Middle School Phenomenon Model Course 1 - Bundle 2
Thermal Energy

This is the second bundle of the Middle School Phenomenon Model Course 1. Each bundle has connections to the other bundles in the course, as shown in the Course Flowchart.

Bundle 1 Question: This bundle is assembled to address the question of "How does a change in thermal energy effect matter?"

Summary
The bundle organizes performance expectations around helping students understand the relationship between matter and thermal energy. Instruction developed from this bundle should always maintain the three-dimensional nature of the standards, but recognize that instruction is not limited to the practices and concepts directly linked with any of the bundle performance expectations.

Connections between bundle DCIs
The concept that substances are made from different types of atoms, which combine with one another in various ways (PS1.A as in MS-PS1-1), connects to the ideas that gases and liquids are made of molecules or inert atoms that are moving about relative to each other, and in a solid, atoms may vibrate in position but do not change relative locations (PS1.A as in MS-PS1-4).

In science, heat refers to the energy transferred due to the temperature difference between two objects (PS3.A as in MS-PS1-4); this connects to the idea that temperature is a measure of the average kinetic energy of particles of matter (PS3.A as in MS-PS3-3). These ideas also connect to the concept that the amount of energy transfer needed to change the temperature of a matter sample by a given amount depends on the nature of the matter, the size of the sample, and the environment (PS3.A as in MS-PS3-4).

These concepts of energy transfer connect to the idea that the ocean exerts a major influence on weather and climate by absorbing energy from the sun, releasing it over time, and globally redistributing it through ocean currents (ESS2.D as in MS-ESS2-6), which in turn connects to the idea that global movements of water and its changes in form are propelled by sunlight and gravity (ESS2.C as in MS-ESS2-4). These concepts also connect to the idea that complex patterns of the changes and the movement of water in the atmosphere, determined by winds, landforms, and ocean temperatures and currents, are major determinants of local weather patterns (ESS2.C as in MS-ESS2-5).

The idea that the iterative process of testing the most promising solutions and modifying what is proposed on the basis of the test results leads to greater refinement and ultimately to an optimal solution (ETS1.C as in MS-ETS1-4) could connect to several concepts, such as energy is spontaneously transferred out of hotter regions or objects and into colder ones (PS3.A as in MS-PS3-3) and weather and climate are influenced by interactions involving sunlight, the ocean, the atmosphere, ice, landforms, and living things, and these interactions vary with latitude, altitude, and local and regional geography (ESS2.D as in MS-ESS2-6). These connections could be made through tasks such as designing a solar cooker or a device designed for a specific location and is used to harness energy for conversion to practical energy for human consumption such as electricity. For example, a wind-powered electrical generator would be effective and practical in some locations but not in others. In both tasks, students need an opportunity to test solutions to identify the most promising and then modify those to optimize their solutions.

Bundle Science and Engineering Practices
Instruction leading to this bundle of PEs will help students build toward proficiency in elements of the practices of planning and carrying out investigations (MS-PS3-4 and MS-ESS2-5), developing and using models (MS-PS1-1, MS-PS1-4, MS-ESS2-4, MS-ESS2-6, and MS-ETS1-4), and constructing explanations and designing solutions (MS-PS3-3). Many other practice elements can be used in instruction.

Bundle Crosscutting Concepts
Instruction leading to this bundle of PEs will help students build toward proficiency in elements of the crosscutting concepts of Cause and Effect (MS-PS1-4 and MS-ESS2-5), Scale, Proportion, and Quantity (MS-PS1-1 and MS-PS3-4), Energy and Matter (MS-PS3-3 and MS-ESS2-4), and Systems and System Model (MS-ESS2-6). Many other crosscutting concepts elements can be used in instruction.

All instruction should be three-dimensional.

