“Energy: Every Day, Everywhere”
Content Background for Teachers

Introduction

Does a marble at the top of a ramp have energy? What about a stationary marble at the bottom of a ramp? Does a hand-crank flashlight have energy before you crank it? When you crank a hand-crank flashlight and it produces light, it seems that you are creating energy. When you stop cranking and the light goes out, it seems that the energy is gone or lost. Can you explain what is happening to the energy? These are the phenomena that we investigate in the “Energy: Every Day, Everywhere” lesson set. The Unit Central Question for the lesson set is, *How does the energy of an object or system change?* And our work in this lesson set will center around answering that question.

Energy is all around us. We use energy to heat and cool our homes, to cook and cool our food, to run appliances and machines, and to communicate. Energy is necessary for water to evaporate, for clouds to form and rain to fall, for the wind to blow, for lightning to flash across the sky and for thunder to roll, for earthquakes, and for the ocean’s tides. Energy is also necessary for plants and animals to grow, to repair cells and tissues, and to reproduce and survive.

You may know quite a bit about energy through your everyday experiences. But could you define *energy*? Do you know about how energy is measured, how energy moves or is transferred from one place to another? Where does energy come from? Is it created when we turn on a light or a rock falls off a ledge? Is it destroyed when we douse a flame or turn off the television? Take a moment to think about your own understanding of energy.

STOP **Stop and Think:** How would you define *energy*? What examples of energy are around you right at this very moment?

Don’t feel badly if coming up with a scientific definition of *energy* is a challenge for you! It eluded some of the best minds in science for centuries, including the brilliant Isaac Newton. But over time, scientists, including Emilie du Chatelet, Thomas Young, James Joule, Albert Einstein, and numerous others, have helped our understanding of energy evolve and develop—a process that continues even today!

This document will challenge you to broaden and deepen your understanding of energy. It is written to support and further your own content learning about how scientists define, measure, and explain phenomena in the world related to energy. It will help you to answer questions such as, *What is the system of interest? What observable or measurable changes are taking place? Where in the system are energy changes occurring? Where does the energy come from? Where does the energy go?* and *What is the evidence for our answers?* The goal is for you to develop a conceptual understanding of these ideas so you will be able to teach elementary students more effectively about energy and energy transfer.

The content is written with you, the teacher, in mind. It presents subject matter knowledge that is tied to the lessons you will be teaching, but it is at a level higher than what your students will come to understand. After all, teachers should know more than what they teach their students!

What is energy?

The word *energy* was used in everyday language long before it became a scientific term. If you look up the word *energy* in a dictionary you will find many different definitions. Energy in everyday language can mean vitality, vigor, or pep. That's the meaning of energy when you buy an energy drink at the grocery store. It can keep you wide awake or make you jittery even if it contains no calories (calories are one way that scientists measure energy). Some days, you may have said, "My students have too much energy today!" Or, on the other hand, you may have said, "I just don't have enough energy to keep up with my students today!" Newspapers contains stories of the shift to cars that use electricity rather than gasoline as their source of energy; we hear about dwindling energy reserves of fossil fuels and the transition to renewable energy.

Scientists use the term *energy* in different ways across scientific disciplines and scale. As Jeffrey Nordine (2016) explains in *Teaching Energy Across the Sciences, K-12*:

> Although we experience some notion of energy daily, the scientific concept of energy can be very difficult to define. Many textbooks offer definitions such as "energy is the ability to do work" or "energy is the capacity to cause a change," but these definitions are often circular ("work" is an energy transfer process measured in the same units as energy). Energy is a fundamentally abstract concept that eludes a clean definition.

One of the reasons that energy is so hard to define is that energy is not a physical thing. Rather, we describe it as a property of an object or of a system (a group of interacting objects we are interested in). Our life experience has taught us that the amount of energy in an object or in a system of objects can depend on many factors, such as the following:

- speed (A fast marble has more energy of motion than a slow marble.)
- temperature (Hot water has more energy than cold water.)
- the amount of matter in a system (Two cookies contain more energy than one cookie.)
- how objects are arranged relative to each other (The child on the top rung of a ladder on a playground has more energy than that child on the bottom rung of the same ladder. In this case, the system includes both the child and Earth, even though we are more worried about the child falling than Earth!)
- the composition of the objects (There is more energy stored between two strong magnets that are an inch away from each other than between two coins that are an inch away from each other. Similarly, there is more energy stored between the atoms and molecules of a stretched rubber band than between the atoms and molecules of a stretched piece of string.)

- the charge on or flow of electricity to an object (A bolt of lightning or a current of electricity from a wall outlet carries far more energy than rubbing your socks on the carpet and touching a friend.)

These experiences show that we can detect the presence of energy by the way it causes something to happen or has the potential to cause something to happen.

Despite our difficulties in defining what energy *is*, we can identify what energy *does*. Changes in energy, in all its manifestations, can be recognized and measured. We measure energy of motion (kinetic energy) based on an object's mass and velocity (kinetic energy = $\frac{1}{2}mv^2$). Stored energy of position (gravitational potential energy) can be measured by multiplying an object's mass, the acceleration of gravity, and its height above the ground (potential energy due to gravity = $mg\Delta h$). We can track energy changes over time and identify when energy enters and leaves a system.

A Framework for K–12 Science Education (NRC, 2012) and the *Next Generation Science Standards* (NGSS; NGSS Lead States, 2013) recommend that students in elementary school do not learn a definition for *energy*. Rather, the *Framework* and NGSS focus on motion, light, sound, heat, and electricity as ways that energy can be moved from place to place. These observed phenomena are familiar to students and associated with energy changes in a system.

Stop and Think: What are some examples of *energy* of objects or systems? How can you detect energy in your everyday life? What names do you give these different ways that energy is experienced in the world?

Forms of energy

Energy is an underlying property of a system. It is manifested in a variety of natural phenomena we can detect with our senses, such as motion, light, sound, electricity, magnetic fields, and heat. As mentioned earlier, scientists measure these different manifestations of energy differently. Scientists often refer to these different manifestations of energy, and the different ways in which they are measured, as "forms" of energy. While describing different forms of energy is useful when scientists are communicating about energy changes in a specific system, the term *forms of energy* may be confusing to students as it implies that energy has a physical form. Some references refer to different "types" of energy; however, "types" of energy can be equally problematic as students may mistakenly infer that there are different kinds of energy. While there is no perfect term to describe the different ways in which we detect and measure energy, the most frequently used term is *forms of energy*.

At a microscopic level, scientists measure three forms of energy—energy of motion (*kinetic energy*), energy due to objects' or atomic particles' relative positions (*potential energy*), and light or *radiation energy*. For example, what often is described as *thermal energy* is actually the motion of molecules or atoms that you can feel as heat. A substance whose molecules are moving faster is warmer; when those same molecules are moving slower, the substance is cooler. (To a scientist, the measurement of *temperature* is simply an indicator of the average energy of motion of the molecules of a substance.) *Sound* is also motion of particles detectable by the ear. When a student hits a drum, it causes the drumhead to vibrate (motion) which causes the air to vibrate (also motion) that causes your eardrum to vibrate (motion again), and that vibration is interpreted by your brain as sound.

