - Gathering new evidence to evaluate and revise conceptual models.

The following day Ms. S. encouraged students to reflect on how their ideas had evolved from the beginning of the instructional segment. She wondered whether changes in students’ ideas would be apparent in their developing models: air molecules slow down; water changes phase to liquid; pressure arrows show the collisions of molecules against the edge of the tanker; and when the gas molecules turn to liquid, there is less pressure on the inside causing the tanker to crumple. Reviewing the driving question from the day before, “What would ***cause*** pressure or a pressure difference?” the class identified two key factors: temperature and pressure. The molecules that made up the steam were also hitting the inside of the tanker, balancing the air molecules hitting the tanker on the outside. Students are thus able to use their **model** of particles to **explain** a macroscopic phenomenon.

Ms. S. asked the class a new question, “What caused the pressure inside the tanker to change?” The students did not respond at first. Then Lorenzo concluded that outside air pressure pressed on the tanker to crush it. Ms. S. asked, “Why would it do that?” This question led Ms. S. to introduce the soda can investigation. She asked the class to make predictions, “What will happen to the soda can if water is heated inside, and the soda can is rapidly cooled?” Students called out their predictions, “It’s going to do what the tanker did.” “Crush!” “Implode.” Jasmine asked, “Are we going to seal the container?,” showing her understanding of the variables involved.

Working in their groups, the class prepared for a simulation of the crushed tanker using an aluminum soda can. The can was filled with a small amount of water, heated to boiling on a hot plate, and then submerged upside down in an ice bath using tongs. The can immediately crushed. The enthusiastic reactions from the students included: “OOOH” “It’s cool!” “Awesome, it sucked it in!” (Some comments were based on incomplete understanding.) The teacher asked the students to draw new models by showing the molecules of gas in the can and writing down their ideas in their science journals.

The following day, Ms. S. provided students with a checklist to guide their review of the can implosion investigation from the day before. The checklist included: movement of molecules (speed), phase of matter, and causes of pressure inside and outside of the can. Ms. S asked the students to write answers in their science journals. Then they discussed their ideas in groups. As she met with each group, Ms. S. pressed students to verbalize core ideas about the behavior of molecules, and left the group with questions to consider. Finally, she directed the students to write about their ideas so far. Ms. S. provided a scaffold for writing complete ideas by giving the class this sentence: *When _____, the can crushed more because ______.*

As their understanding grew, students refined their **models** and **planned further investigations** to explore changes in the variables. Calling the class back together, Ms. S. summarized the variables suggested by the groups: amount of water in the can, temperature of the water bath, amount of time on the hot plate, size of the can, and amount of seal when the can is flipped into the bath. Ms. S. also reminded the students of the connection between the tanker implosion and their can implosion: the molecules of air hitting on the outside were not balanced with the molecules of steam hitting the inside.

Day 3 - Using literacy, discourse, and argumentation to develop a shared understanding.

The following day the **investigations** continued, using students' ideas. Ms. S. asked questions as to why more steam caused more pressure. The class regrouped to perform five experiments with each group taking one idea: amount of water, temperature of bath, time on hot plate, volume of can, and amount of seal. Each group identified three variables to test in order to help develop a more causal explanation. As the groups worked, the teacher questioned the students on their predictions and probed to provide evidence to support their **explanations**. Lorenzo offered, "Steam vapor cools down inside the can when the can is placed in the ice bath and turns into water." "Water liquid molecules move slower than water gas molecules and the water liquid molecules take up less space because the gas condensed into water," added Jaylynn.

The group that turned the can upward in the ice water bath was surprised the can did not crush. Latasia thought there was too much space, so the can did not crush. Mia thought that with more air there was more space because of the ratio between the air and space. As shown in Mia's response, Ms. S. had identified a gap in students' understanding of pressure differences. She assigned a reading assignment on air pressure for homework to help students **obtain information**.

Day 4 – Using revised models to explain phenomena

When students returned the next day, they drew a model of air pressure on people in their science journals. Alicia described her picture of pressure on Earth and pointed out that higher up there was less pressure due to fewer molecules. The class reviewed the meaning of forces and how force arrows explained pressure in the model they were refining for the tanker question.

Student responses became more confident as the lessons continued. Students used a computer simulation of pressure vs. temperature and Ms. S asked them to predict what would happen; the class buzzed with conversation. Next, the students improved their models. Again, Ms. S gave her students incomplete sentences to finish and reflect on what happened with their soda can **investigations**. Ms. S. reminded students to provide **evidence** for their **explanations**, “What are the molecules doing? Let’s say the molecules are at a popular hip-hop concert trying to see the band. What would the molecules be doing?” Jaylynn conjectured that the quantity of molecules influenced the pressure in the can, “The kids would be pushing each other to get a better view of the band. Therefore, in the can more molecules would mean less space in the can. Alicia offered, “And molecules hitting the can from the outside would not be able to push the can in.” Canyon added,

“When the steam cooled in the can, it meant less steam and less pressure. Because fewer molecules were hitting the inside of the can, the can collapsed.” The students’ responses showed they understood the concept that as the temperature decreases, the molecules move slower with fewer collisions.

The students compared the results of the soda can **investigations** with the implosion of the tanker. As they **constructed explanations**, their understanding of gas behavior concepts was evident and their models were more complete. “The tanker imploded and the can got crushed because the number of air molecules hitting the outside far exceed the number of air molecules or water molecules hitting the inside.” “It is the number of molecules that hit the side that causes pressure.” The students concluded that under normal conditions, the tanker would not implode because the number of molecules hitting the outside would equal the number hitting the inside.

Following Days - Application of scientific knowledge to an engineering problem.

At the end of the two- week instructional segment, Ms. S. challenged the teams to apply their knowledge of thermal energy and pressure to design a tanker that would not implode after cleaning. The design constraints included the use of local materials, and a feature that would ensure even poorly trained technicians would not accidentally ***cause*** the tanker to implode. Ms. S. led a discussion about how to evaluate the competing design solutions, and the class agreed upon two criteria: cost effectiveness and no implosion.

The students were given additional aluminum soda cans to allow them to test their ideas. After about 30 minutes of small-group brainstorming, designing, and building, each group had a model to test. Cristiano, Jasmine, and Al proposed keeping the tanker in a warm room after cleaning so that it would cool very gradually. To test their idea, they immersed it in warm water, not ice water. It imploded very slightly. Al suggested, “Let’s use hot water instead of warm. Then it would cool off very slowly.” The group agreed to try that.

Lorenzo’s group punched a small hole at the opposite end of the can and when they immersed the can in the ice bath (with the punched hole just above the waterline), the can did not collapse at all. Lorenzo and Latasia whooped for joy! Mia reacted, “Wait! What happens to the liquid inside if there’s a hole in the tanker?” “What do you mean?” asked Lorenzo. “Well, if the tanker has something like oil in it, the oil will evaporate out of the hole!” The others agreed, but liked their design anyway, and thought that the problem was not that important.

Canyon, Alicia, and Jaylynn whispered together for a long time before asking Ms. S. for materials. Jaylynn argued successfully to immerse a room temperature can (not heated) in ice water. When the group tried that, the can did not implode. Alicia was worried, “Do you think we’re cheating?” Ms. S. pointed out that it was a design worth considering and asked the group if they could think of any problems with this design. Canyon offered, “This design is great! But what if the tanker had a liquid inside that would not clean well with cold water?”

