Description of the Energy Learning Goals Assessed by the ASPECt-MC Instruments

As part of the process of defining the content to be tested by the instruments, we write clarification statements that unpack the learning goals to make explicit the boundaries around the knowledge being targeted. The unpacking includes sub-idea statements that describe what students are expected to know about the targeted idea, and boundary statements that clarify what students are not expected to know. The clarification statements also make clear the different expectations of students at the different levels of the learning progression. These statements served as item writing specifications to ensure that the items are aligned to the learning goals and appropriate for students at the different levels.

The concept of energy is typically separated into four categories: (1) Energy Forms and Transformations, the idea that energy manifests itself in different forms, such as kinetic energy and gravitational potential energy, that can be converted from one to another; (2) Energy Transfer, the idea that energy can be transferred from one location to another in different ways; (3) Energy Dissipation and Degradation, the idea that whenever energy is transformed or transferred some energy is also transferred to the environment as thermal energy; and (4) Energy Conservation, the idea that the total amount of energy in a system remains constant unless energy is added to or released from the system.

For two of the categories—Energy Forms and Transformations, and Energy Transfer—we further defined the specific ideas that make up those categories. For the Energy Forms and Transformation category, we identified and assessed student understanding of five forms of energy along with the idea of energy transformation itself, and we expanded the Energy Transfer category into six specific mechanisms of energy transfer. The forms of energy include (1) kinetic energy, the energy associated with motion; (2) thermal energy, the energy associated with temperature; (3) gravitational potential energy, the energy associated with distance from the center of the earth; (4) elastic potential energy, the energy associated with the stretching, bending, or twisting of an elastic object; (5) chemical energy, the energy associated with arrangements of atoms in a chemical reaction system. Energy transformations, i.e., the conversion of one of these forms of energy into another, makes up the sixth idea in this category. The Energy Transfer category includes (1) conduction, the transfer of energy due to temperature differences between objects in contact; (2) convection, the transfer of energy due to the movement of liquids or gases; (3) radiation, the transfer of energy by electromagnetic waves; (4) the transfer of energy by forces exerted by one object on another; (5) the transfer of energy by sound; and (6) the transfer of energy in a complete electrical circuit. This gives us a total of 14 specific ideas in our energy construct: five forms of energy ideas, one energy transformation idea, six energy transfer ideas, one energy dissipation/degradation idea, and one conservation of energy idea.

For each idea, we describe a progression of conceptual complexity. The *basic* conceptual complexity level focuses on simple energy relationships and easily observable effects of energy processes; the *intermediate* level focuses on more complex energy concepts and applications; and the *advanced* level focuses on still more complex energy concepts, often requiring an atomic/molecular model to explain phenomena. Most ideas have learning goals at each level of conceptual complexity. The exceptions are the ideas about energy transfer electrically and by sound, which have only basic and intermediate learning goals, and energy transformations, which has only intermediate and advanced learning goals.

Table 1 summarizes the learning goals at each level of the progression of conceptual complexity for the energy ideas assessed by the instruments. Below we describe in detail the knowledge expected of students at each level of each energy idea. Boundary statements of knowledge not expected of students are listed when appropriate. A comparison to the expectations included in NGSS is provided at the end of the document.

Table 1

Key Energy Ideas Assessed by the Instruments and Alignment with NGSS Performance Expectations (PEs)
[Grayed-out cells indicate that no PEs match that particular level of the conceptual complexity.]

Energy Idea	Basic level	Intermediate level	Advanced level
Kinetic Energy	The amount of energy an object has depends on how fast it is moving.	The amount of kinetic energy (motion energy) an object has depends on the speed and the mass of the object.	The amount of kinetic energy (motion energy) an object has is proportional to the mass of the object and increases rapidly with increasing speed.
PEs	4-PS3-1	MS-PS3-1*	MS-PS3-1*
Thermal Energy	The amount of energy an object has depends on how warm it is.	The amount of thermal energy an object has depends on the temperature and the mass of the object and the material of which the object is made.	The amount of thermal energy an object has depends on the disordered motions of its atoms or molecules and the number and types of atoms or molecules of which the object is made.
PEs		MS-PS3-4	MS-PS1-4, HS-PS3-2
Gravitational Potential Energy	The amount of energy an object has depends on how high it is above the surface of the earth.	The amount of gravitational potential energy an object near the surface of the earth has is related to the distance the object is above the surface of the earth (or an alternate reference point), and the mass of the object.	Gravitational potential energy is associated with the separation of mutually attracting masses.
PEs		MS-PS3-2	HS-PS3-2
Elastic Potential Energy	The amount of energy an elastic object has depends on how much the object is stretched, compressed, twisted, or bent.	The amount of elastic potential energy an elastic object has is related to the amount the object is stretched or compressed and how difficult it is to stretch or compress the object.	The amount of elastic potential energy stored in a stretched or compressed elastic object increases when the object is further stretched or compressed because stretching and compressing an object changes the distances between the atoms and molecules that make up the object.
PEs			HS-PS3-2
Chemical Energy	Energy is released when fuel is burned. Energy is also released when food is used as fuel in animals	Some chemical reactions release energy into the surroundings, whereas other chemical reactions take in energy from the surroundings	Chemical energy is associated with the arrangement of atoms that make up the molecules of the reactants and products of a chemical reaction. Because the arrangement of atoms making up the molecules is different before and after the chemical reaction takes place, the amount of chemical energy in the system is also different.
PEs	5-PS3-1		HS-PS1-4
Energy Transformations		Most of what goes on in the universe—from exploding stars and biological growth to the operation of machines and the motion of people—involves some form of energy being converted into one or more other forms of energy.	
PEs		4-PS3-4	HS-PS3-3

*MS-PS3-1 aligns to the intermediate kinetic energy level while the underlying disciplinary core idea aligns to the advanced kinetic energy level.

Table 1 continued. *Key Energy Ideas Assessed by the Instruments and Alignment with NGSS Performance Expectations (PEs)*

Energy Idea	Basic level	Intermediate level	Advanced level
Transferring Energy by Conduction	When warmer things are touching cooler ones, the warmer things get cooler and the cooler things get warmer until they all are the same temperature.	Conduction is the transfer of energy that occurs when a warmer object (or quantities of a solid, liquid, or gas) comes in contact with a cooler object (or quantities of a solid, liquid, or gas) without a transfer of matter.	Energy is transferred through a material by conduction by the random collisions of atoms and molecules that make up the material.
PEs	4-PS3-2	MS-PS3-3	MS-PS3-4
Transferring Energy by Convection	When air or water moves to another location, it can change the temperature of the air or water at that location.	Temperature variations in fluids such as air and water lead to currents that circulate the fluid and transfers energy from place to place in the fluid	In a fluid, regions that have different temperatures have different densities. The differences in density lead to an imbalance between the downward gravitational force and upward (buoyant) forces exerted by the surrounding fluid, creating currents that contribute to the transfer of energy.
PEs			MS-ESS2-6
Transferring Energy by Radiation	When light shines on an object, the object typically gets warmer.	Light transfers energy from a light source to a receiver.	Energy can be transferred by electromagnetic radiation.
PEs	K-PS3-1, K-PS3-2	4-PS3-2	
Transferring Energy by Forces	When objects collide, contact forces can transfer energy from one object to another resulting in a change in the objects' motion.	Energy can be transferred mechanically when an object exerts a force on another object even if the objects are not in contact.	When two objects change relative position as a result of a contact force or a gravitational, magnetic, or electric force, the potential and kinetic energies of the system change.
PEs	4-PS3-3	MS-PS3-2	HS-PS3-5
Transferring Energy Electrically	Energy can be transferred electrically when an electrical source is connected in a complete circuit to an electrical device.		Electrostatic potential energy can be stored in the separation of charged objects.
PEs	4-PS3-2		HS-PS3-5
Transferring Energy by Sound	Sound can transfer energy from one location to another.		Energy is transferred by sound because of coordinated collisions between the atoms or molecules that make up the medium through which the sound travels.
PEs	4-PS3-2		
Energy Dissipation & Degradation	Objects tend to get warmer when they use or take in energy or when they interact with each other.	Transformations and transfers of energy within a system usually result in some energy being released into its surrounding environment causing an increase in the thermal energy of the environment.	Unless prevented from doing so, energy will become uniformly distributed.
PEs			HS-PS3-4
Conservation of Energy	Everything has energy.	A decrease in energy in one object or set of objects always is accompanied by an increase in energy in another object or set of objects.	Regardless of what happens within a system, the total amount of energy in the system remains the same unless energy is added to or released from the system.
PEs		MS-PS3-5	HS-PS3-1