In contrast, potential energy describes the position of an object relative to other objects. An object at the top of a hill has potential energy because it is pulled by Earth's gravity and could move down the hill. It is the interaction between the object at the top of the hill and Earth—the two objects are within the gravitational field of Earth. A stretched rubber band has potential energy because if you were to let it go, it would spring back into its relaxed position. In the same way, a battery has potential energy because of the relative position of particular chemical compounds (and their positive and negative ions) inside the battery. Ions and electrons are able to move and create electric current only when a circuit is complete. Even the food you eat has potential energy because of the position of its atoms and electrons in relation to one another. Sometimes, when the position of those atoms and electrons changes through a chemical reaction, energy is released and can be converted by your body to thermal energy, motion, and sound.

Light is also a form of energy known as *radiation energy*. Unlike sound, light does not need to pass its energy through the vibrations and collisions of molecules; it can carry its energy through waves, even through the vacuum of space. We are most familiar with the form of radiation energy known as *visible light* that we can see, but there are many other forms of radiation energy we cannot see as human beings, including ultraviolet light, infrared light, gamma rays, x-rays, and microwaves. For 4th graders, observing visible light is one way to detect a form of energy in a system.

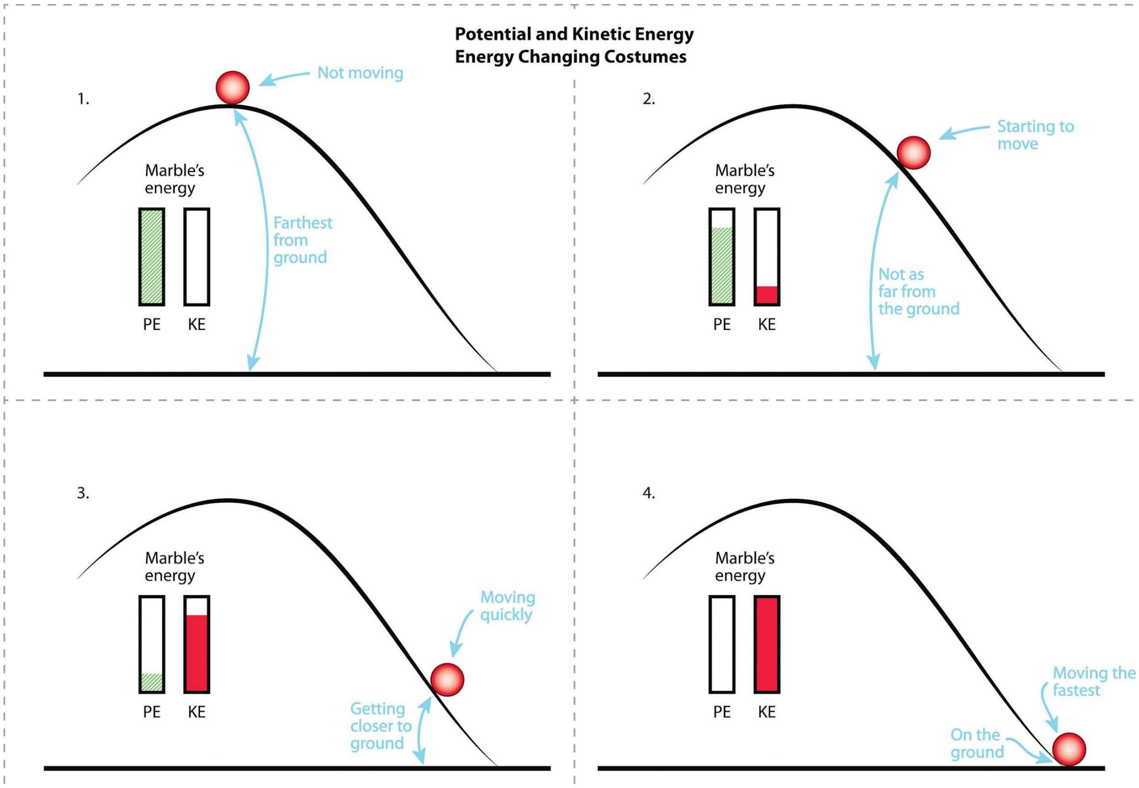
The NGSS emphasize that it is misleading to differentiate the different forms of energy like motion and heat. Differentiating by naming different forms of energy suggests that energy is different in these different forms, when actually, energy is energy—we are just detecting it in different ways. This idea, however, will be very difficult for elementary students to grasp. In the "Energy: Every Day, Everywhere" lessons for 4th graders, we will talk about ways we detect evidence of energy changes in a system by describing sound, light, heat, and motion. We will describe the stored potential energy of an object based on its position, such as an object sitting at the top of a hill or a stretched rubber band.

Energy can be transformed from one form to another.

Where does a roller coaster get its energy to plunge down a hill and move through loops and curves? As the car you are in comes to a momentary stop at the top of the hill, the car has potential energy but no kinetic energy. Then, as the car descends the hill, it moves faster and faster. The car's potential energy decreases as it gets closer to the surface of Earth. At the same time, the car's kinetic energy is increasing as it moves faster and faster. At the bottom of the hill, the car has no potential energy; it has all been converted or transformed into kinetic energy (see text below the illustration about the other forms of energy in this system).

You have just experienced **energy transformation** on the roller coaster. Any time one form of energy increases, another form simultaneously decreases.

Energy transformation: This illustrates how the potential energy of an object moving down a hill transforms to kinetic energy.



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The higher the hill, the faster an object will be going at the bottom of the hill. The more potential energy an object has (the higher it is off the ground), the faster it will move at the bottom of the hill and, therefore, the more kinetic energy it will have.

It is important to clearly define the system of interest when considering potential energy. In this example, we are using the bottom of the hill as our reference point for the place that potential energy is zero. It is the point at which we cannot get any lower to the ground. But if we were talking about a marble rolling down a ramp that sits on a table, we would need to be very clear about whether we are talking about the bottom of the ramp as the lowest point in the system or if we would consider the floor below the table to be part of the system and the point where potential energy is at zero. Defining the system and the system boundaries is important when we consider the transformation of energy from one form to another.

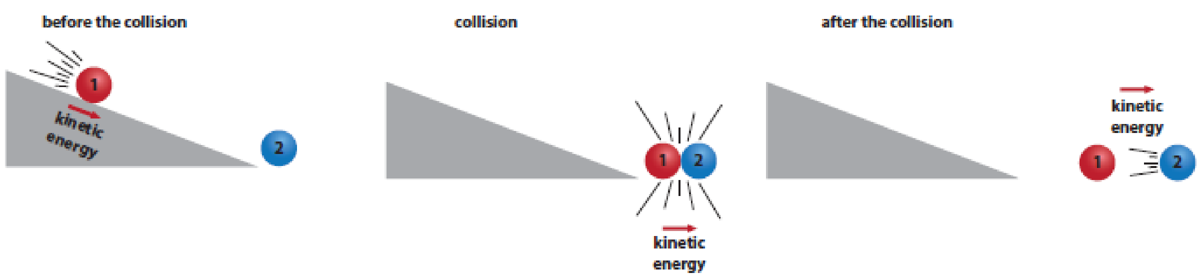
Does *all* the potential energy transform to kinetic energy of motion? Can you detect any other evidence of energy changes in the roller coaster car besides its motion? You may be able to detect evidence of other forms of energy. You can hear the cars rattle and screech as they move along the tracks. If you felt the tracks after a roller coaster had raced over it, the tracks would be very hot. Thus, in addition to kinetic energy of motion of the car, some of the potential energy is also transformed into sound and thermal energy. (Remember that sound and thermal energy are simply the energy of motion of molecules at the microscopic level.)