Rick’s group made a sign that they said they would paint on the tank, so it would never come off. The sign said: “After cleaning, open all doors.” They demonstrated how it would work by immersing the can right side up, so that cool air could flow into the tank.

Ms. S. concluded the class by pointing out that engineering problems often had many solutions, with some better than others. The next day, the groups presented their design solutions. Based on the two criteria that they had established earlier, the class discussed which of the solutions was best.

Performance Expectations
MS-PS1-4 Structure and Properties of Matter *Develop a model that predicts and describes changes in atomic motion, temperature, and state of a pure substance when thermal energy is added or removed.* **MS-ETS1-2 Engineering Design** *Evaluate competing design solutions using a systematic process to determine how well they meet the criteria and constraints of the problem.*

Science and engineering practices	Disciplinary core ideas	Cross cutting concepts
Developing and Using Models **Planning and Carrying Out Investigations** **Constructing Explanations** **Engaging in Argument from Evidence** **Obtaining, Evaluating, and Communicating**	**PS1.A Structure and Properties of Matter** *Gases and liquids are made of molecules or inert atoms that are moving about relative to each other. The changes of state that occur with variations in temperature or pressure can be described and predicted using these*	Cause and Effect Structure and Function

Information	*models of matter.* **ETS1.B Developing Possible Solutions**	
Connections to the CA CCSSM: MP. 2, 3; 7.SP.1, 7.SP.2, 7.SP.3, 7.SP.4, S.IC		
Connections to CA CCSS for ELA/Literacy: SL.8.1, 2, RST.6–8.9, WHST.6-8.7,9		
Connection to CA ELD Standards: ELD.PI.1, 3, 11a		
Connections to the CA EP & Cs: N/A		

Vignette Debrief

The CA *NGSS* vision of blending disciplinary core ideas, scientific and engineering practices, and crosscutting concepts is exemplified in this vignette. The learning progressions of the NGSS disciplinary core ideas allow teachers to assess whether students have the needed foundation for the new concepts. The teacher presented engineering practices when she introduced the tanker design engineering problem. Students were asked to apply the evidence from the soda can experiment to the real-world problem of preventing a tanker from crushing if maintained properly.

The vignette also highlights that learning science has important implications in the real world. In the vignette, the worker who cleaned the tanks had no conceptual understanding – or at least no accurate mental model – of what would happen if he/she closed all the valves after steam cleaning the tank. That was an expensive mistake for the company, and the worker might have lost his/her job over it. This is a lesson about the importance of science in using and maintaining equipment and illustrates the interdependence of science, technology, and engineering.

The students in the vignette engaged in many science and engineering practices, thereby building a comprehensive understanding of what it means to do science. The scientific practice of **developing and using models** is highlighted throughout the vignette. In the course of study, the students constructed two conceptual models: the first for the tanker's implosion and the second for the implosion or lack of implosion of the soda can. The second model was more sophisticated and built on the first model, as new evidence was presented. A third model was based on the concepts from the other two and illustrated a design solution. Throughout the instructional segment, the students were challenged to modify and revise their models as they gained an understanding of the disciplinary core ideas of the pressure and temperature variables. In addition, the students were engaged in the scientific practices of **planning and carrying out investigations** and **engaging in argument from evidence**. In small group and whole group discussions, the students **constructed scientific explanations** for the tanker implosion, revised their explanations as they synthesized the tanker information, used their understanding of core ideas to construct a design solution, and supported or refuted claims. Students completed assignments by **obtaining, evaluation, and communication information** about pressure differences and design explanations.

The NGSS crosscutting concept of ***cause and effect*** was highlighted in the vignette as students described the effect of the forces applied on the tanker and soda can, and made comparisons. The students' observations guided them to provide evidence for the causality of the tanker and soda can collapse. They made predictions about scientific phenomena based on their developing understandings of effects of molecular movement and causes for phase changes. Later the NGSS crosscutting concept of ***structure and function*** applied to the purpose of engineering a solution to prevent the implosion of a tanker

CCSS Connections to English Language Arts and Mathematics

The NGSS supports an interdisciplinary approach to science learning in order to provide experiences across disciplines. It is for this reason that each science standard explains its connections to the CCSS for ELA and mathematics. The students in the vignette grappled with core ideas in physical science while meeting the CCSS for ELA by discussing, writing and revising **explanations** and evaluating the scientific **arguments** presented by others.

RST.9-10.9 *Compare and contrast findings presented in a text to those from other sources (including their own experiments), noting when the findings support or contradict previous explanations or accounts.*

Students had reading assignments throughout the instructional segment: pressure and how pressure differentials are established.

RST.11-12.9 *Synthesize information from a range of sources (e.g., texts, experiments, simulations) into a coherent understanding of a process, phenomenon, or concept, resolving conflicting information when possible.*

Students synthesized information from the video of the tanker, their experiments, and the gas pressure vs. temperature simulation.

SL.9-10.2 *Integrate multiple sources of information presented in diverse media or formats (e.g., visually, quantitatively, orally) evaluating the credibility and accuracy of each source.*

Students analyzed the simulation and compared the results of the simulation questions to their models.

W.9-10.7 *Conduct short as well as more sustained research projects to answer a question (including a self-generated question) or solve a problem; narrow or broaden the inquiry when appropriate; synthesize multiple sources on the subject, demonstrating understanding of the subject under investigation.*

Investigations of the soda can questions were short research projects.

WHST.9-10.1 *Write arguments focused on discipline-specific content.*

With the help of the teacher, the students wrote **arguments** about their **models** and their learning.

The instructional segment also addressed grade appropriate CCSS for mathematics throughout the exploration with core ideas in physical science. In the vignette the students strove to successfully combine math and science practices to present valid explanations.

Math Practice 2 *Reason abstractly and quantitatively.*

In the vignette, student models reflected abstract reasoning, using a symbol system including comparisons of relative pressure.

SP *Investigate patterns of association in bivariate data.*

Students drew the conclusion that as one variable (temperature) increased, the other variable (pressure) increased.

S.IC *Make inferences and justify conclusions from sample surveys, experiments, and observational studies.*

Students inferred the properties of matter from their observations and experiments and justified their conclusions using the models they create.

To relate their experiments of heat transfer to their microscopic **model** of molecular movement, students use interactive computer simulations. These simulations help them visualize the scientific model of molecular motion and extend their own model so that they can **explain** phase changes and the transfer of ***energy*** in terms of colliding molecules. In instructional segment 1, students **argued** that a change in kinetic energy is **evidence** of energy transfer. In this instructional segment, they look at the argument in the other direction and argue that energy is transferred by changes in the kinetic energy of molecules (*MS-PS3-5*). The simulations also help visualize that thermal energy includes both kinetic energy from the translational movement of particles from place to place and kinetic energy from vibrations within molecules and between atoms in a solid.