Basic Level Energy Ideas

At the *basic* level of conceptual complexity, students are expected to be able to think about the most easily observable aspects of energy—objects with more thermal energy are warmer, objects with more motion energy move faster—and to recognize obvious effects of simple energy processes—a rock dropped from a greater height will do more damage than one dropped from a lower height. The ideas at this level are aligned to the disciplinary core ideas from the foundation boxes of the kindergarten, fourth grade, and fifth grade performance expectations found in the PS3: Energy core idea section of the *Next Generation Science Standards* (NGSS) (see Table 1). For the most part, the items aligned to the basic level do not use forms of energy terminology. Therefore, there is no basic level for the idea about energy transformations. Students at this level are only expected to know certain indicators of energy, such as speed and temperature, and not how energy forms can be converted from one to another.

Energy Forms and Transformations

Kinetic energy (Motion energy). Any object that is moving has some amount of energy that is related to how fast it is moving. The faster an object moves, the more energy it has due to its motion, and the slower an object moves, the less energy it has due to its motion. Also, the faster an object is moving, the more damage it can do or the bigger the change in shape it can cause to itself and another object if the two objects hit each other.

Assessment items at this level do not use unit rates or use rate language, such as feet per second or miles per hour, in elementary school because these ideas are not expected until the 6th grade according to the math *Common Core State Standards* (CCSS 6.RP, pg. 42)[1]. This idea refers to motion with respect to the surface of the earth. An object is considered to be "not moving" if its position with respect to a point on the surface of the earth is not changing. Items may show objects moving in a straight line, vibrating back and forth, or rotating. In all cases, students at this level are expected to know only that the energy of motion depends on speed. In items, comparisons are made between objects moving in the same manner (i.e., both rotating) and with the same distribution of mass from the origin.

Thermal energy. Every object, regardless of whether it is a solid, a liquid, or a gas, has some amount of energy that is related to its temperature. The higher an object's temperature is, the more energy it has, and the lower an object's temperature is, the less energy it has (assuming temperature is the only thing that changes).

In assessment items, the temperature changes are limited to those that do not involve changes of state. Students at this level are not expected to know that even very cold objects have thermal energy.

[1] National Governors Association Center for Best Practices, Council of Chief State School Officers. (2010). *Common Core State Standards—Mathematics*. Washington D.C.: National Governors Association Center for Best Practices, Council of Chief State School Officers

Gravitational potential energy. All objects have some amount of energy that is associated with how high the object is above the surface of the earth. The farther away an object is from the surface of the earth, the more energy it has, and the closer an object is to the surface of the earth, the less energy it has (assuming the height above the surface of the earth is the only thing that changes). Also, the higher an object is above the surface of the earth, the more damage it can do when it falls to the ground or the more it can change the shape of the surface of the earth when it falls to the ground.

Assessment items at this level are limited to scenarios in which mass is kept constant by involving only one object or two identical objects.

Elastic potential energy. All elastic objects that are stretched or compressed have some amount of energy that is associated with how much they are stretched, compressed, twisted, or bent. The energy of an elastic object can be increased by stretching or compressing the object out of its original shape. The more the object is stretched or compressed, the more energy the object has, and the less the object is stretched or compressed, the less energy it has (assuming that the amount of stretching or compressing is the only thing that changes). Also, the more an elastic object is stretched or compressed, the farther it can propel itself or another object when released.

Assessment items at this level use only familiar elastic objects such as springs, rubber bands, and rubber balls and are limited to scenarios involving only one object or two identical objects. Items may involve objects stretched, compressed, twisted, or bent. In items, comparisons are made between objects stretched, compressed, twisted, or bent in the same manner (i.e., both bent). Items do not use situations where one object is stretched and another object is compressed. Additionally, items do not compare an object in a stretched and compressed state. In assessment items, objects are not stretched, compressed, twisted, or bent beyond the point where they would return to their original shape (i.e. no plastic deformation).

Chemical energy. Energy is released when fuel is burned and energy is released when food is used as fuel in animals. An increase in temperature or the production of light or sound is an indicator of energy being released (given off). For any particular fuel, the more fuel that is burned, the more energy is released (assuming an unlimited supply of oxygen). The energy released when fuel is burned can be used to make something move or to light or warm a room. When animals (including humans) use food as fuel, the energy released is used by the animal to carry out life functions such as moving, building body structures, and staying warm.

Assessment items aligned to this idea use familiar fuels, e.g. gasoline, coal, propane, oil, natural gas, and wood. The assessment items at this level do not assess the idea that plants use food as fuel to carry our life functions.

Energy transformations. Because energy is treated as unified topic at the basic level, there are no assessment items aligned to the energy transformations idea at this level. Ideas about energy transformations are assessed at the intermediate and advanced level.

Energy Transfer

Transferring energy by conduction. When a warmer object is touching a cooler object, the warmer object will get cooler and the cooler object will get warmer. This is true for liquids and gases as well as for solid objects. For example, when a cooler solid object is in contact with warmer air in a confined space, the cooler object will get warmer and the air will get cooler. Once the objects (including air) reach the same temperature, the objects will remain at that temperature until another warmer or cooler object is introduced.

At this level, students are not expected to know that temperature changes that occur when an object at one temperature is placed next to another object at a different temperature are due to a transfer of energy. The words "transfer" or "conduction" are not used in basic level items. Students at this level are not expected to know that energy can be transferred between an object and the surrounding air even when the air is not in a confined space. Energy dissipation to the surroundings is considered a separate idea. Assessment items will use only confined spaces. Contexts of assessment items are limited to those that do not involve changes of state.

Transferring energy by convection. When air or water moves to another location, it can change the temperature of the water or air at that location. When cooler air or water moves to a new location, it mixes with the air or water at that location, making the air or water at that location cooler. Likewise, when warmer air or water moves to a new location, it mixes with the air or water at that location, making the air or water at that location warmer.

At this level, students are not expected to use the phrase "energy transfer" to describe what happens to the temperature of air or water when cooler or warmer air or water moves from one location to another. The words "transfer" or "convection" are not used in items. Basic level items do not assess students' understanding of convection currents.

Transferring energy by radiation. When light shines on an object, the object typically gets warmer. Light bulbs, fire, and the sun are sources of light. The longer a light shines on an object, the warmer the object can get.

At this level, students are not expected to know that the reason objects get warmer when light shines on them is because energy is transferred to them by light. The words "transfer" or "radiation" are not used in items. Only light sources that give off visible light are used in assessment items at this level. Students at this level are not expected to know that all objects give off "light" as electromagnetic radiation. Additionally, contexts of assessment items are limited to those that do not involve changes of state.

Transferring energy by forces. When one object pushes or pulls on another object by direct contact (e.g. collisions), their speeds change compared to their speeds before the collision and energy is transferred from the one object that slows down to the object that speeds up (assuming no other forces act on the objects). The transfer of energy stops when one object no longer exerts a force on the other object. When two forces act over the same distance and in the same direction, the stronger force transfers more energy than the weaker force.