Stop and Think: You pick up a glass and set it on the table. Describe the energy of the glass. What happens to that energy when you accidentally knock it off the table and it falls to the ground and breaks?

Energy can be transferred from place to place and from object to object.

Energy can move from place to place or object to object when objects interact with each other. When objects collide, energy can be transferred from one object to another, thereby changing their motion. If you place a marble at the top of a ramp, the marble has potential energy. Like the roller coaster car, as the marble rolls down the ramp, energy is transformed; its potential energy decreases as its kinetic energy increases. If the marble collides with another marble sitting motionless at the bottom of the ramp, the first marble slows down and then stops. The second marble starts to move (and eventually stops). The first marble transferred some of its kinetic energy to the second marble through the collision. The first marble may still move at a slower speed after the collision because not all its kinetic energy was transferred to the second marble; the fact that it continued to roll indicates that it still had some kinetic energy.

Energy transfer: This illustrates how the kinetic energy of an object moving down a hill is transferred to a stationary object at the bottom.



There are other ways that energy can move from place to place. Light also transfers energy from place to place but does not need collisions of material objects to do so. Magnetic and electric fields have the potential to move objects without collisions. Energy can also be transferred from place to place by electric currents. Electricity can be used to produce motion, sound, heat, or light. The electric currents themselves may have been produced by transforming the energy of motion (steam turning a turbine or a stream flowing through a generator in a hydroelectric dam) into electrical energy.

Energy is dissipated in all macroscopic processes.

Both marbles eventually stop because there were other collisions that occurred that were not observable. As the marble rolled over a surface, many microscopic collisions occurred between the marble and the surface—collisions we call *friction*. These tiny collisions transferred energy from the marble to the surface, causing an imperceptible motion in the molecules of the surface and raising the temperature of the surface very slightly. There were also microscopic collisions between the moving marble and the air molecules it displaced, resulting in a very small increase in the temperature of the air through which the marble traveled.

You can use the idea of the collision that occurred between the two marbles to explain why a cup of hot tea sitting on the counter cools over time. Moving molecules of hot tea collide with molecules in the air. As these collisions take place, molecules in the air move faster. In other words, they get warmer. The energy of the tea is transferred to the air. You can feel this if you hold your hand over the cup of tea. Over time these collisions continue to occur until the cup of tea is the same temperature as the air around it. Collisions between the molecules in the air and molecules in the tea continue even after the tea has cooled. But now, molecules from the air are transferring just as much energy to the tea as the tea is transferring to the air. The transfer of energy has become equal in each direction, so there is no more change in temperature from the continuing collisions. This tendency towards equilibrium is known as *dissipation*.

The spreading out of energy can happen quickly or slowly depending on the differences between the object and its surroundings. If one object is much larger than the other, it becomes much more difficult to follow the transfer and dissipation of energy. For example, the number of molecules in the cup of tea is much, much smaller than the number of molecules in the surrounding air. This means that, while the cooling of the tea is easily observed, the warming of the surrounding air throughout the room would be much more difficult to observe. This is why it is difficult for students to understand the law of conservation of energy, even while they are able to recite it.

Using an analogy may be helpful when explaining the spread of heat from a cup of hot tea to the air of a classroom. Two are provided below:

1) One way that may help students visualize why it is difficult to detect where the heat from the hot cup of tea goes is to understand that even in a modest-size classroom (25 feet × 25 feet × 8 feet tall), the air has a mass of 182 kg (401 pounds) at sea level. For comparison, actor Dwayne “The Rock” Johnson has a mass of only 118 kg (260 pounds). Thus, the air in the classroom has a mass of about one and a half times more than The Rock. Drinking one cup of hot tea would not raise The Rock’s temperature noticeably, just as it would be very hard to notice the air in the room getting any hotter as the teacup cools to room temperature.

Or

2) One way that may help students visualize why it is difficult to detect where the heat from a hot cup of tea goes is to understand that in a modest-size classroom (25 feet × 25 feet × 8 feet tall), the air has a mass of 182 kg (400 pounds) at sea level. This is the same mass as a large bathtub filled with 800 cups (50 gallons) of room-temperature tea. If one cup of hot tea was added to the large bathtub of room-temperature tea, the temperature in the bathtub would not increase

noticeably, just as it is very hard to notice the air in the room getting any warmer over time as the tea gets cooler.

Stop and Think: Can you think of an example in your everyday life of energy transferring from object to object? Consider turning on a radio, putting on your clothes, cooking dinner, or observing a collision. Can you trace the energy interactions involved in these everyday activities back to the Sun? Can you trace the flow of energy from these everyday activities to explain how the energy will eventually escape Earth as heat going to outer space?

Energy can be measured.

How do you measure energy? You have heard terms that quantify the amount of sound, light, thermal energy, or motion, terms such as *decibels*, *volts*, *degrees Celsius* (or *Fahrenheit*), *meters/second*, or *miles/hour*. These are not units of energy, but they are all related to the amount of energy in a system. These units can help us detect greater or lesser amounts of energy in many situations. Each, in its own way, is related to either some form of motion or some measure of position that indicates there is energy in a system.

Each of these is a way of quantifying energy by measuring the change it caused (or has the potential to cause). Fourth grade students do not need to quantify energy to have some sense of how much energy there is. Your students can use qualitative descriptors rather than scientific units to measure energy. For example, your students will be able to say that the faster an object is moving, the more energy it has. The brighter the light, the more energy it has. The louder the sound, the more energy it has. The hotter an object, the more energy it has. We can represent these semiquantitative differences using energy bars.

However, qualitative descriptions of energy such as *louder*, *faster*, *hotter*, and *brighter* can also be misleading. In general, if you have two cups with the same amount of tea and one is hotter than the other, you can say that there is more energy in the cup of tea at a higher temperature than in the cup of tea at a lower temperature. But what if you have a cup of water at 75° Celsius and a large bathtub of water at 75° Celsius? Do they have the same amount of energy? No! The water in the tub holds more energy than the water in the cup at the same temperature because the bathtub holds so many more molecules of water. Since the average speed of the molecules is the same in both the bathtub and the cup, the bathtub has more energy. In the same way, a marble that is rolling very fast has more energy than the same marble that is rolling at a slower speed. But what if you have a marble rolling at 1 foot per second and a car driving down the street at 1 foot per second? Do they have the same amount of energy? No. The moving car has more energy than the rolling marble because it has a greater mass. The more mass there is at a certain speed, or a certain temperature, the more energy there is.

Energy cannot be created or destroyed.