With this **model** of thermal energy, students can start to **explain** the ***flow of energy*** in various situations. In instructional segment 1, students saw that some of an object's kinetic energy gets converted to thermal energy by friction as it slides against another object. Sliding along rough surfaces essentially re-orients the motion of individual particles so that their systematic motion (from which we calculate their kinetic energy) is converted to randomly oriented movements (from which we calculate their thermal energy)[52] . The particles continue moving the same speed, on average, as they were originally such that no energy is actually lost. The major change is in the average orientation of the motion (along with the fact that some of the energy is also transferred

[52] PhET, Friction: https://phet.colorado.edu/sims/html/friction/latest/friction_en.html

to the ‘stationary’ object as the molecules of the two objects collide). The dissipation of sound waves with distance works the same way: systematic vibrations devolve into random movement. Even though a person’s whisper cannot be heard on the other side of a room, the energy of their voice is used to warm the room up very slightly. Car crashes in real life undergo the same process: both cars appear to be moving quickly in one direction at the beginning of the crash but are stopped at the end. Where does the energy go? Again, the systematic motion of the car overall decays into random vibrations and movements of the individual molecules in the car. When a car collides with another object, whatever energy that isn’t transferred to the kinetic energy of that object is converted primarily into thermal energy and sound energy by the end of the crash (with a small amount of the energy going into permanent changes to the relative position of the molecules within the deformed materials, but this turns out to be less than 10% of the original kinetic energy for many metals). Engineers design the crumple zones so that all this deformation and energy conversion into heat is concentrated in areas away from the passenger compartment, which remains a rigid protective cage. The crumpling also ensures that the passenger compartment slows down gradually, thereby reducing the force on the occupants. There is significant effort by engineers today to select materials and structures that ‘absorb energy’ even more efficiently, which means converting it to heat.

Engineering Challenge: Design a vehicle radiator

Engineering Connection

Many ***systems*** from human bodies to spacecraft operate best when they are neither too hot nor too cold. Living organisms have evolved so that they have mechanisms to avoid overheating (dogs pant, people sweat, rabbits have large ears, etc.) or becoming too cold (birds have inner down feathers, mammals have layers of fur, penguins huddle in groups, etc.). Many of these adaptations illustrate how the heat transfer ***function*** is supported by the specific shape or ***structure*** of the organism. Thermal regulation is also important in many different technologies. Obvious examples include keeping the inside of refrigerators cool and the inside of ovens warm, but engineers also include thermal regulation in the designs of all sorts of technology. Computer chips that are present in just about every electronic object become damaged when they overheat, so almost all of these everyday objects also include design elements to keep them cool. Students engage in a design challenge in which they plan, build, and improve a ***system*** to maximize or minimize thermal ***energy*** transfer (*MS-PS3-3*). Ideas for the challenge include designing well-insulated homes[53], a beverage or food container[54], a solar oven[55], or even a cooling system for a nuclear powered submarine[56]. The design challenge could also integrate with the course theme of vehicles by having students design an effective radiator for a car. Their design could take advantage of liquids with different heat capacities flowing through tubes and/or fin-shaped metal heat exchangers, just like the radiators in the cars and buses that might take them to and from school. Students can consider the environmental impact of different materials as one of the many factors constraining their design (*MS-ETS1-1*). Since the performance of thermal regulation systems is easy to measure with a thermometer, students **plan** a rigorous testing process (*MS-ETS1-4*), **analyze the data** from the tests (*MS-ETS1-3*) and **evaluate** different potential solutions (*MS-ETS1-2*) in order to iteratively improve their final design. Heat flow is also easily simulated on a computer using freely available software[57], so students can perform some of their planning and initial testing and revision in a simulator before actually building any physical objects. During the design process, students will likely need to become familiar with different mechanisms of heat transport (conduction, convection/advection, and radiation). While these processes are not explicitly mentioned in the PE's for 8th grade, students should be applying "scientific principles" to guide their design, and different methods of heat flow require different design strategies

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[53] Concord Consortium, Build and Test a Model Solar House: http://concord.org/stem-resources/model-solar-house
[54] NASA, Design Challenge: How to keep gelatin from melting: http://www.messenger-education.org/teachers/Modules/Lessons/gelatinmelting.pdf
[55] TeachEngineering, Hands-on Activity: Cooking with the Sun: https://www.teachengineering.org/view_activity.php?url=collection/cub_/activities/cub_energy2/cub_energy2_lesson09_activity3.xml
[56] Lisa Allen, Historic Ship Nautilus: Submarine Heat Exchange Lesson Plan: http://www.ussnautilus.org/education/pdf/stemlessons/heat-exchanger-lesson.pdf
[57] Concord Consortium, Energy2D: Interactive Heat Transfer Simulations for Everyone: http://energy.concord.org/energy2d/

to exploit or minimize overall ***energy*** transfer. Such information could have been introduced during the **investigations** of *MS-PS3-4*, but the emphasis there was on the ***quantity*** of overall energy transfer and different mechanisms were not essential. The distinction becomes more important for this design challenge because effective insulation designs often need to reduce all three mechanisms and effective heat exchange designs typically exploit them all. Students should already have applied models of convection to understanding ***energy flow*** in Earth's atmosphere and interior during 6th grade (*MS-ESS2-1* and *MS-ESS2-6*). Students can now relate their macroscopic understanding of heat transport processes to their models of the movement of individual particles. Conduction involves the transfer of energy directly by collision between particles. Energy moves in convection when particles with large amounts of thermal energy move to a different location and take their energy along with them. Hot particles can also radiate energy as electromagnetic waves, which can be absorbed by other particles leading to the energy transport process called radiation. Students finish the activity by creating a product information sheet where they **argue** that people should buy their product. They will **communicate** the features of their product that allow it to perform better than their imaginary competitors as well as **evidence** from their **investigations** and testing showing that it actually does.

Grade 8 Instructional segment 6: Chemical Energy and Reactions

Instructional segment 6: Chemical Energy and Reactions
Guiding Questions: How do car engines turn gasoline into motion? How do people use technology change natural materials into synthetic ones?
Highlighted Scientific and Engineering Practices: Developing and Using Models Constructing Explanations and Designing Solutions Obtaining, Evaluating, and Communicating Information
Highlighted Cross-cutting concepts: Cause and Effect Scale, Proportion, and Quantity Systems and System Models Energy and Matter Stability and Change
Students who demonstrate understanding can: **MS-PS1-1.** **Develop models to describe the atomic composition of simple molecules and extended structures.** [Clarification Statement: Emphasis is on developing models of molecules that vary in complexity. Examples of simple molecules could include ammonia and methanol. Examples of extended structures could include sodium chloride or diamonds. Examples of molecular-level models could include drawings, 3D ball and stick structures, or computer representations showing different molecules with different types of atoms.] [Assessment Boundary: Assessment does not include valence electrons and bonding energy, discussing the ionic nature of subunits of complex structures, or a complete description of all individual atoms in a complex molecule or extended structure is not required.] **MS-PS1-2.** **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 hydrogenchloride.] [Assessment Boundary: Assessment is limited to analysis of the following properties: density,

	melting point, boiling point, solubility, flammability, and odor.]
MS-PS1-3.	**Gather and make sense of information to describe that synthetic materials come from natural resources and impact society.** [Clarification Statement: Emphasis is on natural resources that undergo a chemical process to form the synthetic material. Examples of new materials could include new medicine, foods, and alternative fuels.] [Assessment Boundary: Assessment is limited to qualitative information.]
MS-PS1-4.	**Develop a model that predicts and describes changes in particle motion, temperature, and state of a pure substance when thermal energy is added or removed.** [Clarification Statement: Emphasis is on qualitative molecular-level models of solids, liquids, and gases to show that adding or removing thermal energy increases or decreases kinetic energy of the particles until a change of state occurs. Examples of models could include drawings and diagrams. Examples of particles could include molecules or inert atoms. Examples of pure substances could include water, carbon dioxide, and helium.]
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.