This idea is limited to transfers of energy as a result of direct contact forces and elastic collisions and is limited to systems containing two objects that are moving or that can be moved. Examples of direct contact include when billiard balls hit each other, when a ball is thrown or kicked, when a baseball or golf ball is hit with a bat or club, when an object is set in motion by a rubber band or spring, or when a bobsled or swing is pushed. Transfers of energy as a result of forces that act at a distance are introduced at the intermediate level.

Assessment items include contexts where there is a clear transfer of energy (one object will slow down and the other will speed up). Items do not include collisions between objects that are significantly different in mass where the change in speed of the more massive object is negligible.

Transferring energy electrically. There are only two levels for this idea. The basic/intermediate level is described in the Intermediate level section below.

Transferring energy by sound. There are only two levels for this idea. The basic/intermediate level is described in the Intermediate level section below.

Energy Dissipation and Degradation

Energy dissipation. Objects tend to get warmer when they are involved inuse or take in energy or when they interact with each other. For example, when two objects are rubbed against or collide with each other, they both get warmer. When an electrical device (e.g., computer, radio, cell phone, or remote-controlled car) is used, the device gets warmer. When a machine “uses” energy (e.g., to make something happen), the machine and the surrounding environment get warmer. When an animal “uses” energy (e.g., to perform basic body functions), the animal and the surrounding environment get warmer.

Ideas about energy degradation are not assessed at this level. Energy degradation is assessed at the advanced level.

Energy Conservation

Conservation of energy. Everything has energy and different things can have different amounts of energy. The amount of energy an object has can change. Changes in motion and temperature or giving off and taking in sound and light are indicators that the energy of an object has changed.

Intermediate Level Energy Ideas

At the *intermediate* level, students are expected to be familiar with less easily observable aspects of energy—thermal energy is related to both temperature and mass—and to be able to explain energy-related phenomena or evaluate energy applications using more complex energy concepts. For the most part, the ideas at this level are aligned to the disciplinary core ideas from the foundation boxes of the middle school performance expectations found in the PS3: Energy core idea section of the *Next Generation Science Standards* (NGSS) (see Table 1).

Energy Forms and Transformations

Kinetic energy (Motion energy). The amount of kinetic energy an object has depends on both the speed and the mass of the object. Kinetic energy is the energy of motion and applies to the motion of macroscopic objects, microscopic objects, molecules, or atoms. Any object that is moving has kinetic energy and the kinetic energy of an object that is not moving is zero. When comparing objects of the same mass, the object with the greatest speed has the greatest amount of kinetic energy and the object with the lowest speed has the least amount of kinetic energy. When comparing objects traveling at the same speed (greater than zero), the object with the greatest mass has the greatest amount of kinetic energy and the object with the least mass has the least amount of kinetic energy.

Assessment items use the phrase "kinetic energy (motion energy)" to avoid confusing students who are not familiar with the phrase "kinetic energy." Assessment items at this level expect students to compare relative speeds and masses to determine relative amounts of kinetic energy. Students are not expected to calculate the exact amount of kinetic energy. Assessment items use either metric or non-metric units of speed (e.g. meters per second or miles per hour) as described in CCSS for mathematics.

This idea refers to motion with respect to the surface of the earth. An object is considered to be "not moving" if its position with respect to a point on the surface of the earth is not changing. Items may show objects moving in a straight line, vibrating back and forth, or rotating. In all cases, students are expected to know only that the amount of energy of motion an object has depends on its speed and mass. In items, comparisons will be made between objects moving in the same manner (i.e., both rotating) and with the same distribution of mass from the origin.

Thermal energy. The amount of thermal energy an object has depends on the temperature and the mass of the object and the material of which the object is made. Every object, regardless of whether it is a solid, a liquid, or a gas, and regardless of whether it feels warm or cold to the touch, has some thermal energy even if the object's temperature is very low. When comparing objects that are made of the same material and have the same mass, the object with the highest temperature has the most thermal energy and the object with the lowest temperature has the least thermal energy. When comparing objects that are made of the same material and at the same temperature, the object with the greatest mass has the most thermal energy and the object with the least mass has the least thermal energy. Objects that are made of different materials may have different amounts of thermal energy even if they have the same mass and temperature.

At this level, students are expected to compare relative temperature and masses to determine relative amounts of thermal energy. Assessment items do not ask students to use formulas, such as 3/2 kT and $m(\Delta T)c$, to calculate thermal energy. Items do not assess the idea that heat capacity is a measure of how much the temperature of an object will increase with the addition of a given amount of thermal energy, or why an object could feel colder than other objects at the same temperature. Items also do not assess students' knowledge of which specific types of materials have more thermal energy than others. Students are only expected to know that equal amounts of different materials may have different amounts of thermal energy. In assessment items, the temperature changes are limited to those that do not involve changes of state. Items may use either Fahrenheit (ºF) or Celsius (ºC) as the units of temperature.

Note: Our research has shown that the idea that thermal energy depends on mass is difficult for students (Herrmann-Abell & DeBoer, 2018). During our field testing, we found that items testing this idea were more difficult than items aligned to the advanced level thermal energy idea. Perhaps having a solid understanding of atomic/molecular ideas related to thermal energy is helpful for making sense of the idea that thermal energy depends on mass. If students understand that thermal energy increases as the number of atoms/molecules increases and that mass is a measure of the amount of matter/number of atoms/molecules that make up the object, then they can reason that thermal energy increases as the mass increases.

Note: The term "heat" can be used in everyday conversation as a verb or a noun. When heat is used as a verb, the meaning is basically to raise the temperature of an object as in "I heated the water." When heat is used as a noun, it usually is intended to mean "thermal energy," but that use is not scientifically correct. Technically, "heat" is the energy transferred from one system to another (or between a system and its environment) due to a temperature difference between the systems (or between the system and its environment). Students are not expected to know the proper use of the term heat. To avoid confusion, the everyday use of "heat" as a noun will be avoided in assessment items for middle school and beyond. The use of "heat" as a verb does not cause a problem, however.

Gravitational potential energy. For objects near the surface of the earth, gravitational potential energy depends on the distance the object is above the surface of the earth (or an alternate reference point), and the mass of the object. Objects that are zero distance from the reference point (i.e. the surface of the earth) have no gravitational potential energy. When an object is lifted above the surface of the earth, the change in its gravitational potential energy is related to the change in the height, not to the path taken to get there. Another way of saying this is that the amount of gravitational potential energy an object has is independent of its history (e.g. the path the object takes to get to the height above the reference point). When comparing objects that have the same mass, the object farthest from the surface of the earth will have the most gravitational potential energy and the object closest to the surface of the earth will have the least gravitational potential energy. When comparing objects that are equal distances from the surface of the earth (greater than zero), the object with the greatest mass will have the most gravitational potential energy, and the object with the least mass will have the least gravitational potential energy. The relationships between an object's height, mass, and gravitational potential energy are mathematically represented by the equation $GPE = mgh$ where h is the height, m is the mass of the object, and g is the acceleration due to gravity, which for an object near the surface of the earth is a constant equal to 9.8 m/s^2.

The distance used in the assessment items is the distance above the surface of the earth unless a substitute reference plane, such as the floor, is explicitly stated in the assessment item. When this is the case, the reference plane is chosen so that there will be only positive values for the distance. Assessment items at this level are limited to systems involving the earth. Assessment items use the phrase "gravitational potential energy" and not "gravitational energy" because students often confuse "gravitational energy" with "gravitational force." Assessment items expect students to compare relative distances and masses to determine relative amounts of gravitational potential energy. Students are not expected to calculate the exact amount of gravitational potential energy.