One of the most fundamental concepts about energy is that it cannot be created or destroyed. This is called the *law of conservation of energy*. This is also one of the most confusing ideas about energy and does not seem to match our experiences with energy in the world. We fill our car's gas tank and then drive to work every day for a week. At the end of the week, the gas tank is empty and needs to be refilled. The gas may have been used up, but was the energy? Similarly, we eat a meal and several hours later, we're ready for more. Have we "used up" that energy? If so, is the energy destroyed? Even more confusing, when we turn on a flashlight, we can see that the energy in the battery has changed into light, but what happens to that energy when we turn off the flashlight and the room goes dark? Where did the energy go? Is it gone? When a marble rolls to the bottom of a ramp, it gained speed—and thus kinetic energy. When it stopped rolling after reaching the bottom of the ramp, where did the energy go?

The best way to understand the idea that energy is never created or destroyed is to take a much broader view of energy than we normally do. Art Sussman, in his book *Dr. Art's Guide to Planet Earth* (Sussman, 2000), describes it this way:

> Our local energy company charges us for the oil or natural gas that we use to heat our home. If we refuse to pay the bill and send a letter to the gas company arguing that the scientific law tells us that we did not use up the energy, what do you think the answer will be?

The energy company might respond to our letter saying:

> *Thank you for reminding us about the law of energy conservation. Last month we supplied you with 200,000 units of energy that was initially contained in coal, oil, and natural gas. That energy has already left our planet as heat. If you can capture it and package it in a convenient form, we will buy it back from you.*
>
> *-The Energy Company*

When we heat our home, we pay attention only to the fuel and the heat in the house. The law of energy conservation follows the heat after it leaves the house, watches it escape through the atmosphere and spread into outer space, and notices that the heat continues to exist forever—it is never destroyed. Further, the amount of heat energy exactly equals the amount of chemical energy released from the fuel (such as gas, oil, or wood). The company does not bill us because we destroy energy. We pay the electric and gas bill because we use a particularly convenient form of stored energy and change the energy into a form that is much less useful because it cannot be used to perform the same task again.

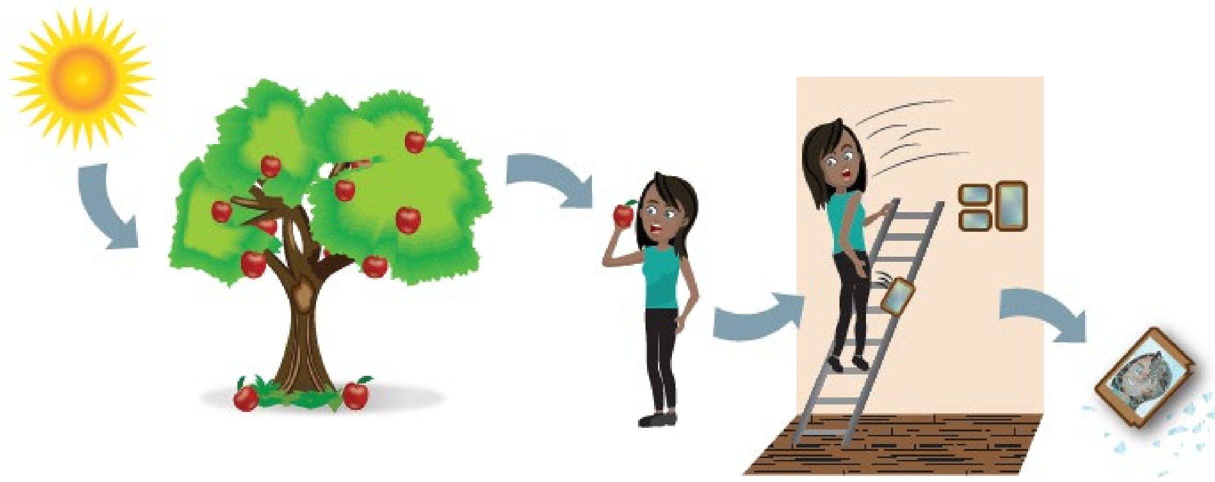
Thinking about energy changes in a system

To better understand the law of conservation of energy, think about energy as part of a very large, global system. Consider Earth's energy in terms of a balanced budget. Just like your family's budget has money coming in each month and money going out each month, so, too, Earth has a global energy budget. Most of the energy on Earth comes from the Sun. The rest, a tiny amount compared to the energy of the Sun, comes from deep inside Earth. This is heat left over from Earth's creation billions of years ago and from the ongoing decay of radioactive materials deep in Earth's core. Earth's surface gets energy from these two sources every minute of every day. The amount of energy that flows into Earth's surface from the Sun and from Earth's core is exactly equal to the amount that flows away from Earth's surface and atmosphere as heat to outer space.

With this larger view in mind, we can begin to trace energy from the Sun (and to a much smaller degree, energy from inside Earth) to the everyday experiences we have with energy. We can account for energy as it flows from the Sun to some part of Earth, then goes through a variety of changes, and ultimately ends up as heat that escapes Earth's global system into outer space.

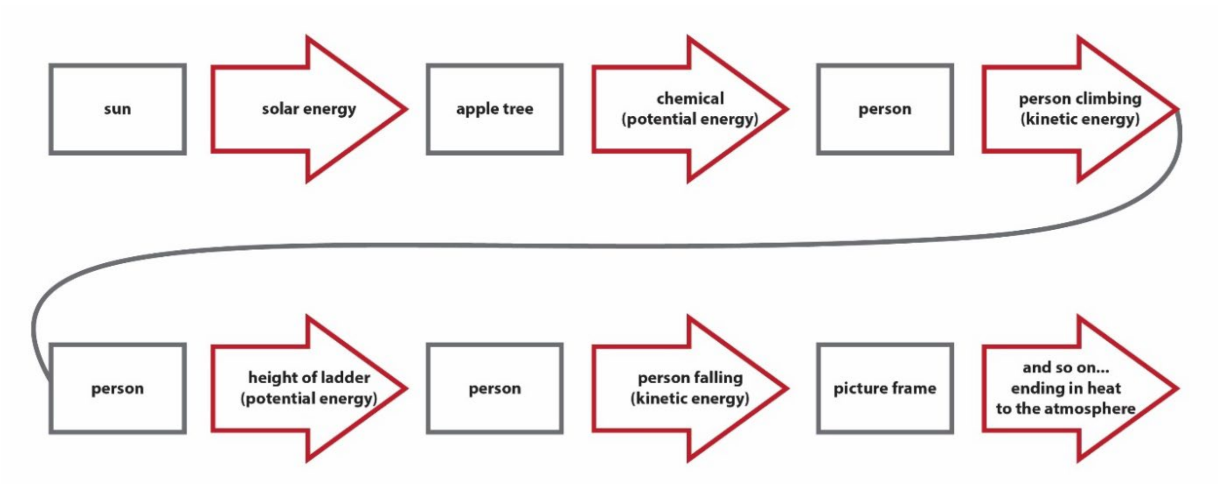
Here is a simple example that might help to clarify this complex idea. Plants capture a very tiny amount of the sunlight that comes to Earth and convert it to potential energy associated with the chemical bonds in the sugars they make as food for themselves. You know this as the process of photosynthesis. Plants use water, carbon dioxide, and the energy from the Sun to make basic building blocks for living things and, in the process, store that energy in the bonds holding together the atoms and molecules that make up the plant. This energy was earlier described as "potential energy" that is stored because of the position of the atoms and electrons in relation to one another. Imagine the energy, transformed by capturing the incoming energy of the Sun, is being stored in a bright, juicy, delicious apple. You eat this apple, and your body releases the energy that is then used in a variety of ways. Some of the energy is heat that radiates from your body and eventually escapes to outer space. Some of it is used as fuel supplying the energy for your muscles to move. If you use some of that energy to climb a ladder, you have not destroyed that energy. Some of it was changed into potential energy because now, at the top of the ladder with gravity pulling on you, you have the potential to fall with a big *thud*. Because of your position, this potential energy (which came from climbing the ladder, which came from the food you ate, which came from the Sun) could once again turn into kinetic (motion) energy when you fall. Let us say when you fall you break a picture frame. It took some of the energy from your fall to first knock the picture frame over and then to rearrange the pieces of wood and glass as it shattered into a hundred pieces.