Significant Connections to California's Environmental Principles and Concepts:

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

Background and instructional Suggestions

In the previous instructional segment, students represented matter as moving particles. In this instructional segment, they modify that understanding to show that the particles can consist of smaller pieces called atoms and that particles come in different sizes and shapes called molecules, each with a unique set of properties that differs from the properties of the individual atoms. These molecules break apart and combine together through chemical reactions. The *CA NGSS* PEs for 8th grade do not require students to probe atoms at a finer ***scale*** nor to **investigate** the mechanisms by which chemical reactions are accomplished. The focus is instead on bulk properties of materials and how changes to them can be explained by reorganizing atoms into different molecules. The PE's ensure that students build a robust **model** of the relationship between chemical reactions and the particulate model of matter, ***conservation of matter***, and the macroscopic effects of chemical reactions. The ***structure*** of atoms, the periodic table, and the details of bonding are all addressed in detail when it is developmentally appropriate during high school (HS-PS1-1 through HS-PS1-8). This focus contrasts with the 1998 Science Content Standards where the periodic table was introduced in 5th grade and the interior ***structure*** of atoms was introduced in 8th grade.

Common Core Connection: "All natural" ingredients

Students begin the instructional segment by bringing in one of their favorite objects from home. What is it made out of? Most objects in our everyday life are made out of synthetic materials, meaning that natural materials were taken from the natural environment and then transformed by chemical processes into materials with new properties. These materials are often stronger, more durable, or lighter-weight than the original natural material. Students **obtain information** about the materials that make up their object (*MS-PS1-3*). What natural materials were the raw ingredients to their own object of interest? How do the properties of the final product differ from the raw ingredients? What processes did the materials have to undergo in order to change? After using internet resources to find answers to these questions, students **communicate** some of their findings with presentations to small groups. Each group then compares the products and identifies commonalities in both raw materials and manufacturing processes. These ***patterns*** help set the stage for the rest of the instructional segment, which seeks to **explain** what is actually happening during these processes. Another goal of this activity is to help students make the connection between natural resources and the built environment. Based on their research about the source materials for their object, students must present an **argument** about whether or not they agree or disagree with the statement that their object should be labeled, “All natural.”

What happens when materials are mixed together? Sometimes nothing, but sometimes materials change in exciting ways. These transformations are at the heart of the chemical processes that convert natural materials to synthetic ones and occur every instant in living organisms and in the non-living environment. This instructional segment begins with an **investigation** into a series of mystery powders and liquids, most available at the local supermarket (powders include flour, Epsom salts, powdered lemonade, calcium chloride, washing soda and corn starch. Liquids include water, vinegar, lemon juice, iodine tincture. Purple cabbage juice can be added as a colorful pH indicator)[58]. The materials are not identified by name, which is done to emphasize the observation component of the activity while no time will be devoted to naming chemical compounds. Students first observe the different properties of individual liquids and powders, including their color and texture, and density (students have been

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[58] Minnesota Science Teachers Education Project, Chemical Reactions: Investigating Exothermic and Endothermic Reactions: http://serc.carleton.edu/sp/mnstep/activities/19869.html

conducting such **investigations** since 2nd grade, *2-PS1-1*, *5-PS1-3*). Next, students combine different combinations of two unknown powders with one unknown liquid in a plastic zip-lock bag. They conducted a similar **investigation** in 5th grade (*5-PS1-4*), but this time the emphasis will be on observing properties to determine whether or not a chemical reaction has occurred (*MS-PS1-2*). In this inquiry approach, students are not given any criteria for identifying chemical reactions, but record careful notes about which powders and liquids were used in each combination using a collaborative online spreadsheet. Because they are pooling observations, they are able to collect a large number of different combinations that allows them to recognize ***patterns*** in the events. Changes in phase, density, odor, and unusual color changes are all indicators that a chemical change has occurred. In many cases, however, students will observe no unusual changes (e.g., red colored liquids might turn into a pink squishy gel when combined with a white powder) because no chemical change resulted from the combination. They should be able to analyze the data and use the patterns predict what will happen with a previously untested combination of powders and liquids. Their prediction should be specific, including describing changes in properties such as density, melting or boiling point, solubility, or odor.

One of the most obvious changes students observe is a temperature change inside the bag when certain combinations of the powders and liquid are chosen. In some cases, the bag heats up. Students define the ***system*** of interest as the ingredients inside the zip-lock bag and try to model the ***flow of energy*** using the same energy source/receiver diagrams they have used in previous instructional segments (**Figure 33**). Knowing that the energy to warm up the materials has to come from somewhere, students can use their observations and this model to support the **argument** that there must be a chemical potential energy in which energy can be stored, and that this energy can convert into thermal energy. They should also be able to model the opposite situation where the bag cools down. At this point, students should have many **questions** about what chemical energy is or how it is stored, but most of these questions remain unanswered until high school. They can infer that the relative position of the ingredients plays a role because potential energies are related to the relative position of objects. At this point, students' model should simply consist of the relationship that chemical reactions ***cause*** energy to be converted through a change in the position of the particles relative to one another. They will **refine this model** later in the instructional segment.

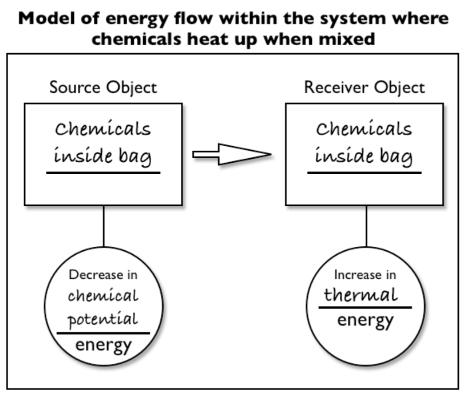

Figure 33. Model of energy flow within a system where chemicals heat up when mixed.

Engineering Connection: Designing a hand warmer powered by chemical reactions

Students now imagine that they will travel to a very cold place to explore and play and that they will want a way to keep their hands warm for as long as possible. Their goal is to **analyze data** from the previous experiment to help design a hand warming pad powered by chemical reactions (*MS-PS1-6*). Students will need to **define the criteria** for judging hand warmer performance (*MS-ETS1-1*). Is it best to have the hand warmer reach its peak temperature quickly and cool back down quickly, or to warm slowly to a lower peak temperature? The engineering challenge works best when the whole class records their findings from the mixtures with two powders and a liquid in a collaborative spreadsheet so that a large number of unique combinations can be tested. Students should discover ***patterns*** in the class observations to identify which two materials consistently react before they select their materials and begin to test them. They then perform iterative tests to determine the relative concentration of the two ingredients that lead to optimal hand warmer performance (*MS-ETS1-2, MS-ETS1-4*). By **communicating** their findings to the class, teams with different solutions can compare the relative performance of their hand warmers to decide the relative merits of each one (*MS-ETS1-3*).