NOTE: Any plane on which all points are essentially equidistant from the center of the earth, such as the floor of a room, can be used as a substitute for the center of the earth in determining the amount of gravitational potential energy an object has. Because all points on this reference plane are considered to be equidistant from the center of the earth, all objects on the plane can be considered to have zero gravitational potential energy. (There will be only one reference plane that applies to all objects in the situation.) In assessment items the "reference plane" will be referred to as a "reference point."

Elastic potential energy. The elastic potential energy of an object is related to both the amount the object is stretched, compressed, twisted, or bent and how difficult it is to stretch, compress, twist, or bend the object. The amount of elastic potential energy of an object has can be determined from these two factors alone, and not its mass. Any elastic object that is stretched, compressed, twisted, or bent has elastic potential energy. An elastic object that is not stretched or compressed has no elastic potential energy. When comparing elastic objects that are identical except for how much they are stretched or compressed, the object stretched or compressed the most will have the most elastic potential energy and the object stretched or compressed the least will have the least elastic potential energy. When comparing elastic objects stretched or compressed the same amount (greater than zero), the object that was the most difficult to stretch or compress has the most elastic potential energy, and the object that was the least difficult to stretch or compress has the least elastic potential energy.

Assessment items do not ask students to use formulas, such as $\frac{1}{2}kx^2$, to calculate elastic potential energy. Students are expected to compare relative amounts of deformation (stretch, compress, twist, or bend) and how difficult it is to deform the objects to determine relative amounts of elastic potential energy. Assessment items use only familiar elastic objects such as springs, rubber bands, and rubber balls. Students are not expected to know the stiffness or rigidity of specific materials or the spring constants of specific springs. In assessment items, the relative rigidity is provided when necessary. Items may involve objects stretched, compressed, twisted, or bent. In items, comparisons are made between objects stretched, compressed, twisted, or bent in the same manner (i.e., both bent). Items do not use situations where one object is stretched and another object is compressed. Additionally, items do not compare an object in a stretched and compressed state. In assessment items, objects are not stretched, compressed, twisted, or bent beyond the point where they would return to their original shape (i.e. no plastic deformation).

Chemical energy. Some chemical reactions release energy into the surroundings, whereas other chemical reactions take in energy from the surroundings. When energy is released from a chemical reaction, the products of the reaction have less chemical energy than the reactants; when energy is taken in from the surroundings the products of the reactants have more chemical energy than the reactants. The amount of energy released or taken in during a chemical reaction depends on the specific reactants and the amounts of each reactant present in the system. Increasing the amounts of reactants increases the amount of energy released or taken in and decreasing the amounts of reactants decreases the amount of energy released or taken in.

The production of light or sound or an increase in temperature or motion in the surroundings is evidence that energy was released during the chemical reaction. In the case where the temperature of the surroundings increases, some chemical energy was converted to thermal energy and that thermal energy was transferred to the surroundings. One way to determine the relative amount of energy released during two chemical reactions is to compare the change in temperature of the surroundings that accompanies each reaction. The larger the increase in temperature of the surroundings, the more energy was released during the reaction. Examples of chemical reactions that release energy include burning (a chemical reaction between a fuel and oxygen) and cellular respiration (a chemical reaction between food and oxygen that occurs in plants and animals). Energy released during a chemical reaction can be used to drive/power a variety of processes. For example, energy released during chemical reactions that occur inside of a battery can be used to power a flashlight and energy released during chemical reactions that occur inside an animal’s body can be used to contract muscles that the animal uses to move.

A decrease in the temperature of the surroundings during a chemical reaction is evidence that energy from the surroundings was taken in and thermal energy was converted to chemical energy. Additionally, light and sound can also be taken in from the surroundings but this may be difficult to observe. An example of a chemical reaction during which light is taken in is photosynthesis (a chemical reaction that occurs in plants and forms sugar from carbon dioxide and water).

At this level, students are not assessed on the definitions of the words “reactants” and “products” but they should understand reactants and products to be the starting and ending substances of a chemical reaction. For this idea, dissolving is considered a chemical change (because the configuration of and interactions between atoms change). Therefore, item contexts may include the dissolution of ionic solids (e.g. cold packs). Students at this level are not expected to know that the energy released from or absorbed by a chemical reaction system depends on other conditions such as temperature or type of solvent. They are also not expected to quantify how much chemical energy is stored in any particular chemical reaction system. For example, students are not expected to use tables of bond energies or do calculations involving such data. The sub-ideas above describe semi-quantitative relationships.

Energy transformations. Most of what goes on in the universe—from exploding stars and biological growth to the operation of machines and the motion of people—involves some form of energy being converted into one or more other forms of energy. If there is a decrease in one form of energy, there will be an increase in one or more other forms of energy. Similarly, if there is an increase in one form of energy, there will be a decrease in one or more other forms of energy. All forms of energy can be converted to other forms of energy, and all forms of energy can result from a transformation. Energy transformations typically occur when energy is transferred from one object or place to another. For example, when a compressed spring is used to push a ball, elastic potential energy is transformed into motion energy and energy is transferred from the spring to the ball. Energy cannot be transformed into a force and vice versa (This is because energy is a property of an object or system and force is an interaction between objects or systems.).

Assessment items require students to analyze real world situations involving energy transformations and identify the forms in which energy is manifested before and after the transformation. Items do not ask students to calculate how much of one form of energy is converted into another given properties such as mass, velocity, height, etc. Items may use contexts in which energy transformations occur between kinetic energy (motion energy), thermal energy, gravitational potential energy, chemical energy, and elastic potential energy. They do not use contexts in which energy transformations occur between electrical energy, sound energy, or radiant energy because we consider these to be mechanisms of energy transfer and not forms of energy. At this level, items will not include transformations involving electrostatic potential energy because this form of energy is part of the advanced level.

Energy Transfer

Transferring energy by conduction. Conduction is the transfer of energy that occurs when a warmer object (or quantities of a solid, liquid or gas) comes in contact with a cooler object (or quantities of a solid, liquid or gas) without a transfer of matter. Two objects (or quantities of a solid, liquid or gas) must be in contact with each other for energy to be transferred by conduction. Energy can also be transferred from one part of an object to another by conduction. There must be a temperature difference between the objects or samples of matter in contact or there must be a temperature difference within a single object for energy to be transferred by conduction. The greater the temperature difference the greater the amount of energy that can be transferred by conduction and the faster the transfer occurs (assuming the material making up the objects and their masses are held constant). As the temperatures of the two objects get closer together, the rate of energy transfer slows down. The energy transferred by conduction goes from the warmer matter to the cooler matter not from the cooler matter to the warmer matter. As energy is transferred from the warmer to the cooler matter by conduction, the thermal energy (and temperature) of the warmer matter will decrease and the thermal energy (and temperature) of the cooler matter will increase until the objects or samples are at the same temperature (assuming neither object or sample of matter changes state). During conduction, energy is transferred without the transfer of matter. This is unlike convection, where matter and its energy move from one location to another together.

Assessment items assume a net transfer of energy from the warmer object to the colder object without referring to it as a net transfer. Items will do not ask students to make calculations about how much energy is transferred by conduction (e.g. they will not be asked to make calculations given mass, heat capacity, and temperature). Contexts of assessment items are limited to those that do not involve changes of state.

Transferring energy by convection. Convection is the transfer of energy by the movement of fluids (liquids or gases). The movement of the fluid can be due to temperature variations in the fluid or an external force like a fan. Natural convection occurs from temperature variations within a fluid. Energy is transferred by natural convection in oceans, the air, and as molten rock moves in the earth's mantle. Forced convection occurs when the motion of the fluid is produced by an external source like a blower, fan, or suction device. Central heating and air conditioning systems rely on forced convection to transfer energy throughout buildings. Wind pushing surface water on oceans and lakes is another example of forced convection. During convection, matter and its energy move from one location to another. This is unlike conduction, where energy is transferred without the transfer of matter. The introduction of warmer fluid into a location increases the thermal energy of the fluid at that location and the introduction of cooler fluid into a location decreases the thermal energy of the fluid at that location. Convection is usually the dominant form of energy transfer in liquids and gases (compared to conduction) because large quantities of liquids and gases can flow from one place to another within the fluid. Convection cannot occur in solids because regions of a solid cannot flow from one part of the solid to another.