Performance Expectations MS-ESS2-5 and MS-ESS2-6 are partially assessable.	MS-PS1-1. **Develop models to describe the atomic composition of simple molecules and extended structures.** [Clarification Statement: Emphasis is on developing models of molecules that vary in complexity. Examples of simple molecules could include ammonia and methanol. Examples of extended structures could include sodium chloride or diamonds. Examples of molecular-level models could include drawings, 3D ball and stick structures, or computer representations showing different molecules with different types of atoms.] [*Assessment Boundary: Assessment does not include valence electrons and bonding energy, discussing the ionic nature of subunits of complex structures, or a complete description of all individual atoms in a complex molecule or extended structure is not required.*] MS-PS1-4. **Develop a model that predicts and describes changes in particle motion, temperature, and state of a pure substance when thermal energy is added or removed.** [Clarification Statement: Emphasis is on qualitative molecular-level models of solids, liquids, and gases to show that adding or removing thermal energy increases or decreases kinetic energy of the particles until a change of state occurs. Examples of models could include drawing and diagrams. Examples of particles could include molecules or inert atoms. Examples of pure substances could include water, carbon dioxide, and helium.] MS-PS3-3. **Apply scientific principles to design, construct, and test a device that either minimizes or maximizes thermal energy transfer.*** [Clarification Statement: Examples of devices could include an insulated box, a solar cooker, and a Styrofoam cup.] [*Assessment Boundary: Assessment does not include calculating the total amount of thermal energy transferred.*] MS-PS3-4. **Plan an investigation to determine the relationships among the energy transferred, the type of matter, the mass, and the change in the average kinetic energy of the particles as measured by the temperature of the sample.** [Clarification Statement: Examples of experiments could include comparing final water temperatures after different masses of ice melted in the same volume of water with the same initial temperature, the temperature change of samples of different materials with the same mass as they cool or heat in the environment, or the same material with different masses when a specific amount of energy is added.] [*Assessment Boundary: Assessment does not include calculating the total amount of thermal energy transferred.*] MS-ESS2-4. **Develop a model to describe the cycling of water through Earth's systems driven by energy from the sun and the force of gravity.** [Clarification Statement: Emphasis is on the ways water changes its state as it moves through the multiple pathways of the hydrologic cycle. Examples of models can be conceptual or physical.] [*Assessment Boundary: A quantitative understanding of the latent heats of vaporization and fusion is not assessed.*]

Performance Expectations (Continued)	MS-ESS2-5. **Collect data to provide evidence for how the motions and complex interactions of air masses result in changes in weather conditions.** [Clarification Statement: Emphasis is on how air masses flow from regions of high pressure to low pressure, causing weather (defined by temperature, pressure, humidity, precipitation, and wind) at a fixed location to change over time, and how sudden changes in weather can result when different air masses collide. Emphasis is on how weather can be predicted within probabilistic ranges. Examples of data can be provided to students (such as weather maps, diagrams, and visualizations) or obtained through laboratory experiments (such as with condensation).] [*Assessment Boundary: Assessment does not include recalling the names of cloud types or weather symbols used on weather maps or the reported diagrams from weather stations.*] MS-ESS2-6. **Develop and use a model to describe how unequal heating and rotation of the Earth cause patterns of atmospheric and oceanic circulation that determine global climates.** [Clarification Statement: Emphasis is on how patterns vary by latitude, altitude, and geographic land distribution. Emphasis of atmospheric circulation is on the sunlight-driven latitudinal banding, the Coriolis effect, and resulting prevailing winds; emphasis of ocean circulation is on the transfer of heat by the global ocean convection cycle, which is constrained by the Coriolis effect and the outlines of continents. Examples of models can be diagrams, maps and globes, or digital representations.] [*Assessment Boundary: Assessment does not include the dynamics of the Coriolis effect.*] MS-ETS1-4. **Develop a model to generate data for iterative testing and modification of a proposed object, tool, or process such that an optimal design can be achieved.**
Example Phenomena	Water boils when heat is added. Precipitation only occurs when there are clouds in the sky. Some parts of the world get lots of precipitation; others get almost none at all. Climates near the equator tend to be warmer than climates near the poles.
Suggested Practices Building to the PEs	**Asking Questions and Defining Problems** ● Define a design problem that can be solved through the development of an object, tool, process, or system and includes multiple criteria and constraints, including scientific knowledge that may limit possible solutions. Students could *define a design problem* [related to] **interactions involving sunlight, the ocean, and ice** *that can be solved through the development of an object, tool, process, or system and includes multiple criteria and constraints*. MS-ESS2-6 **Developing and Using Models** ● Develop a model to describe unobservable mechanisms. Students could *develop a model to describe* [how] **water continually cycles among land, ocean, and atmosphere,** [including] *unobservable mechanisms* [of the processes of] **transpiration and evaporation**. MS-ESS2-4 **Planning and Carrying Out Investigations** ● Conduct an investigation and/or evaluate and/or revise the experimental design to produce data to serve as the basis for evidence that meet the goals of the investigation. Students could *conduct an investigation* [of how] **the relationship between the temperature and the total energy of a system depends on the types, states, and amounts of matter present**. MS-PS3-3