Earlier in the instructional segment, students applied their understanding of potential energies to infer that chemical reactions must ***cause*** particles to change their position relative to one another. This relates to students' work in 7th grade when they developed a model of how food molecules are rearranged through chemical reactions (*MS-LS1-7*). They focused in on the simple chemical equations of photosynthesis and respiration. Now they can revisit those reactions. In what way are the particles 'rearranged'? Using the familiar molecules involved such as water and carbon dioxide, teachers can illustrate how atoms combine to form simple molecules with very simple shapes. Students can then make physical models of these combinations (*MS-PS1-1*) using interconnecting plastic toy bricks, sticky notes, or digital representations. Not only do these models depict atoms that are chemically bonded together, but they also introduce students to the concept of molecular shape. Molecular ***structure*** is crucial in determining the behavior and function of these molecules in living ***systems***, but also in determining the properties of water and other inorganic compounds. It should be emphasized that explaining these applications is outside the scope of middle school (for example, water's polarity cannot be explained without a detailed understanding of the internal ***structure*** of the atom and chemical bonding), but this PE lays the foundation for more advanced study.

Thermal energy plays an important role in chemical reactions, as the challenge of the hand warmer at the beginning of this instructional segment illustrates. Students can apply the kinesthetic **model** where their bodies act as atoms to represent a reaction in which chemical potential energy is converted to thermal energy (*MS-PS1-4*). The products of the chemical reaction in a hand warmer are noticeably hotter than the original unreacted material, which means that they must speed up after the chemical reaction. The same is true in a number of other important chemical reactions such as combustion and respiration. Natural gas in the burner on a gas stove reacts with oxygen and produces a very hot combination of water and carbon dioxide. These gases are hot enough to cook food, transferring some of their thermal energy to warm it up. The new molecules created by combustion, water and carbon dioxide, both float away harmlessly into the room so that there is no smoke or soot on the pot. A similar reaction occurs in a vehicle engine. Gasoline also combusts with oxygen and the carbon dioxide and water produced are moving fast enough that they collide with the walls of the engine and push up a cylinder that turns the axel of a car. These molecules remain hot enough to remain gases until they eventually exit out the exhaust pipe. Sometimes exhaust pipes will drip water, which just means that the water produced during the combustion reaction cooled enough to condense before getting to the end of the exhaust pipe. The speed of molecules also plays an important role before the chemical reaction. Particles that are moving faster are more likely to collide with one another and therefore encounter a new partner more quickly during a chemical reaction.

Students should be able to use their models of particles interacting during chemical reactions to depict the difference between pure substances (made of a single type of atom or a single type of molecule) and mixtures. For example, a jar contacting a mixture of hydrogen and oxygen atoms is extremely flammable and will easily ignite, but a jar containing the exact same number of hydrogen and oxygen atoms bonded together to form the pure substance of water is not flammable at all. Once simple structures have been mastered, students must also be able to represent larger combinations of multiple atoms using different shapes.

While physical models often depict individual molecules, it is important to remind students that these molecules typically exist is a sea of an uncountable number of similar molecules that interact with one another and different atoms and molecules. Whether the material behaves as a solid, a liquid, or a gas depends on the relationship and interaction between these molecules. When molecules are close enough to strongly interact, they behave as a solid. Some solid materials form extended crystal structures where the same pattern of atoms repeats and it is not necessarily clear where one ‘molecule’ begins and another ends. The clarification statement for *MS-PS1-1* mentions diamonds and salt as examples of extended structures, but the vast majority of inorganic solids are crystalline, including pure metals and all minerals. Glass, wax, plastics, thin films, and gels are all examples of solids without a crystal structure that are common in synthetic products but rarer in nature.

Interactions between molecules of different types sometimes result in collisions in which atoms change partners completely. Students should be able to use their models of simple molecular structures to illustrate chemical reactions as atoms changing partners. Physical manipulatives can be useful to illustrate the conservation of mass where the number of atoms at the beginning of a chemical reaction must equal the number of atoms at the end because students have actual objects left over if they haven't recombined the atoms correctly (*MS-PS1-5*). Students can also use their own bodies as a physical model to represent individual atoms that change partners (**Figure 34**). Chemical equations are also models of chemical reactions, but the assessment boundary for *MS-PS1-5* states that students will not be responsible for balancing symbolic chemical equations. Nonetheless, students should be able to balance a chemical equation using physical manipulatives (by making sure that all starting atoms are included) and also support the claim that the mass of the ***system*** does not change during the chemical reaction because the number of atoms has not changed.

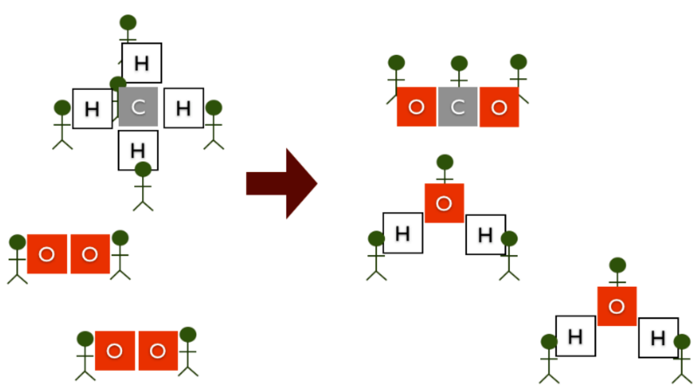

Figure 34. Students using their bodies as a physical model of the combustion of methane.

Students now return to their research into synthetic and natural objects from the beginning of the instructional segment. What atoms were in the natural materials and how were they rearranged? Often during manufacturing, 'impurities' are removed. These atoms do not go away, and so these processes often generate waste. Rearranging atoms can sometimes release ***energy*** when it happens spontaneously, but many manufacturing processes rearrange atoms in ways that do not occur naturally.

These process require energy input, which means that manufacturing requires energy resources. The source for this energy can be chemical reactions, as it is for fossil fuels. But accumulating the source materials such as coal, oil, and natural gas come at significant cost. Students **obtain information** about energy sources and waste products and communicate how the ***technology*** of their synthetic material ***influences society and the natural world***.

Science Literacy and English Learners

The vignette presents an example of how teaching and learning may look in a 7th grade classroom when the CA NGSS are implemented in tandem with the CA CCSS for ELA/Literacy and the CA ELD Standards. The purpose is to illustrate how a teacher engages students in three-dimensional learning by providing them with experiences and opportunities to develop and use the Science and Engineering Practices and the Crosscutting Concepts to understand the Disciplinary Core Ideas associated with the topic in the instructional segment. An additional purpose is to provide examples of how language and literacy development are cultivated through interactive and engaging science literacy learning tasks. The vignette includes scaffolding approaches for English learner (EL) students. It is important to note that the vignette focuses on only a limited number of standards. It should not be viewed as showing all instruction necessary to prepare students to fully achieve NGSS performance expectations or complete the instructional segment. Neither does it indicate that the performance expectations should be taught one at a time. This vignette is based on similar CA NGSS Performance Expectations presented in this chapter's "Middle School Vignette: Structure, Function, and Information Processing."

The vignette uses specific classroom contexts and themes, but it is not meant to imply that this is the only way in which students are able to achieve the indicated performance expectations and learning target. Rather, the vignette highlights examples of teaching practices, lesson organization, and possible students' responses. Science instruction should take into account that student understanding builds over time and is extended by revisiting topics and concepts throughout the course of the year. In addition, some topics or concepts require different pedagogical and scaffolding approaches, depending on individual student needs. Finally, while the vignette provides several illustrations of pedagogical practices, it does not include everything that educators need to consider when designing and facilitating learning tasks. All learning environments should follow research-based guidelines.