Temperature variations in fluids such as air and water lead to currents that circulate the fluid and transfers energy from place to place in the fluid. Temperature variations can exist between different regions of a given sample of fluid. When a region of the fluid is warmer than the fluid around it, it rises, and when a region is cooler than the fluid around it, it sinks. If a rising or sinking region of fluid encounters a boundary that blocks its movement (such as the top of a container or the surface of a liquid) the fluid will begin to flow horizontally along the boundary. The combination of warmer regions of a fluid rising, cooler regions sinking, and movement along boundaries causes circulation of the materials that make up a fluid. Energy is transferred by way of currents when a fluid and the thermal energy that the fluid has circulates.

Assessment items at this level do not assess students' knowledge of convection due to the rise and fall of the tides or variations in salinity or that convection is due to the differential effect of gravity on areas of different densities caused by differences in temperature. They also do not expect students to know how much warmer or colder a fluid needs to be than the fluid around it in order to circulate. Items do not ask students to calculate how much energy is transferred by convection in a particular situation.

Transferring energy by radiation. Energy can be transferred by light when light from a light source shines on another object (receiver). For example, when a light bulb (or the sun) shines light on an object, energy is transferred from the light bulb (or the sun) to the object. Light transfers energy through space; it does not need a medium such as air or another object in order to transfer energy from one object to another. Light is given off by objects in all directions [except for lasers and other specially designed light sources or when the light is reflected or blocked] and travels in straight lines; therefore, energy can be transferred from an object by light in all directions to any object in the path of the light. Because light is transferred in all directions, the amount of energy transferred by light from a light source to an object decreases as the distance between the source and object increases. The amount of energy transferred by light depends on the color of the light source. Light sources can give off light of different colors, ranging from red [through orange, yellow, green, blue] to violet. For a given period of time and equal brightness, violet light can transfer the highest amount of energy and red can transfer the lowest amount of energy. The amount of energy transferred by light depends on the brightness of the light source. The brighter the light, the more energy can be transferred. The dimmer the light, the less energy can be transferred. The longer a light source shines on another object, the more energy is transferred from the source to the object. When an object absorbs light, the object gets warmer (unless energy is transferred away from the object), which means the thermal energy of the object typically increases. For example, when the sun shines on a person, the person's body becomes warmer. When an object gives off light, the object gets cooler, which means the thermal energy of the object typically decreases (unless additional energy is supplied to the light source (e.g. a lamp plugged into an electrical outlet)). For example, as a glowing hot piece of metal cools, some of the temperature decrease is due to the fact that light is being given off.

Assessment items at this level do not expect students to know that all objects give off "electromagnetic radiation." Assessment items are limited to contexts involving visible light. Contexts of assessment items are also limited to those that do not involve changes of state. Additionally, students at this level are also not expected to know that the temperature of the object the light shines on increases asymptotically. Items use time periods during which the temperature of the object noticeably increases the longer the light shines on the object.

Transferring energy by forces. Energy can be transferred mechanically when an object exerts a force on another object even if the objects are not in contact. When one object pushes or pulls on another object at a distance (such as gravitational, magnetic, and electric forces), energy is transferred mechanically from the one object to the other, and the speed (velocity) of both objects changes (assuming no other forces act on the objects). When a magnet is brought close to another magnet or magnetized object, the magnet pushes or pulls on the magnet/object even when they are not touching. This push or pull transfers energy to the magnet/object and causes the motion of the magnet/object to change. Examples of this include a magnet being brought close to a metal paper clip causing the paper clip to move toward the magnet and like poles of two magnets being brought close to each other causing the magnets to move away from each other.

Because gravitational, magnetic, and electric forces do not require a medium, a medium is not required in order for energy to be transferred by these non-contact forces. The transfer of energy stops when the one object no longer exerts a force on the other object. When two forces act over the same distance and in the same direction, the stronger force transfers more energy than the weaker force.

Assessment items are limited to systems containing two objects that are moving or that can be moved. Examples of forces acting at a distance include magnets pushing or pulling on other magnets or magnetized objects, interactions between electrically charged objects, and the earth exerting a gravitational force on objects near it. Assessment items do not use the word "work" because students tend to confuse the lay definition of work and the scientific definition of work. The idea that a change in position or shape is necessary for energy to be transferred is not assessed at this level. This idea is introduced at the advanced level.

Transferring energy electrically. Energy can be transferred electrically when an electrical source is connected in a complete circuit to an electrical device. A complete circuit is a complete path of conductors through which an electric current can travel. If the electrical circuit is not complete, energy will not be transferred from the electrical source to the electrical device. The transfer of energy electrically can produce motion, sound, heat, or light. Examples of electrical sources include batteries and generators and examples of electrical devices include light bulbs, speakers, heaters, motors, electric toys, and computers.

This idea is not quantitative. Assessment items do not ask students to calculate how much energy is transferred electrically in a particular situation (e.g. Power = current × voltage).

Transferring energy by sound. Sound can transfer energy from one location to another. A vibrating object (such as a guitar string, a drum, or a tuning fork) can transfer energy to another object by producing sound that travels through a material such as air, water, or another solid object between the two objects. A medium (solid, liquid, or gas) is required in order to transfer energy by sound. Sound cannot travel through empty space (a vacuum). In a given material, the amount of energy that is transferred by sound is related to the loudness and pitch (how high or low the sound is) of the sound. The louder the sound, the greater the amount of energy transferred; the higher the pitch, the less the amount of energy transferred. The amount of energy that can be transferred by sound decreases the farther away the source of the sound is from the receiver. The amount of energy that can be transferred by sound increases the greater the size of the receiver. When energy is transferred to a receiver by sound, the receiver gains energy and, as a result, its motion or temperature may change, even though this gain in energy may be difficult to detect. A vibrating object that transfers energy by sound needs a continuous input of energy to keep it vibrating. Otherwise, the vibrations slow down until the vibration stops and no more energy is transferred.

Assessment items are limited to one vibrating object producing a sound wave. Contexts used in the items are limited to audible sound.

Energy Dissipation and Degradation

Energy dissipation. When objects interact with each other or with the surrounding environment, some amount of energy is transformed into thermal energy that is transferred to the surrounding environment. Because thermal energy usually results from these interactions, it is impossible to convert 100% of one form of energy into another form of energy. Processes that involve an interaction between objects or between an object and the surrounding environment will eventually stop unless additional energy is added to keep them running because the amount of energy available to keep the process running decreases as energy is transferred to the surrounding environment. Some interactions between objects or between objects and the surrounding environment transfer more energy to their environment than others. For example, increasing the amount of friction, including air resistance, increases the amount of energy transfer to the surrounding environment. There are ways to reduce the amount of energy transferred to the environment, for example, by using insulation to reduce the amount of energy transferred by conduction or using reflective materials to reduce the amount of energy transferred by radiation

Items do not ask students to make any calculations about how much energy is transferred to the surrounding environment. Ideas about energy degradation and entropy are not assessed at this level. Energy degradation is assessed at the advanced level.

Energy Conservation

Conservation of energy. The amount of energy in an object or set of interacting objects (system) can change. When energy is transferred to a system, the amount of energy in that system increases (assuming no energy is transferred out of the system). When energy is transferred out of a system, the amount of energy in that system decreases (assuming no energy is transferred to the system). Whenever there is an increase in the amount of energy in one objects or set of objects, there will be a decrease in the amount of energy in another object or set of objects.