After all this, was the energy gone? Was it finally used up? No! Remember that our law of energy conservation says that energy is never used up. Most of the energy ultimately turned into heat after friction with the air and the ground, and the picture frame released this energy into the floor and air as heat, much like the heat from your home furnace eventually escapes into the atmosphere. This is why it is common to hear the phrase "energy flows." It is not created or destroyed but undergoes many changes and eventually changes to heat that radiates to outer space.



We can picture the observable changes in the system.

We can also create a diagram to track the energy in the system.



This diagram shows energy transfer from object to object, and changes in energy are evident in a variety of different forms. We can follow the arrows in this energy diagram to give us a cause-and-effect storyline for what happens to the energy from the Sun to the broken picture frame and even beyond. This diagram does not capture all the energy changes. For example, it does not describe the heat energy that leaves your body as you climb the ladder or the sound energy heard when you land on the floor with a *thud*. It does not describe the small amount of heat transferred to the ladder as friction holds your foot in place with each step up the ladder. Describing each of these small energy interactions would make the diagram more complete (and complex) and account for the ways that energy is not created or destroyed but changes as objects (like your foot and the ladder) interact with each other.

To support students in thinking about the energy changes in a system, it is useful to consider a progression of questions:

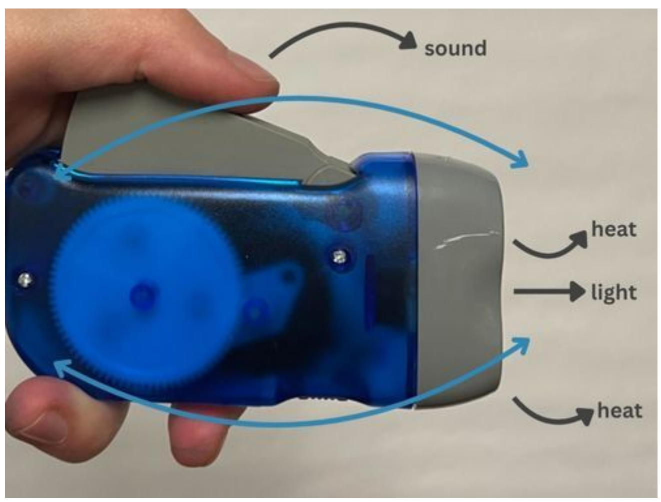
- What is the system of interest?

- What observable or measurable changes are taking place?
- Where in the system are energy changes occurring?
- Where does the energy come from (flow from)?
- Where does the energy go (flow to)?
- What is the evidence for our answers?

The *Framework* and NGSS recommend that 4th grade students focus on identifying forms of energy and finding evidence of energy transformations and transfers in phenomena.

Using systems to think about conservation of energy

"Systems thinking" is a useful alternative way to make sense of conservation of energy. For example, consider the system involving a student and a hand-crank flashlight. We can represent this system with the following image.



First, notice the dashed line forming a box around the flashlight and hands. This line represents the imaginary boundary of the system, which is made up of the student's hands and the flashlight. Note that energy is represented by black arrows. These arrows are one way to show how energy changes within this system. In this example, the energy of motion of the student's hand transforms to light, heat, and sound. Within the system, energy transfers from object to object and transforms but is not created or destroyed.

The relationship among energy, force, work, and power

It is natural for many scientific words such as *energy*, *force*, *work*, and *power* to be used interchangeably in everyday language. Because these are all abstract scientific concepts, it is helpful to understand the relationships among these words in scientific terms.

Often confusion arises for students between the terms *energy* and *force* in describing observations of the interactions of objects. One way to distinguish between these terms is that it is *energy* that gives one object the ability to produce a particular *force* (a push or a pull) on another object for a particular distance, such as when a car pulls a trailer up a hill using the stored energy in its gas tank. As the trailer gains energy from being pulled farther and farther up the hill, the car loses energy by pulling the trailer, specifically in its gas tank. When there is no more energy in the gas tank, the car cannot pull (force) the trailer any farther (any more distance) up the hill. Scientists call this process of transferring energy from one object to another object using a particular force acting for a particular distance doing *work*, where the quantity of work performed is the quantity of energy transferred between objects. Fortunately, when work is performed, it is usually accompanied by observable differences in the system of objects we are interested in, such as seeing the trailer get pulled up the hill and seeing on the fuel gauge how much gas in the tank is used up. These differences help us describe the process and direction of the energy transfer between the objects.

Similarly, confusion often arises between the related terms *energy* and *power* in describing observations of energy transformations. *Power* is simply the rate at which *energy* can be transformed each second. Imagine two cars that have the same exact size and mass. Car 1 has an old engine that can cause it to accelerate from 0 to 60 miles/hour (96 kph) in ten seconds. Car 2 has a new engine that can cause it to accelerate from 0 to 60 miles/hour in only five seconds. During this acceleration to 60 miles/hour, both engines have transferred exactly the same amount kinetic *energy* (energy of motion) to the cars from the potential energy in the gas tanks. However, we say that car 2 has twice the *power* of car 1 because the same amount of *energy* was transferred twice as fast in car 2 than in car 1. (As an equation, we can say: power = energy transferred/time of the energy transfer. This equation is not necessary for 4th graders; however, understanding that energy can be transferred at different rates is a great start!)

Correspondingly, if the brakes on car 2 can stop it from a speed of 60 miles/hour in half the time as the brakes on car 1, we say that car 2's brakes have twice the *power* of the brakes on car 1 since they can transfer the same amount of energy of motion into heat but in half the time (converting the energy of motion into thermal energy in the brakes, tires, and ground).

Potential energy can also be an elusive term to describe because it also is associated with the forces between two or more objects. The magnitude of potential energy depends on the arrangement of the objects relative to each other. For example, *gravitational potential energy* is associated with the force of gravity that exists between two objects, Earth and the object that may fall. The greater the difference in the height between two objects, the greater the potential energy. The convenient part of comparing gravitational potential energies is that the height of the object that may fall can be measured from whatever is the lowest point of the system that we are interested in, say, the top of a table instead of all the way to the ground. *Elastic potential energy* is associated with the electromagnetic force between the charged particles in the atoms and molecules that make up the elastic material. The amount of potential energy of a rubber band depends on how far it is stretched, which affects how far apart the atoms or molecules are from each other inside the material.