7th Grade Vignette:
Interconnected Systems (Structure, Function, and Information Processing)

Background

Ms. K's 7th students are learning about interacting systems. To provide her students with rich and varied learnings experiences the meet the needs of all of her diverse learners, Ms. K designs her lessons so students have opportunities to make scientific discoveries, understand science concepts, and learn to read and write like scientists—all in a supportive environment that includes ample discussion and collaboration. In this instructional segment, she wants her students to make connections about the relationships between and among systems, so they more fully understand both their own bodies and the natural world. The big idea that guides her lesson planning is:

> *Systems affect one another, so that changes in one system or sub-system may affect other systems or subsystems within an organism or ecosystem.*

The thirty-two seventh graders in Ms. K's fifth-period class have a wide variety of backgrounds and bring a rich diversity of experiences and knowledge into the classroom. About one-third of her students speak a non-standard dialect of English at home. In addition, ten of her students have been reclassified as fully English proficient within the last three years, while another five are at the late Expanding or early Bridging level of English proficiency. These students have a strong grasp of conversational English but need support understanding and using some academic language. Two of her students are newcomers and are at the early Emerging level of English language proficiency, and they regularly need substantial support in order to participate in all classroom activities. Ms. K's goal is to provide an appropriate level of support for all of her students so each can not only learn science content deeply but also increase their ability to read and write complex scientific texts.

Lesson Context

Ms. K's current instructional segment has two parts, and is mid-way through the second part. In the first part, the class focused on cells as tiny living systems, and they are currently studying how these cells interact and work together to make more complicated organisms involving more complicated interacting subsystems, including those within the human body.

To help students build their understanding of more complex systems, Ms. K's class has studied pine trees, examining, discussing, and writing about the tree as a system consisting of several sub-systems.

The class has co-created a large multi-media composition of a pine tree on butcher paper that covers the wall in the back of the classroom. The pine tree has been painted, but real pine needles have been glued on to the butcher paper, as have small twigs and pieces of bark. The pine tree's parts are labeled in the home languages of the students in the classroom: English, Spanish, and Filipino. Other academic and domain-specific language related to the content is also included on the mural, including short, student-friendly definitions. Ms. K posed a set of questions that the students had to answer together, co-writing their responses on the mural:

What would happen if the root system were damaged?

What if the trunk and bark were compromised due to fire or a lightning strike?

How does the tree obtain energy and matter and move them around?

How does each sub-system contribute to the tree's survival?

In their written responses, Ms. K supported students in using the academic and domain specific vocabulary from the instructional segment.

After her students have studied the sub-systems within a pine-tree in depth, Ms. K facilitates a series of lessons in which students begin to transfer their understanding of systems and sub-systems from trees to the human body.

Students first examined organs and tissue within the human body. Students worked in collaborative groups to explore an online interactive body tour, choose and research an organ and a tissue, and give a group presentation on the group's chosen organ and tissue. For these group projects, Ms. K strategically creates linguistically heterogeneous groups; the students in each group represent a range of English language proficiency. Whenever possible, each newcomer is placed in a group in which at least one student speaks his or her home language. As a component of the presentation, each group creates a labeled graphic that is then posted on the classroom walls. The class also co-creates a word wall that includes the words necessary to understand the content, as well as student-friendly definitions.

As students continue to build both their science conceptual understandings and language and literacy skills, they will use what they have learned to write a scientific argument in response to the question, "If the organ or tissue you chose partially or completely failed, which other sub-system(s) would it affect, and how might it affect the functioning of the human body as a whole?" The following learning target and NGSS performance expectation guide teaching and learning for the lesson.

Learning Target: Students will write an evidence-based argument demonstrating understanding of the relationship of body systems to survival.
CA NGSS Performance Expectations: **MS-LS1-3. From Molecules to Organisms: Structures and Processes:** Use argument supported by evidence for how the body is a system of interacting sub-systems composed of groups of cells.

Lesson Excerpts

Building models

Following the students' group research assignments and presentations, Ms. K begins the next phase of the instructional segment in which the objective is to help her students understand how the organs and tissues of the body work together as sub-systems to complete tasks and regulate body functions necessary for survival.

As a first step, Ms. K asks her students to build models of the circulatory system in small groups, as this format promotes interdependence and is conducive to peers providing support. She divides the students into eight groups of four, again ensuring that the groups incorporate students representing a range of English language proficiencies. Four of the groups will each build a model of the heart that shows its function; the other four groups will each build a model of the kidneys that shows their function. Ms. K has a set procedure for models and experiments in which she organizes the materials and places them in bins before class, and each group immediately assigns a materials manager to collect the materials. For the heart, students are provided a water bottle, different sizes of surgical tubing, duct tape, red food coloring, balloons, and foam core board; for the kidneys students work with a larger water bottle, a smaller water bottle, a plastic cup, cotton balls, and a tea bag. Ms. K wants her students to be inventive and demonstrate independence. Because she also wants to support them, she has written instructions to build each of the models and provided YouTube videos keyed up on the classroom computers that show each of the models in action. Ms. K informs students know that if they feel stuck or overwhelmed, they can request written instructions, watch a video of the model in action, request to observe what another group is doing, or ask Ms. K for assistance. Ms. K circulates during the modeling activity to ensure her students understand and to judiciously provide appropriate levels of support.

Ms. K stops by one of the groups working on the heart model to see how their models are progressing. The group consists of four students: Yesenia, Patricia, Dominic, and Carlos. In particular, Ms. K monitors how Patricia, who is at the early Emerging level of English proficiency, is understanding the group task.

Yesenia: (Holding the water bottle.) This should be the heart, 'cause we could make it beat. (She squeezes the water bottle a few times.)

Dominic: Yeah, it could push the blood out and around.

Yesenia: Pump the blood.

Ms. K: It sounds like you're already thinking through your approach. From our recent work, do you remember what word we used to discuss blood moving around the body?

Carlos: Umm…circulate?

Yesenia: (Still holding and pumping the water bottle.) This heart could circulate the blood all around the body.

Dominic: Throughout the whole body in the veins.

Ms. K: I see you are using academic vocabulary. Can you create a sentence to describe what you're planning that uses academic ocabulary?

Dominic: We can use the bottle to create…

Yesenia: We can use the bottle as the heart to circulate the blood…

Carlos: …Circulate the blood throughout the body in the veins.

Dominic: We can use the bottle as the heart to circulate the blood throughout the body in the veins.

Ms. K: ¿*Entiendes*, Patricia?

Patricia: (Making a "so-so" motion with her hand.) Tipo de…

Ms. K: Yesenia, can you help Patricia understand your approach?

Yesenia: (Holding up the bottle.) *Podemos utilizar la botella como un corazón*… (She squeezes the bottle) …*para mover la sangre por todo cuerpo.*

Patricia: *El corazón* es the bottle. *Circula la sangre*. *S*i. (She turns to Ms. K.) I understand.

Yesenia: (Prompting Patricia.) The blood circulates.

Patricia: The blood circulates.

Ms. K: (Smiles and makes eye contact with all the students in the group.) Thank you. Please continue your work.

Ms. K moves on to different groups, continuing to circulate, encouraging, and supporting her students in building viable models and using appropriate domain-specific vocabulary to discuss their approaches to building the models. After the students complete their models, each group discusses answers to the questions below before sharing out to the class. Ms. K also provides sentence stems to support students in answering the questions and sharing answers with the class.