Assessment items at this level do not assess the idea that the increase in energy somewhere equals the decrease in energy somewhere else. This idea is covered at the advanced level. Assessment items may use the misconceptions that energy can be created or destroyed as distractors but the idea that because energy cannot be created destroyed any increase in energy must be equally balanced by a decrease in energy somewhere else is not explicitly assessed. At this level, students are not expected to know about energy-mass conversions such as nuclear reactions or other subatomic interactions.

Advanced Level Energy Ideas

At the highest level of conceptual complexity, the advanced level, students are expected to understand even more complex and abstract energy concepts, often requiring an atomic/molecular model to explain phenomena. For example, students are expected to know that the thermal energy of an object also depends on the random motion of its atoms and molecules. This level also includes an understanding of the law of conservation of energy, which has been shown to be the most difficult energy concept for students to achieve. For the most part, the ideas at this level are aligned to the disciplinary core ideas from the foundation boxes of the high school performance expectations found in the PS3: Energy core idea section of the Next Generation Science Standards (NGSS) (see Table 1).

Energy Forms and Transformations

Kinetic energy (Motion energy). Kinetic energy is proportional to the mass of a moving object and increases rapidly with increasing speed. For an object traveling at constant speed, the kinetic energy of the object is directly proportional to the mass of the object. For example, doubling the object's mass will double the amount of kinetic energy the object has (assuming constant speed) and halving the object's mass will halve the amount of kinetic energy the object has (assuming constant speed). For an object of constant mass, the kinetic energy is directly proportional to the square of the speed. For example, doubling the object's speed will increase the amount of kinetic energy the object has by four times (assuming constant mass) and halving the object's speed will decrease the amount of kinetic energy the object has by a factor of four (assuming constant mass). The relationships between an object's speed, mass, and kinetic energy are mathematically represented by the equation $KE = ½mv^2$, where v is the speed and m is the mass of the object.

This idea refers to motion with respect to the surface of the earth. An object is considered to be "not moving" if its position with respect to a point on the surface of the earth is not changing. Items may show objects moving in a straight line, vibrating back and forth, or rotating. In all cases, students are expected to know only that the amount of energy of motion the object has depends on its speed and its mass. In items, comparisons will be made between objects moving in the same manner (i.e., both rotating) and with the same distribution of mass from the origin. In cases dealing with rotational motion, students are not expected to be familiar with the concepts of angular velocity and moment of inertia or the units of angular velocity and moment of inertia. They are expected to know that if the speed at which an object is rotating increases, the kinetic energy increases. In these items, the distribution of mass from the origin will remain constant and the speed of rotation will only be qualitatively described (increasing or decreasing).

Thermal energy. The thermal energy of an object is related to the average speed of its atoms or molecules due to their random motion, the number of atoms or molecules, and the types of atoms or molecules of which the object is made. The amount of thermal energy an object has is related to these three factors alone, e.g. thermal energy is not due to atoms or molecules rubbing against one another. All matter has thermal energy because all matter is made up of atoms and molecules that are constantly in random motion. The thermal energy of an object is the sum of the kinetic energy of all of the individual atoms and molecules that make up the object. When comparing objects that are made of the same number and type of molecules, the object that is made up of the molecules with the highest average speed (and therefore, the highest kinetic energy) will have the most thermal energy and the object that is made up of the molecules with the lowest average speed (and therefore, the lowest kinetic energy) will have the least thermal energy. With all else equal, the greater the number of atoms and molecules the greater the thermal energy, and the fewer the number of atoms and molecules the lower the thermal energy.

In assessment items, the temperature changes are limited to those that do not involve changes of state. Items do not assess students' knowledge of which kinds of atoms/molecules have more thermal energy nor do they assess students' knowledge of *why* thermal energy depends on the types of atoms or molecules. Items only assess the idea *that* thermal energy depends on the types of atoms or molecules. Assessment items do not ask students to use formulas, such as $3/2\ kT$ and $m(\Delta T)c$, to calculate thermal energy. The sub-ideas above describe semi-quantitative relationships. Students are expected to compare relative speeds or amounts of kinetic energy of the atoms that make up the objects and the relative number of atoms that make up the objects to determine relative amounts of thermal energy.

Note: The speed and kinetic energy referred to in this idea are the speed and kinetic energy related to the random motion of the atoms and molecules that make up the object. (We consider the thermal energy of a stationary object to be identical to the thermal energy of the same object when it is moving in relation to the surface of the earth.)

Gravitational potential energy. Gravitational potential energy is associated with the separation of mutually attracting masses. Because all objects exert an attractive gravitational force on all other objects, whenever two objects are separated by some distance, the objects tend to move toward each other when they are released. (If they do not move toward each other, it is because some other force greater than or equal to the force of gravity acts to oppose their coming together.) The energy the objects have due to their separation is called gravitational potential energy. The gravitational potential energy of a system of two objects depends on the mass of the two objects and the distance between their centers of mass. Increasing the distance between the objects, increases the amount of gravitational potential energy in the system that is made up of those two objects. Decreasing the distance between the objects, decreases the amount of gravitational potential energy. The gravitational potential energy of a system depends on the distance between the objects and not on how the objects in the system came to be in that configuration.

Assessment items expect students to compare relative distances and masses to determine relative amounts of gravitational potential energy. Students are not expected to calculate the exact amount of gravitational potential energy.

Elastic potential energy. The amount of elastic potential energy stored in a stretched or compressed elastic object increases when the object is further stretched or compressed because stretching and compressing an object changes the distances between the atoms and molecules that make up the object. There are both attractive and repulsive forces between the atoms and molecules that make up an object. These forces result in a stable separation of the atoms and molecules. Compressing or stretching an object changes the distances between the atoms and molecules that make up the object. When an elastic object is stretched or compressed, interatomic (monatomic substances) and intermolecular forces tend to restore the atoms and molecules to their unstretched or uncompressed positions. The energy an elastic object gains as atoms or molecules are moved closer together or farther apart from their unstretched or uncompressed position is elastic potential energy. The amount of elastic potential energy an object has increases as the distance between the atoms and molecules increases from the unstretched or uncompressed distance (when the object is stretched) and increases as the distance between the atoms and molecules decreases from the unstretched or uncompressed distance (when the object is compressed). The amount of elastic potential energy an object has depends on the strength of the interatomic and intermolecular forces that tend to restore the atoms and molecules to their original positions. The stronger the interatomic and intermolecular forces, the greater the amount of elastic potential energy for a given change in atomic or molecular positions.

Assessment items at this level do not expect students to calculate the change in elastic potential energy that is stored in any particular elastic object when it is stretched or compressed. The sub-ideas above describe semi-quantitative relationships. Students are expected to compare relative distances and interatomic forces to determine relative amounts of elastic potential energy. Students are also not expected to know the strength of the interatomic and intermolecular forces for any particular pair of atoms or molecules. In assessment items, the comparative strength of the forces is provided when necessary. In assessment items, objects are not stretched, compressed, twisted, or bent beyond the point where they would return to their original shape (i.e. no plastic deformation).

Chemical energy. The amount of chemical energy in a system of reactants or products before or after the reaction occurs depends on the types and number of atoms in the system and how they are arranged in molecules. Different systems of reactants and products typically have different amounts of chemical energy because they have different configurations of atoms.