If energy is never destroyed, why do we need to "conserve energy"?

Here is another example of when the words scientists use, as in "conserve energy," are different from the common usage of the same phrase. Today, we are quite concerned about running out of fossil fuels necessary to heat our homes and drive our cars. We are also concerned about the effects of continued burning of fossil fuels on our climate. But a source of energy is not the same thing as energy. Fossil fuels are a source of energy—they have potential energy because of the arrangement of their molecules and atoms. The energy can be released as the atoms and molecules are rearranged in a chemical reaction—the combustion of the fuel that occurs in your furnace or in your car's engine.

We know that coal, oil, and gas—what are referred to as *fossil fuels*—come from materials that were once plants and animals on Earth. The energy held in the once-living matter of leaves, wood, algae, plankton, bacteria, muscles, and flesh was stored as it changed over time into oil, gas, and coal. When we talk in everyday terms about conserving energy, we are really talking about the fact that in today's industrial age we use the stored energy in these fuel sources faster than they can be replenished by the natural processes that captured and stored energy from the Sun over thousands or millions of years. That is one reason why people today talk of relying more on renewable energy resources, such as solar, wind, hydroelectric, and geothermal, or nuclear energy. These sources of energy do not require many thousands or millions of years to turn into a usable form.

Conserving fossil fuel resources is only one reason to rely more on renewable energy sources. Earlier, it was discussed that Earth has a global energy budget. Essentially, to maintain the current average temperature of Earth, all the energy from the sunlight that enters Earth's atmosphere must eventually be reflected or radiated back into outer space. So, there is a balance that occurs. All the solar energy that is not reflected quickly back to space is absorbed by plants and other objects on Earth, transformed into other forms of energy, and, eventually, converted into heat energy which gets radiated back to outer space. If Earth is to stay the same average temperature as it is now, that balance (energy into Earth = energy radiated back to outer space) must be maintained. In our atmosphere, several naturally occurring gases absorb heat as it is radiated back into the atmosphere and help Earth to maintain its temperature. These include the gases carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O) among others and are known as *greenhouse gases* because they act in much the same way that a glass window in a greenhouse or car traps energy from the Sun to warm up the inside. The Sun's light can enter the atmosphere, but some of the heat radiated back from the surface of Earth (after numerous collisions and energy transformations) gets trapped by the chemical bonds in these atmospheric greenhouse gases. Without these natural gases, the rate of heat radiating back to space would be too quick and Earth would be too cold to support life as we know it. Essentially, the gases act as a blanket around Earth, trapping heat just long enough to keep us at the right temperature. Before the use of fossil fuels, this balance between absorbed solar energy and re-emitted heat energy was fairly well maintained for the past several millennia.

However, the modern practice of extracting and burning fossil fuels for industry, commercial and residential uses, transportation, and electricity generation (and to a smaller extent some agricultural practices) has generated higher concentrations of the natural greenhouse gases in the atmosphere than we have seen over the past several thousand years. As these concentrations rise, the rate that heat energy is radiated back to outer space slows and the average temperature of Earth's surface has started to rise. This is akin to adding an extra blanket to your bed when you are already comfortable. The extra blanket will capture extra heat and will raise the temperature of your bed possibly to an uncomfortable temperature. On Earth, this extra heat trapped by the atmosphere will continue to raise air, surface, and ocean temperatures, melt ice and snow more quickly, evaporate more liquid water, alter wind patterns, and even melt the areas of permafrost in the Arctic and under the oceans that have been frozen for tens of thousands of years. Recalling from our earlier discussion, since temperature is a measure of the energy of motion (kinetic energy) of a system, there is now more energy in Earth's system, and this increase in energy has the ability to drive changes to the world climate.

Stop and Think: How did the coal, natural gas, and oil that we use for common sources of fuels start with energy from the Sun? How do they ultimately end up as additional heat moving from Earth to outer space?

References

Crissman, S., Lacy, S., Nordine, J., & Tobin, R. (2015). Looking Through the Energy Lens. *Science and Children, 52*(6), 26-31.

Driver, R., Squires, A., Rushworth, P., & Wood-Robinson, V. (2015). *Making sense of secondary science: Research into children's ideas* (2nd ed.). London: Routledge.

National Research Council. (2012). *A Framework for K-12 Science Education: Practices, Crosscutting Concepts, and Core Ideas.* Committee on a Conceptual Framework for New K-12 Science Standards. Board on Science Education, Division of Behavioral and Social Sciences and *Education. Washington, DC: The National Academies Press.*

NGSS Lead States. 2013. Next Generation Science Standards: For States, By States. Washington, DC: The National Academies Press.

NOAA Climate.gov. (2022). *Climate Change: Global Temperature*. Retrieved from https://www.climate.gov/news-features/understanding-climate/climate-change-global-temperature

Nordine, J. (2016). *Teaching energy across the sciences, K-12*. Arlington, VA: NSTA Press, National Science Teachers Association.

Sussman, A. (2000). *Dr. Art's Guide to Planet Earth*. San Francisco, CA:. West Ed.

U.S. Environmental Protection Agency. (2022). *Sources of Greenhouse Gas Emissions*. Retrieved from https://www.epa.gov/ghgemissions/sources-greenhouse-gas-emissions

U.S. Environmental Protection Agency. (2022). Retrieved from https://www.epa.gov/ghgemissions/global-greenhouse-gas-emissions-data

Common Student Ideas about Energy

Common student idea	Scientific explanation
Energy is associated only with living things. (human-centered model)	Students will often associate energy only with living things, suggesting that energy is needed for life or activity (as in, "When we run out of energy, we need food and rest."). All objects, living and nonliving, have energy associated with them.
Some objects "have" energy, and some objects "need" it. (depository model)	It is common to use anthropomorphic language in explanations of scientific phenomena. Students might say, "Heat *wants* to move from hot to cold" or "The marble *likes* being at the bottom of the ramp" or "The Styrofoam *needs* to stop." Inanimate objects do not have these human qualities.
Energy is associated only with obvious activity (e.g., movement or burning). (obvious activity model)	All energy can be thought of at the atomic scale as a mixture of energy of motion (kinetic), stored energy (potential), and radiation. *Kinetic energy* is energy associated with motion. *Potential energy* often describes energy associated with the position of an object relative to another object. Energy is best understood at the microscopic scale, at which it can be modeled either as motions of particles or as stored in force fields (electric, magnetic, gravitational). For example, a pencil lying on a table is higher than the floor. The pencil and the floor are within the gravitational field of Earth. Because of the force of gravity, the pencil has the potential to fall from the higher tabletop to the lower floor. Even if it is not moving, the pencil has energy due to its position within the gravitational field. The key idea is that both kinetic energy and potential energy are energy. We measure the amount of energy differently once we determine the form of energy, but they are not different natural phenomena any more than a person wearing a costume is a different person.
Energy is a "thing", or it is a substance or fluid that flows from one place to another. (flow transfer model)	Energy is a concept scientists use to explain changes in everyday objects. Energy is a measurable property of a system. We can measure differences in distance, temperature, speed, and even color. When these measurable quantities change, energy is involved. We do not see the actual energy; we see the changes or differences that energy causes. Energy is not a concrete "thing"; it is not found "in" an object or a chemical bond. Energy is always associated with the state of an object or a system of objects—a very abstract concept.
Energy is dormant within some objects or substances and can be released by some trigger. (ingredient model)	A common idea is that energy in food and fuel is stored in the chemical bonds and that energy is released when bonds are broken. While energy can be released in chemical reactions which involve the making and breaking of chemical bonds, the chemical bonds themselves do not contain energy. In general, chemical bonds within molecules are created to form arrangements of atoms with lower potential energy than the same atoms in an unbonded arrangement. When food or fuel reacts with oxygen to form carbon dioxide and water, the arrangement of atoms in the food or fuel had higher potential energy than the arrangement of atoms in