Suggested Practices Building to the PEs (Continued)	**Analyzing and Interpreting Data** • Use graphical displays (e.g., maps, charts, graphs, and/or tables) of large data sets to identify temporal and spatial relationships. Students could *use graphical displays (e.g., maps, charts, graphs, and/or tables) of large data sets to identify spatial relationships* [related to] **weather and climate** [as they are] **influenced by interactions involving sunlight, the ocean, the atmosphere, ice, landforms, and living things**. MS-ESS2-6 **Using Mathematics and Computational Thinking** • Apply mathematical concepts and/or processes (e.g., ratio, rate, percent, basic operations, simple algebra) to scientific and engineering questions and problems. Students could *apply mathematical concepts to scientific questions* [about how] **the relationship between the temperature and the total energy of a system depends on the types, states, and amounts of matter present**. MS-PS3-4 **Constructing Explanations and Designing Solutions** • Construct an explanation using models or representations. Students could *construct an explanation* [about] **the changes of state that occur with variations in temperature or pressure** *using models* **of matter**. MS-PS1-4 **Engaging in Argument from Evidence** • Respectfully provide and receive critiques about one's explanations, procedures, models, and questions by citing relevant evidence and posing and responding to questions that elicit pertinent elaboration and detail. Students could *respectfully receive critiques about models* [of] **global movements of water and its changes in form** [and how these are] **propelled by sunlight and gravity** *by responding to questions that elicit pertinent elaboration and detail*. MS-ESS2-4 **Obtaining, Evaluating, and Communicating Information** • Critically read scientific texts adapted for classroom use to determine the central ideas and/or obtain scientific and/or technical information to describe patterns in and/or evidence about the natural world. Students could *critically read scientific texts adapted for classroom use to obtain scientific information to describe patterns* **of the changes and the movement of water in the atmosphere, determined by winds, landforms, and ocean temperatures and currents,** [which] **are major determinants of local weather patterns.** MS-ESS2-5 • Communicate scientific and/or technical information (e.g. about a proposed object, tool, process, system) in writing and/or through oral presentations. Students could *communicate scientific information through oral presentations* [about how] **substances are made from different types of atoms, which combine with one another in various ways** [and that] **atoms form molecules that range in size from two to thousands of atoms.** MS-PS1-1