All chemical reactions involve both bond breaking and bond forming. Energy is always required to separate the atoms that make up molecules (bond breaking), and energy is always released when atoms connect to form molecules (bond forming). The relative amounts of energy required to break bonds and released when bonds are formed determines whether energy is given off to or taken in from the surroundings during a chemical reaction. For exothermic chemical reactions (reactions that release more energy than they take in), the amount of energy released as the product molecules form is greater than the energy required to separate the atoms of the reactant molecules. The energy transferred to the surroundings can be manifest as an increase in thermal energy or motion energy or the production of light or sound. For endothermic chemical reactions (reactions that take in more energy than they release), the amount of energy released as the product molecules form is less than the energy required to separate the atoms of the reactant molecules. The energy transferred from the surroundings can be detected by a decrease in temperature of the surroundings or the absorption of light or sound. If energy is released during a chemical reaction, then the reverse reaction takes in energy [but the reverse reaction is not always possible]. If energy is taken in during a chemical reaction, then the reverse reaction releases energy (e.g., photosynthesis and cellular respiration).

For this idea, dissolving is considered a chemical change (because the configuration of and interactions between atoms change). Therefore, item contexts may include the dissolution of ionic solids (e.g. cold packs).

At this level, assessment items do not assess the definitions of the words “endothermic” and “exothermic.” Students are not expected to know that the energy that can be released from or absorbed by the reactants in a chemical reaction depends on other conditions such as temperature or type of solvent. Students are also not expected to quantify how much chemical energy is stored in any particular chemical reaction system. Students are not expected to know or use formulas associated with chemical potential energy such as equations for calculating the change in enthalpy. The sub-ideas above describe semi-quantitative relationships.

Energy transformations. At this level, assessment items may include transformations involving electrostatic potential energy because electrostatic potential energy is being treated as a form of energy at the advanced level.

Energy Transfer

Transferring energy by conduction. Energy is transferred through a material by conduction by the random collisions of atoms and molecules that make up the material. The atoms and molecules that make up an object are constantly in motion, and when they collide they transfer energy from one to another. When rapidly moving atoms or molecules collide with slower moving atoms, there is a net energy transfer from the rapidly moving atoms to the slower moving atoms. The slower moving atoms increase in speed while the rapidly moving atoms decrease in speed. Energy is transferred from a warmer part of an object to a cooler part of the object or from a warmer object to a cooler object when the objects are in contact, through the random collisions of atoms or molecules. When the faster moving atoms and molecules of a warmer object (or part of an object) collide with the slower moving atoms and molecules of a cooler object (or part of an object), the average speed of the faster moving atoms and molecules decreases, which means that the warmer object (or part of an object) gets cooler and, therefore, has less thermal energy than before. The average speed of the slower moving atoms and molecules of the cooler object increases, which means that the cooler object (or part of an object) gets warmer and, therefore, has more thermal energy than before. Different substances will transfer energy by conduction at different rates depending on the types of atoms/molecules that make them up. The transfer of energy by conduction typically occurs faster in solids and liquids than in gases because the atoms or molecules that make up a solid or liquid are more closely packed compared to the atoms or molecules that make up gases, and therefore the atoms and molecules that make up a solid or liquid are in closer proximity to other molecules with which they can interact.

Contexts of assessment items are limited to those that do not involve changes of state. Items do not ask students to calculate how much energy is transferred by conduction in a particular situation. While the mass of the atoms or molecules of a substance and interatomic bonding play a role in determining how much kinetic energy the atoms or molecules have and, therefore, how much energy can be transferred by conduction, items use contexts in which the atoms or molecules of the warmer object are moving faster than the atoms or molecules of the cooler object so that mass or bonding do not have to be considered.

Transferring energy by convection. In a fluid, regions that have different temperatures have different densities. The differences in density lead to an imbalance between the downward gravitational force and upward [buoyant] forces exerted by the surrounding fluid, creating currents that contribute to the transfer of energy. In a fluid system in which the fluid is the same temperature throughout, the upward forces and downward gravitational force are balanced and natural convection will not occur. When a region of a fluid is heated, it becomes less dense. When a region of a fluid is cooled, it becomes denser. The gravitational force on a denser region is greater than the gravitational force on a less dense region of equal volume. Heating a fluid from below will create a warmer region that is less dense than the cooler, denser region above it. When a warmer region of a fluid is below a cooler region, the upward force and downward gravitational force are unbalanced so that the warmer region rises and the cooler region sinks. As the warmer region rises, its thermal energy is transferred from one location in the fluid to another. As a region of fluid moves to new locations, adjacent regions of fluids move in to fill the space left behind. When the rising fluid encounters a boundary such as the surface of the fluid, it moves horizontally. As regions warmer than the surroundings move horizontally, they transfer energy to the surroundings, and this causes the fluid to cool and become denser. This region then begins to sink when it becomes denser than the region below it. As the region sinks, its gets closer to a heat source causing its temperature to increase and its density to decrease, and the cycle continues.

Assessment items do not ask students to calculate how much energy is transferred by convection in a particular situation. They also do not expect students to know how much denser a fluid needs to be than the fluid around it in order to sink. Assessment items do not use the term “buoyant force,” nor do they assess students’ understanding of buoyant forces.

Transferring energy by radiation. Energy can be transferred by electromagnetic radiation. Electromagnetic radiation is always given off by all objects. Some of this electromagnetic radiation transfers energy to objects that absorb it and some electromagnetic radiation is radiated into space. Because electromagnetic radiation transfers energy through space, a medium such as air or another material is not needed to transfer energy from one object to another. Electromagnetic radiation is given off by objects in all directions [except from lasers and other specially designed light sources or when the radiation is reflected or blocked] and travels in straight lines; therefore, energy can be transferred from an object by electromagnetic radiation in all directions to any object in the path of the electromagnetic radiation. The temperature of an object affects the rate at which electromagnetic radiation is given off by the object. The higher the temperature of an object, the more electromagnetic radiation the object gives off over a fixed period of time. The surface area of the object absorbing the electromagnetic radiation affects the amount of energy transferred to it. The larger the surface, the more energy is transferred to the object over a fixed period of time. The angle at which the electromagnetic radiation strikes an object also affects the amount of energy transferred to it. The closer the angle is to 90°, the more energy is transferred to the object over a fixed period of time.

Energy is transferred by radiation between objects in both directions. When there is more energy transferred from the first object to the second object than from the second to the first, there is a net transfer of energy from the first object to the second. It is also possible that the same amount of energy is transferred by radiation in both directions, in which case there is no net transfer of energy between the objects. Objects that absorb more energy by radiation than they give off get warmer, which means the thermal energy of the object increases. Objects that give off more energy by radiation then they absorb get cooler, which means that the thermal energy of the object decreases (unless additional energy is supplied to the object (e.g. a lamp plugged into an electrical outlet)).

Assessment items do not ask students to calculate how much energy is transferred by radiation in a particular situation. Items testing the idea that the temperature of an object affects the rate at which the object radiates electromagnetic radiation do not use contexts involving light bulbs of any kind. Contexts of assessment items are limited to those that do not involve changes of state. Students are not expected to know that the temperature of the object the radiation shines on increases asymptotically. Items use time periods during which the temperature of the object noticeably increases the longer the radiation shines on the object.

Transferring energy by forces. When two objects change relative position as a result of a contact force or a gravitational, magnetic, or electric force, the potential and kinetic energies of the system change. A gravitational, magnetic, or electric force can change the potential and kinetic energies that a system of two object has so that some of the energy of the system is converted from potential energy to the kinetic energy of one or both of the objects as the objects move to new locations. If the force acting on an object is attractive (magnetic, electric, or gravitational), the potential energy of the system decreases and the kinetic energy of one or both of the objects increases as the objects move closer together [in the absence of other forces]. If the force acting on an object is repulsive (magnetic or electric but not gravitational), the potential energy of the system decreases and the kinetic energy of one or both of the objects increases as the objects move farther apart [in the absence of other forces]. Energy is being transferred by forces as long as 1) one object exerts a force on another object and 2) the position and/or shape (or orientation in the case of magnetic forces) of the object being pushed or pulled is changing. The transfer of energy stops when one object no longer exerts a force on the other object or when the change in position and/or shape stops. There is no transfer of energy by forces between objects that are at rest. When two equal forces act in the same direction but over different distances, the force that acts over the longer distance transfers more energy than the force that acts over the shorter distance.