Common student idea	Scientific explanation
	carbon dioxide and water. The difference in potential energies is transformed to kinetic and thermal energy. The energy in a battery of a flashlight is not dormant, released when the flashlight is turned on. Rather, the battery has potential energy which is transformed to electrical energy and then again into light and thermal energy when the flashlight is turned on.
Only visible things have energy.	It is common to think that energy requires a visible agent to express it. For example, a hammer hits a nail. The hammer is a visible agent of motion energy. But invisible objects are also agents of energy transfers and energy transformations. For example, heat lamps at restaurants keep food warm until the food is served. The infrared radiation (heat waves) these lamps use is invisible to us. Yet it warms the food when the energy from the infrared radiation is absorbed by the food and transformed, causing the food molecules to vibrate more quickly (raising the temperature, the average kinetic energy of the molecules). This extra heat is transferred throughout the food through collisions of adjacent molecules.
There are many distinct kinds of energy.	All energy is fundamentally the same, and it can be manifested in different phenomena that are often referred to as different “forms” or “types” or “categories” of energy. Energy is a fundamental underlying property of a system, and the forms of energy we observe are simply manifestations of this single underlying property. To learners, the idea that there are different forms of energy, such as thermal energy, mechanical energy, and chemical energy, can be misleading if it implies that the nature of the energy in each of these manifestations is distinct when, at the atomic scale, they all are ultimately some mixture of kinetic energy, stored energy, and radiation. An effort should be made to stress that these different forms of energy are all still energy. Scientists often use the term “form of energy” when they are describing observable transformations of energy.
Energy transformations only occur between certain types of energy.	Because all forms of energy are manifestations of the same thing, they can be converted or transformed into any other form. There are no improbable transformations of energy.
Energy transfer only happens if there is a collision.	Certainly, collisions, both macroscopic and microscopic, transfer energy. But there are other ways energy can move from place to place or object to object as well. Electromagnetic radiation (anything from radio waves to microwaves to visible light to gamma rays) can transfer energy. For example, sunlight moves energy from the Sun more than 90 million miles (145 million kilometers) through the vacuum of space and strikes our skin. Our skin responds by warming and possibly even burning.

Common student idea	Scientific explanation
A moving object's energy gets used up as it slows down and eventually stops.	Objects have energy that can be transferred or transformed within a system. The total amount of energy in the system remains constant (conserved). The term *used up* might convey the idea that energy can be destroyed. Instead, a rolling marble has kinetic energy that decreases as the marble slows down and eventually stops. The marble stops because of the many tiny collisions that occurred between the marble and the surface (and the marble and the air) that we call *friction*. These tiny collisions resulted in the marble's kinetic energy transferring to the surface and air as heat. If the marble collides with another marble, some of the motion energy of one marble transfers to motion energy of the other marble, while some is also transformed into the sound of the marbles hitting or a small amount of heat being produced. Through all these changes, the total amount of energy in the system is conserved.
Energy is the same thing as force and power.	It is natural for some words to be used interchangeably in everyday language. In science, words tend to have very precise meanings. Energy, force, and power are all abstract concepts. A force is a push or pull. Energy transfers occur between objects when they push or pull on each other over some distance. Often, when students use the terms *force* and *energy* interchangeably, they tend to focus on the observable changes in the object or system rather than on the more abstract transformations of energy in the object or system. Every type of potential energy is associated with a force acting between two objects. The magnitude of potential energy depends on the arrangement of the objects relative to each other. For example, gravitational potential energy is associated with the force of gravity that exists between two objects: Earth and the object that may fall. The greater the difference in height between two objects, the greater the potential energy. Elastic potential energy is associated with the electromagnetic force between the charged particles in the atoms and molecules that make up the elastic material. The amount of potential energy of a rubber band depends on how far it is stretched, which affects how far apart the atoms and molecules are from each other inside the material. Power is a measure of how quickly energy is transferred over time. A racecar speeding around a track has energy of motion. The more quickly (in the shortest period of time) the racecar's engine can transform the potential energy stored in the fuel tank to the kinetic energy in the motion of the car, the more powerful the engine is said to be.
Energy can be used up or destroyed.	Energy cannot be used up or destroyed. Energy can, however, change forms. Energy can transform from potential energy to kinetic energy, for example, when a rock falls down a hillside. The rock had potential energy at the top of the hill, and when it fell, the potential energy changed into kinetic energy. Energy can undergo other types of changes, too. The chemical energy (potential energy associated with the chemical bonds) in the gasoline in your car's tank can change into the kinetic energy of your moving car and also into the roar of the sound energy from the car's

Common student idea	Scientific explanation
	engine, the heat produced by the engine, and the heat produced as friction as the tires grip the road. Not all the energy of the gasoline is converted to the kinetic energy of the moving car--some energy leaves the system and is no longer useful. Eventually, the car comes to rest to park, losing all its kinetic energy to heat from friction. If we could keep track of all the increased heat energy in engine, air, tires, road, and brakes, it would be exactly the same amount as the potential energy lost by the gasoline in the tank. However, this heat energy is now less useful to us than the gasoline's potential energy was because we cannot use it to perform the same tasks, like driving the car again. Newer cars, such as hybrids and cars with regenerative braking, can transfer some of the energy from braking into electrical energy that can be used to give the car kinetic energy later. In your cell phone, when a battery goes "dead" the device did not "use up" the energy. But rather, the potential energy stored in the battery (because of relative positions of charged particles inside the battery) was transformed into the electrical energy needed to operate the phone. This electrical energy was then transformed again into the sounds you heard, the light given off by the phone, the vibrations it made while alerting you of a new text, and the radio waves it sent to the cell tower. You might also have noticed that your phone got warmer as you used it, as some of the electrical energy is always unfortunately transformed into heat. All these forms of energy dissipate (spread out) into the environment. If you could keep track of them, they would again equal the potential energy lost by the battery, but they are no longer very useful to us anymore. Energy changes occur, but the total amount of energy remains the same. Interestingly, when the rechargeable battery in the cell phone is recharged, by design, the charged particles are returned to the relative positions (by the electrical energy from the outlet) where they store the potential energy associated with a fully charged battery. Nonrechargeable batteries are not designed to allow the charged particles to be returned to their original positions when their original potential energy has been transformed into other energy forms.
Energy can be created.	Energy is not created. It may appear that you create energy when you strike a match or make a loud sound with a horn. Energy doesn't instantly come into existence; however, energy does change. Energy may seem to be created because some energy is not visible directly. For example, the motion of air molecules we call wind is not easily observed. Yet the energy can transfer from the wind to a flag to make it move. Similarly, thermal energy cannot be seen directly. Yet when heat transfers from the stove to a pot of water, we can feel the warm water or see the water start to boil.
Energy is fuel and therefore a natural resource which we will run out of.	Students are familiar with ideas about energy conservation and nonrenewable forms of energy such as fossil fuels. They may hold the common idea that fuel is energy rather than fuel has potential energy that can be transformed to kinetic and thermal energy when combined with oxygen in chemical reactions.