Suggested Crosscutting Concepts Building to the PEs	**Systems and System Models** ● Systems may interact with other systems; they may have sub-systems and be a part of larger complex systems. Students could describe *that systems may interact with other systems; they may have sub-systems and be a part of larger complex systems* within the context that **water continually cycles among land, ocean, and atmosphere via transpiration, evaporation, condensation and crystallization, and precipitation, as well as downhill flows on land**. MS-ESS2-4 **Energy and Matter** ● The transfer of energy can be tracked as energy flows through a designed or natural system. Students could *track the transfer of energy as energy flows through* **the ocean which absorbs energy from the sun, releases it over time, and globally redistributes it through currents, exerting a major influence on weather and climate.** MS-ESS2-6 **Stability and Change** ● Explanations of stability and change in natural or designed systems can be constructed by examining the changes over time and forces at different scales, including the atomic scale. Students could *construct explanations of* **the changes of state** [of matter] **that occur with variations in temperature or pressure** *in natural systems by examining the changes over time and forces at different scales, including the atomic scale.* MS-PS1-4
Additional Connections to Nature of Science	**Scientific Knowledge is Open to Revision in Light of New Evidence** ● Scientific explanations are subject to revision and improvement in light of new evidence. Students could [use the history of the discovery that] **substances are made from different types of atoms, which combine with one another in various ways** [to describe how] *scientific explanations are subject to revision and improvement in light of new evidence*. MS-PS1-1 **Science is a Way of Knowing** ● Science is both a body of knowledge and the processes and practices used to add to that body of knowledge. Students could describe that *science is both a body of knowledge and the processes and practices used to add to that body of knowledge* [as they plan for an investigation about] **the amount of energy transfer needed to change the temperature of a matter sample**. MS-PS3-4

MS-PS1-1 Matter and its Interactions

Students who demonstrate understanding can:

MS-PS1-1. Develop models to describe the atomic composition of simple molecules and extended structures. [Clarification Statement: Emphasis is on developing models of molecules that vary in complexity. Examples of simple molecules could include ammonia and methanol. Examples of extended structures could include sodium chloride or diamonds. Examples of molecular-level models could include drawings, 3D ball and stick structures, or computer representations showing different molecules with different types of atoms.] [*Assessment Boundary: Assessment does not include valence electrons and bonding energy, discussing the ionic nature of subunits of complex structures, or a complete description of all individual atoms in a complex molecule or extended structure is not required.*]

The performance expectation above was developed using the following elements from the NRC document *A Framework for K-12 Science Education*:

Science and Engineering Practices	Disciplinary Core Ideas	Crosscutting Concepts
Developing and Using Models Modeling in 6–8 builds on K–5 and progresses to developing, using and revising models to describe, test, and predict more abstract phenomena and design systems. • Develop a model to predict and/or describe phenomena.	**PS1.A: Structure and Properties of Matter** • Substances are made from different types of atoms, which combine with one another in various ways. Atoms form molecules that range in size from two to thousands of atoms. • Solids may be formed from molecules, or they may be extended structures with repeating subunits (e.g., crystals).	**Scale, Proportion, and Quantity** • Time, space, and energy phenomena can be observed at various scales using models to study systems that are too large or too small.

Observable features of the student performance by the end of the course:			
1	Components of the model		
	a	Students develop models of atomic composition of simple molecules and extended structures that vary in complexity. In the models, students identify the relevant components, including:	
		i.	Individual atoms.
		ii.	Molecules.
		iii.	Extended structures with repeating subunits.
		iv.	Substances (e.g., solids, liquids, and gases at the macro level).
2	Relationships		
	a	In the model, students describe* relationships between components, including:	
		i.	Individual atoms, from two to thousands, combine to form molecules, which can be made up of the same type or different types of atom.
		ii.	Some molecules can connect to each other.
		iii.	In some molecules, the same atoms of different elements repeat; in other molecules, the same atom of a single element repeats.
3	Connections		
	a	Students use models to describe* that:	
		i.	Pure substances are made up of a bulk quantity of individual atoms or molecules. Each pure substance is made up of one of the following:
			1. Individual atoms of the same type that are connected to form extended structures.
			2. Individual atoms of different types that repeat to form extended structures (e.g., sodium chloride).
			3. Individual atoms that are not attracted to each other (e.g., helium).
			4. Molecules of different types of atoms that are not attracted to each other (e.g., carbon dioxide).
			5. Molecules of different types of atoms that are attracted to each other to form extended structures (e.g., sugar, nylon).
			6. Molecules of the same type of atom that are not attracted to each other (e.g., oxygen).
		ii.	Students use the models to describe* how the behavior of bulk substances depends on their structures at atomic and molecular levels, which are too small to see.