- What about our approach was successful? (The aspects of our approach that were successful are…)
- How does our model accurately reflect the circulatory system? (Our model accurately reflects the circulatory system because…)
- How does our model not accurately reflect the circulatory system? (Some aspects of our model do not inaccurately reflect the circulatory system because…)

Ms. K uses the numbered heads together routine for sharing out. In this routine, Ms. K assigns each student a number. The students are familiar with this routine and understand that they will not know who shares out until after the discussion. As such, the group's responsibility is to help all students feel prepared to share out. The students also know that, during share-out time, helping the reporter is encouraged, but no reporter is allowed to pass.

Preparing to write:

The day following the building of the heart and kidney models, Ms. K begins to prepare her students to write their argument essays. To successfully write this essay, students must be able to answer the question, What might happen to the body if one of the body's organs were compromised? Because understanding the answer to this question is so important, Ms. K has planned a series of scaffolds to support her students.

First, she partners her students strategically, ensuring that each student at the Emerging level of English Language Proficiency (ELP) is partnered with at least one English-proficient student who speaks the same primary language. She also partners her other students based on their individual needs and language ability. For example, she tries to partner her students who were recently reclassified as fully English proficient with either a native speaker of English or with a student at the Expanding or Bridging level of English proficiency. Ms. K makes sure to keep her partner pairings flexible over the course of each day, week, and month so that each student sometimes has the opportunity to be the more knowledgeable or able peer and sometimes has the opportunity to work with a partner who has more advanced linguistic and/or content understanding. She also sometimes creates homogenous groups or pairs, depending upon the purpose of the task. For her newcomer students, though, she ensures they are with a partner who will effectively support them with the language demands of all the learning activities.

Using the Think-Write-Pair-Share routine, Ms. K asks her students to jot down in pairs the organs and tissues (along with their respective purposes) they researched and reported on earlier in the week. She encourages them to refer to the posters on the walls and the heart- and kidney-based circulatory system models they completed. She asks each student to first think about what they have learned this week about organs, tissues, and body systems. She then gives them a minute of think time followed by two minutes of writing time. While the students are thinking and writing, she checks in with each of her ELs at the Emerging level of English language proficiency to make sure they understand the task.

She then puts a piece of paper under her document camera and draws four vertical lines down the paper, creating five vertical columns. She explains that each student will record his or her own response and use this chart in preparation for writing their science argument essays. She labels the first column “Organ or tissue,” the second column “Body system,” the third column “Function,” the fourth column “What happens if it is compromised?” and the fifth column “How might its compromise affect other sub-systems or the whole body system?” She explains to her students that she would like them to complete their own tables in their pairs, using their collective knowledge. Ms. K then models the first row for the students. She deliberately chooses neither the heart nor the kidneys as her example. Since the students have studied these organs in more detail, she wants students to use their own knowledge of them independently. Instead, she chooses the skin, which is not an entirely new concept for the students, since one of the groups presented on the skin earlier in the week. Ms. K “thinks aloud” as she completes the chart:

> “One of the organs I remember is the skin. The skin is part of the integumentary system. Let’s all say that together.” The class chorally repeats the word “integumentary.” “I know that this particular organ is made of two layers of tissue called the dermis and the epidermis. I remember from the presentation earlier this week that the function of the skin is to protect the body from external damage, to absorb nutrients, and to regulate temperature. Since we’re just making notes here, I think it’s okay to use bullet points. So, if the skin protects us and something damages it, bacteria and chemicals may more easily get inside the body and harm it. For example, if the bacteria caused an infection, the whole system of the body might be at risk. In extreme cases, a person’s survival might even be at risk.”

As Ms. K “thinks aloud,” she pauses periodically to complete an anchor chart students may refer to during an upcoming writing task.

Organ or tissue	**Body System**	**Function**	**What happens if it is compromised?**	**How might its compromise affect other sub-systems or the whole body system?**
The skin, including the dermis	Integumentary system	○ To protect the body from external damage	It is easier for chemicals or bacteria to get	The body might get an infection, which could affect the

and the epidermis.		○ To absorb nutrients ○ To regulate temperature	inside the body.	body's whole system. In extreme cases, it might put a person's survival at risk.

"What is the next organ or tissue you might want to try?" Ms. K asks. She instructs students to quickly turn and talk to a partner. Students share with one another, and most students say that they would like to try the heart or the kidney. But some students want to try other organs they worked with earlier in the week. Ms. K tells her students they can continue two to three rows of the chart using the organs or tissues of their choice, but that they must negotiate and agree with their partners. She reminds students of the resources they are regularly encouraged to use to get more information if they need it: anchor charts, word walls, and student-created material on the classroom walls; the four classroom computers with Internet access and encyclopedia software loaded; each other; and herself, Ms. K. As students work on their charts, Ms. K circulates to support students with both their content understanding and their use of academic and domain-specific vocabulary.

After the students have completed their charts, Ms. K brings the class back together and asks a series of questions, gradually working toward jointly constructing a statement about the interconnected relationship of the sub-systems of the body.

> Ms. K: Think about what you know about organs…What might happen if an organ is compromised? Please think for a minute, and when you answer I'd like you to use the sentence frame: "If the (organ/tissue) ______ is/are damaged, then _______ might __________. "Let me give you an example. If the skin is damaged, then bacteria might get inside the body and create an infection. (Ms. K has prepared this sentence stem on a chart paper so students have a visual reminder of how she would like them to respond.) Please turn and talk with your partner, take turns thinking of several sentences, and make sure one of you is comfortable sharing out one sentence. (After about one minute of students taking turns speaking…) Lakisha, would you please share with us what you and Jose Luis discussed?
>
> Lakisha: So, if the heart is damaged, then someone might have a heart attack.
>
> Ms. K: Absolutely, that is one result of damage to the heart. When a person has a heart attack, the heart might become damaged. Can you say more about what happens to the body if the heart is damaged?

Lakisha: The heart pumps blood through the body and…

Jose Luis: If it gets damaged it might not be able to…

Lakisha: It might not be able to pump the blood it needs to.

Ms. K: That sounds reasonable to me. Would another group like to add on to what Lakisha and Jose Luis have shared?

Maria: If the heart can't pump the blood throughout the body…

Yesenia: Circulate!

Maria: Yeah, if the heart can't circulate the blood throughout the body, cells don't get the stuff they need.

Ms. K: Thank you, Yesenia and Maria for using the term "circulate." I agree, Maria, the cells don't get what they need. Let's try to be more specific about that. What do cells need? Let's all think for a moment.

Joseph: (After a moment…) I think they need oxygen?

Ms. K: They do indeed need oxygen. Maria, can you repeat your idea using the word "oxygen"?

Maria: Sure. Um, if the heart can't pump…circulate blood in the body, cells don't get the oxygen they need.

Ms. K: This is an important piece of information. Let's write this down together. I'll write under the doc cam, and I'd like every one of you to write in your science notebook. (Writes "If the heart becomes damaged and cannot…") What word should I put here?

Several students: Circulate!

Ms. K: (Writes "…circulate the blood in the body, then…") What do you think goes next? Please turn and talk with your partner. (She gives students a moment to turn and talk.) Miguel, what do you think?

Miguel: Then cells don't get what they need.

Ms. K: (Writes "…cells don't get what they need.") That is certainly true. Is there a way we can say this that incorporates more specific terminology?

Gloria: Cells don't get the oxygen they need.