References

Driver, R., Squires, A., Rushworth, P., & Wood-Robinson, V. (2015). *Making sense of secondary science: Research into children's ideas*. London: Routledge.

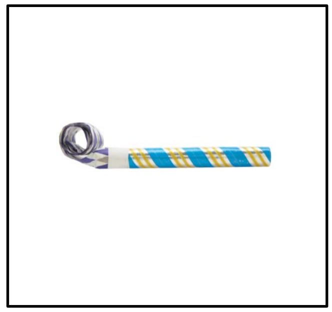
National Research Council. (2012). *A Framework for K-12 Science Education: Practices, Crosscutting Concepts, and Core Ideas.* Committee on a Conceptual Framework for New K-12 Science Standards. Board on Science Education, Division of Behavioral and Social Sciences and Education. Washington, DC: The National Academies Press.

Nordine, J. (2016). *Teaching energy across the sciences, K-12*. Arlington, VA: NSTA Press, National Science Teachers Association.

"Energy: Every Day, Everywhere"
Pretest/Posttest

Name: ______________________________________ Date: ________________________________

1. Ishaan's sister Asha has a noisemaker like the one in the pictures. When she blows into the noisemaker, it unrolls with a crackling sound. When it is all the way unrolled, it makes a loud honking sound. Ishaan thought about the energy changes happening with the noisemaker.



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   a. What is the evidence that energy changes are happening as Asha plays with the noisemaker?

   b. What is one question Ishaan could investigate about the energy changes happening with the noisemaker?

2. Taylor and Alex go to the amusement park. They are excited to ride the bumper cars. When they get on the ride, Alex cannot get their blue car to move. Taylor steps on the accelerator, and Taylor's red car moves quickly towards Alex's blue car. Taylor's red car crashes into Alex's blue car, and there is a loud bang. Then Taylor's red car stops moving, and Alex's blue car moves forward.

The diagram below shows the bumper cars when they collide.

a. Add words to the diagram that describe the energy changes in the bumper car system.

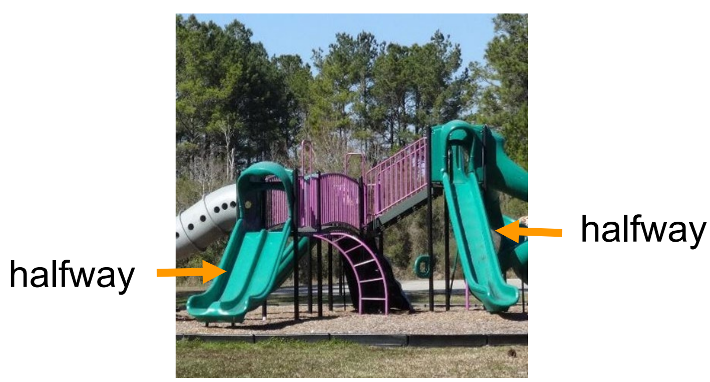
b. What is the evidence for each change? Write in complete sentences.

3. Look at the slides in the picture.

a. Imagine you are sitting still on the top of a short slide. Do you have any energy? What is your evidence?

b. Now imagine you are sliding down this short slide. Describe your energy when you are halfway down the slide. What is your evidence?

c. Imagine you are halfway down the tall slide. Now imagine you are halfway down the short slide. Predict how your energy will be different when you are halfway down the tall slide than when you are halfway down the short slide. Explain how you know this.



“Energy: Every Day, Everywhere”
Pretest/Posttest KEY

Name: ______________________________________ **Date:** ________________________________

1. Ishaan’s sister Asha has a noisemaker like the one in the pictures. When she blows into the noisemaker, it unrolls with a crackling sound. When it is all the way unrolled, it makes a loud honking sound. Ishaan thought about the energy changes happening with the noisemaker.

   a. What is the evidence that energy changes are happening as Asha plays with the noisemaker?

   When Asha blows into the noisemaker, there is motion energy as it unrolls. When the noisemaker unrolls, there is sound energy when it makes the crackling sound, and when it is all the way unrolled it makes the honking sound.

   b. What is one question Ishaan could investigate about the energy changes happening with the noisemaker?

   Will the noisemaker unroll faster if Asha blows harder and adds more energy?
   Is the honking sound louder if Asha blows harder and adds more energy?

2. Taylor and Alex go to the amusement park. They are excited to ride the bumper cars. When they get on the ride, Alex cannot get their blue car to move. Taylor steps on the accelerator and Taylor's red car moves quickly towards Alex's blue car. Taylor's red car crashes into Alex's blue car and there is a loud bang. Then Taylor's red car stops moving, and Alex's blue car moves forward.

The diagram below shows the bumper cars when they collide.

a. Add words to the diagram that describe the energy changes in the bumper car system.

b. What is the evidence for each change? Write in complete sentences.

There is motion energy from Taylor's red car because it is moving. Or, before the collision, Taylor's red car had motion energy because it was moving.

Some motion energy was transferred from Taylor's red car to Alex's blue car. The evidence is that Taylor's red car stopped moving and Alex's blue car is pushed away.

Some motion energy of Taylor's red car was transformed to sound energy that left the system into the air around it. The evidence for this is the loud BAM sound.

Look at the slides in the picture.

c. Imagine you are sitting still on the top of a shorter slide. Do you have any energy? What is your evidence?

Yes, I have position energy. My evidence for this is that I am higher up above the ground.

d. Now imagine you are sliding down this short slide. Describe your energy when you are halfway down the slide. What is your evidence?

When I am halfway down the slide, some of my position energy has been transformed to motion energy. I know this because I am moving faster as I go down the slide. I have less position energy because some of it was transformed into motion energy as I move closer to the ground.

e. Imagine you are halfway down the tall slide. Now imagine you are halfway down the short slide. Predict how your energy will be different when you are halfway down the tall slide than when you are halfway down the short slide. Explain how you know this.

I will have more energy when I am halfway down the tall slide than when I am halfway down the short slide. I had more position energy at the top of the tall slide. Some of my position energy is transformed to motion energy as I move down the slide. Because I'm starting with more position energy on the tall slide, there is more position energy to be transformed into more motion energy than on the short slide.