Assessment items are limited to systems containing two objects that are moving or that can be moved. For magnetic interactions, assessment items are limited to systems containing macroscopic magnets and macroscopic magnetized objects, and not individual particles in a magnetic field. Assessment items do not use the words “work” or “field.”

Transferring energy electrically. Electrostatic potential energy can be stored in the separation of charged objects. Because all charged objects (including atoms and molecules) exert a force on all other charged objects, whenever two charged objects are separated by some distance, the objects tend to move toward each other (in the case of two opposite charges) or move away from each other (in the case of two like charges). (If they do not move toward each other, it is because some other force equal to the force of attraction or repulsion acts to oppose their coming together or moving apart.) The energy the charged objects have due to their separation is called electrostatic potential energy. In cases where the charges are not allowed to move toward each other or away from each other (e.g. as in capacitors, which are oppositely charged conductors separated by a non-conducting (insulating) material), the electrostatic potential energy can be transferred electrically to power electrical devices. The electrostatic potential energy of a system of two charged objects depends on the magnitude of the charges on them and the distance between them. Increasing the magnitude of the charges increases the electrostatic potential energy and decreasing the magnitude of the charges decreases the electrostatic potential energy. When comparing objects that have like charges, the electrostatic potential energy increases as the distance between the charged objects decreases, and the electrostatic potential energy decreases as the distance between the charged objects increases. When comparing objects that have opposite charges, the electrostatic potential energy increases as the distance between the charged objects increases, and the electrostatic potential energy decreases as the distance between the charged objects decreases.

Assessment items do not ask students to use formulas, such as $U_E = (k_e q_1 q_2)/r$ or $U_E = \frac{1}{2} CV^2$, to calculate electrostatic energy. The sub-ideas above describe semi-quantitative relationships.

Transferring energy by sound. Energy is transferred by sound because of coordinated collisions between the atoms or molecules that make up the medium through which the sound travels. Energy is transferred when a molecule of a vibrating object collides with a molecule of an adjacent medium. As sound travels through a medium, the molecules that make up the medium are displaced and move in a back-and-forth wave-like motion, which can cause the molecules of the medium to collide with one another. The collisions between molecules move through the medium as a wave, and when the sound wave reaches the receiver, the molecules of the medium collide with the molecules of the receiving object, transferring energy to the receiver in the process. In the medium, the closer together the molecules are to each other, the more frequent the collisions, the faster the sound travels and the faster energy is transferred. Therefore, energy is transferred by sound faster through solids than through liquids or gases, and faster through liquids than through gases. The greater the displacement of the molecules of the medium (amplitude of the sound) the greater the amount of energy transferred. The greater the amplitude the greater the loudness. The reason that the amount of energy that can be transferred by sound decreases the farther away the source of the sound is from the receiver is that some energy is absorbed by the molecules of the medium as the sound passes through. Low frequency sound travels farther through a given medium than high frequency sound because there are fewer collisions of the molecules and, therefore, less energy is absorbed by the medium as the low frequency sound travels to the receiver. Therefore, the higher the frequency the lesser the amount of energy transferred to the receiver. The pitch of the sound is related to the frequency.

Items do not ask students to calculate how much energy is transferred by conduction in a particular situation. The sub-ideas above describe semi-quantitative relationships. Assessment items are limited to one vibrating object producing a sound wave.

Energy Dissipation and Degradation

Energy degradation. Unless prevented from doing so, energy will become uniformly distributed among the atoms/molecules within a system or between the system and the surrounding environment. When energy becomes uniformly distributed, the amount of energy present has not changed but the energy becomes less useful and less concentrated. After a given amount of energy had become uniformly distributed, it takes additional energy to concentrate the diffuse energy and make it useful again. Thermal energy in the surrounding environment is sometimes considered a less useful type of energy.

Assessment items do not assess students' understanding of entropy or the relationship between energy and entropy. Items do not ask students to perform any calculations. For example, students are not asked to use equations like $KE = 1/2mv^2$ or $PE = mgh$.

Energy Conservation

Conservation of energy. Regardless of what happens within a system, the total amount of energy in the system remains the same unless energy is added to or released from the system. Even though the forms of energy present within a system may change, the total amount of energy in the system remains the same unless energy is added to or released from the system. If the total amount of energy in a system decreases or increases, an equal amount of energy must have gone to or come from somewhere outside the system. If no energy enters or leaves a system, a decrease of one form of energy by a certain amount within the system must be balanced by an increase of another form of energy by that same amount within the system (or a net increase of multiple forms of energy by that same amount). Similarly, an increase of one form of energy by a certain amount within a system must be balanced by a decrease of another form of energy by that same amount within the system (or a net decrease of multiple forms of energy by that same amount). Energy can neither be created nor destroyed but it can be transferred and/or transformed within and between systems. If energy is transferred to or from a very large system (or a very complex system), increases or decreases of energy may be difficult to detect and, therefore, it may appear that energy was not conserved.

Assessment items avoid using the phrases "energy conservation" or "conservation of energy" because students often associate these terms with efforts to conserve energy resources. Items do not ask students to make calculations about the amount of energy in a system or about changes in energy. They do not expect students to know about energy-mass conversions such as nuclear reactions or other subatomic interactions.

Comparison to Next Generation Science Standards

Development of the assessment items included in this project pre-dates the release of NGSS and, therefore, items were not written to assess three-dimensional learning. The items were developed mainly to diagnose students' understanding of and misconceptions about energy. Although some of the items do incorporate science practices, the NGSS science and engineering practices and crosscutting concepts were not systematically integrated into the assessments. Never the less, we checked to see how closely our learning goals match what is in the Framework and NGSS. We first surveyed the NGSS performance expectations (PEs) listed for each grade and the underlying disciplinary core ideas (DCIs) found in the foundation boxes under each PE. For the NGSS energy core idea, there are seven elementary PEs, five middle school PEs, and five high school PEs. Additionally, we identified two middle school PEs (MS-PS1-4 and MS-ESS2-6) and one high school PE (HS-PS1-4) that were listed under other NGSS core ideas. We then matched each PE to our learning goals (see Table 1).

Overall there is very good alignment between NGSS and our learning goals. All of the 14 energy ideas could be matched with at least one PE. When we looked at the alignment by complexity level, we saw that, for the most part, our basic level matches the NGSS elementary school PEs; the intermediate level corresponds with the middle school PEs; and the advanced level parallels the high school expectations. There are some ideas for which we were unable to find PEs that match every level in the progression. For example, although there is an elementary school PE for the idea that energy is transferred by sound, there is no high school PE for this idea. And although the elastic potential energy, convection, and dissipation ideas are included at the high school level, they are not included at the elementary or middle school levels. Additionally, there is very little in NGSS about thermal energy, gravitational potential energy, or conservation of energy in the elementary school grade band. In our progression, we included learning goals at all levels for each energy idea in order to present a more complete picture of the nature of energy. Introducing each idea at a basic level supports younger students' progress toward the complex understanding expected in the high school performance expectations. Previous research has shown that elementary students can attain an understanding of basic ideas about gravitational potential energy, thermal energy, dissipation, and conservation when appropriate instructional supports are in place (Lacy et al., 2014).

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The Assessing Students' Progress on the Energy Concept (ASPECt) project was supported by the Institute of Education Sciences, U.S. Department of Education, through Grant R305A120138 to the American Association for the Advancement of Science. The opinions expressed are those of the authors and do not represent views of the Institute or the U.S. Department of Education. For more information about the ASPECt project, contact Cari Herrmann Abell at cabell@aaas.org.