Ms. K: That is more specific, and it includes one of the academic terms we've been using. (Crosses out "what" and adds "the oxygen.")

Ms. K continues to support her students in understanding and expressing ideas using both academic and domain-specific language. She guides her students through questioning and prompting, moving from the heart to the kidneys, to co-construct statements about the interdependent nature of the sub-systems of the body:

- If the heart is damaged and cannot circulate blood throughout the body, cells do not get the oxygen they require to survive. If cells do not get oxygen, they die. If cells die, especially cells in important places like the brain, the body can also die.
- If the kidneys are damaged and cannot filter toxins and water from the blood, those toxins are circulated throughout the body and can damage or kill the cells in our body. Without oxygen-rich clean blood, our cells cannot survive.
- Each of our organs is made of cells that need to be healthy for the organ to be healthy. If one of our organs, such as the heart or kidneys, is damaged, it can affect the health of other organs by damaging their cells. Therefore, the sub-systems of the body affect the body as a whole.

Ms. K leads her students through an analysis of the language they used to make this scientific argument. She draws her students' attention to the causal "if…then" statements and terminology such as "therefore."

The next day, it is time for students to begin their individual scientific arguments.

After careful observation during each of the phases of the instructional segment, Ms. K considers that most of her students are ready to tackle writing an argument on their own. She reminds students that they will follow the writing process and will each have the opportunity to receive feedback from two peers as well as from Ms. K herself, or another adult, before submitting a final argument. She assigns her students a writing prompt.

If an organ or tissue partially or completely failed, which other sub-system(s) would it affect, and how might it affect the functioning of the human body as a whole? Choose a human organ or tissue. Write an essay that explains the effects of the failure of the organ or tissue that you chose.

Be sure to support your discussion with evidence from classroom discussions, notes, and other appropriate resources.

Ms. K reminds the students who will be writing independently of their resources they have available: anchor charts and other materials on the walls, the computer, each other, and her. She encourages them to use the ideas the class generated together, but emphasizes that they will need to include more details and specificity in their writing. Alternatively, they can opt to challenge themselves to select an organ or tissue that has not been discussed in class.

Ms. K wants to provide additional support to the three ELs at an Emerging level of English Proficiency, as well as four of her students who struggle with writing, two of whom are ELs at the late Expanding level of English proficiency. She pulls these seven students to the back of the room and leads them through the process of planning their arguments, including creating a controlling idea and supporting it with evidence using a causal structure and vocabulary typical of science arguments (e.g., because, since, consequently, as a result, may be due to, this lead to, so that, in order to, if…then, for this reason).

Teacher Reflection and Next Steps

Ms. K evaluates the first drafts of her students' writing in order to make strategic decisions about her next steps. She notices that most of her students seem to understand the concept of the interactivity of sub-systems, but they are a little less clear in their writing about how damage to an organ can cause cell death. She notes this as an area for further discussion and inquiry.

She also notices that some of her English learners are doing well using domain-specific vocabulary but are having trouble using some general academic terminology. During designated ELD time, she decides to set up several days of targeted instruction using a seven-step vocabulary routine on high-leverage Tier 2 words (e.g., indicate, require, react, apply, clarify, etc.).

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Performance Expectations

MS-LS1-3. From Molecules to Organisms: Structures and Processes

Use argument supported by evidence for how the body is a system of interacting sub-systems composed of groups of cells.

Science and engineering practices	Disciplinary core ideas	Cross cutting concepts
Engaging in Argument from Evidence *Use an oral and written argument supported by empirical evidence and scientific reasoning to support or refute an explanation or a model for a phenomenon or a solution to a problem.* **Obtaining, Evaluating, and Communicating Information** *Gather, read, and synthesize information from multiple appropriate sources and assess the credibility, accuracy, and possible bias of each publication*	**LS1.A: From Molecules to Organisms: Structures and Processes** *In multicellular organisms the body is a system of multiple interacting sub-systems. These sub-systems are groups of cells that work together to form tissues and organs that are specialize for particular body functions.*	**Systems and System Models** *Systems may interact with other systems; they may have sub-systems and be a part of larger complex systems.* **Structure and Function** *Complex and microscopic structures and systems can be visualized, modeled, and used to describe how their function depends on the relationships among its parts; therefore, complex natural and designs structures/systems can be to determine how they function.*

and method used, and describe how they are supported or not supported by evidence.		

CA CCSS for ELA/Literacy:

WHST.6-8.1 - Write arguments focused on discipline-specific content.

a. Introduce claim(s) about a topic or issue, acknowledge and distinguish the claim(s) from alternate or opposing claims, and organize the reasons and evidence logically.

b. Support claim(s) with logical reasoning and relevant, accurate data and evidence that demonstrate an understanding of the topic or text, using credible sources.

c. Use words, phrases, and clauses to create cohesion and clarify the relationships among claim(s), counterclaims, reasons, and evidence.

d. Establish and maintain a formal style.

e. Provide a concluding statement or section hat follows from and supports the argument presented.

WHST.6-8.4: Produce clear and coherent writing in which the development, organization, and style are appropriate to task, purpose, and audience.

WHST.6-8.5: With some guidance and support from peers and adults, develop and strengthen writing as needed by planning, revising, editing, rewriting, or trying a new approach, focusing on how well purpose and audience have been addressed.

WHST.6-8.7: Conduct short research projects to answer a question (including a self-generated question), drawing on several sources and generating additional related, focused questions that allow for multiple avenues of exploration.

SL.7.1: Engage effectively in a range of collaborative discussions (one-on-one, in groups, and teacher-led) with diverse partners on grade 7 topics, texts, and issues, building on others' ideas and expressing their own clearly.

a. Come to discussions prepared, having read or researched material under study; explicitly draw on that preparation by referring to evidence on the topic, text, or issue to probe and reflect on ideas under discussion.

b. Follow rules for collegial discussions, track progress toward specific goals and deadlines, and define individual roles as needed.

c. Pose questions that elicit elaboration and respond to others' questions and comments with relevant observations and ideas that bring the discussion back on topic as needed.

d. Acknowledge new information expressed by others and, when warranted, modify their own views.

CA ELD Standards (Expanding):

ELD.PI.7.1 - *Exchanging information/ideas* Contribute to class, group, and partner discussions by following turn-taking rules, asking relevant questions, affirming others, adding relevant information, and paraphrasing key ideas

ELD.PI.7.2 – *Interacting via written English* Engage in longer written exchanges with peers and collaborate on more detailed written texts on a variety of topics, using technology when appropriate.

ELD.P1.7.4. *Adapting language choices* Adjust language choices according to purpose (e.g., explaining, persuading, entertaining), task, and audience.

ELD.P1.7.10 *Writing* a. Write longer literary and informational texts (e.g., an argument for wearing school uniforms) collaboratively (e.g., with peers) and independently using appropriate text organization.

ELD.PII.7.1 - *Understanding text structure* Apply understanding of the organizational features of different text types (e.g., how narratives are organized by an event sequence that unfolds naturally versus how arguments are organized around reasons and evidence) to comprehending texts and to writing increasingly clear and coherent arguments, informative/explanatory texts and narratives.

ELD.PII.7.2 - *Understanding cohesion* b. Apply growing understanding of how ideas, events, or reasons are linked throughout a text using a variety of connecting words or phrases (e.g., for example, as a result, on the other hand) to comprehending texts and writing texts with increasing cohesion.