MS-PS1-4 Matter and its Interactions

Students who demonstrate understanding can:

MS-PS1-4. **Develop a model that predicts and describes changes in particle motion, temperature, and state of a pure substance when thermal energy is added or removed.** [Clarification Statement: Emphasis is on qualitative molecular-level models of solids, liquids, and gases to show that adding or removing thermal energy increases or decreases kinetic energy of the particles until a change of state occurs. Examples of models could include drawing and diagrams. Examples of particles could include molecules or inert atoms. Examples of pure substances could include water, carbon dioxide, and helium.]

The performance expectation above was developed using the following elements from the NRC document *A Framework for K-12 Science Education*:

Science and Engineering Practices	Disciplinary Core Ideas	Crosscutting Concepts
Developing and Using Models Modeling in 6–8 builds on K–5 and progresses to developing, using and revising models to describe, test, and predict more abstract phenomena and design systems. • Develop a model to predict and/or describe phenomena.	**PS1.A: Structure and Properties of Matter** • Gases and liquids are made of molecules or inert atoms that are moving about relative to each other. • In a liquid, the molecules are constantly in contact with others; in a gas, they are widely spaced except when they happen to collide. In a solid, atoms are closely spaced and may vibrate in position but do not change relative locations. • The changes of state that occur with variations in temperature or pressure can be described and predicted using these models of matter. **PS3.A: Definitions of Energy** • The term "heat" as used in everyday language refers both to thermal energy (the motion of atoms or molecules within a substance) and the transfer of that thermal energy from one object to another. In science, heat is used only for this second meaning; it refers to the energy transferred due to the temperature difference between two objects. *(secondary)* • The temperature of a system is proportional to the average internal kinetic energy and potential energy per atom or molecule (whichever is the appropriate building block for the system's material). The details of that relationship depend on the type of atom or molecule and the interactions among the atoms in the material. Temperature is not a direct measure of a system's total thermal energy. The total thermal energy (sometimes called the total internal energy) of a system depends jointly on the temperature, the total number of atoms in the system, and the state of the material. *(secondary)*	**Cause and Effect** • Cause and effect relationships may be used to predict phenomena in natural or designed systems.

Observable features of the student performance by the end of the course:			
1	Components of the model		
	a	To make sense of a given phenomenon, students develop a model in which they identify the relevant components, including:	
		i.	Particles, including their motion.
		ii.	The system within which the particles are contained.
		iii.	The average kinetic energy of particles in the system.
		iv.	Thermal energy of the system.

		v. Temperature of the system.
		vi. A pure substance in one of the states of matter (e.g., solid, liquid, gas at the macro scale).
2	Relationships	
	a	In the model, students describe* relationships between components, including:
		i. The relationships between:
		1. The motion of molecules in a system and the kinetic energy of the particles in the system.
		2. The average kinetic energy of the particles and the temperature of the system.
		3. The transfer of thermal energy from one system to another and:
		A. A change in kinetic energy of the particles in that new system, or
		B. A change in state of matter of the pure substance.
		4. The state of matter of the pure substance (gas, liquid, solid) and the particle motion (freely moving and not in contact with other particles, freely moving and in loose contact with other particles, vibrating in fixed positions relative to other particles).
3	Connections	
	a	Students use their model to provide a causal account of the relationship between the addition or removal of thermal energy from a substance and the change in the average kinetic energy of the particles in the substance.
	b	Students use their model to provide a causal account of the relationship between:
		i. The temperature of the system.
		ii. Motions of molecules in the gaseous phase.
		iii. The collisions of those molecules with other materials, which exerts a force called pressure.
	c	Students use their model to provide a causal account of what happens when thermal energy is transferred into a system, including that:
		i. An increase in kinetic energy of the particles can cause:
		1. An increase in the temperature of the system as the motion of the particles relative to each other increases, or
		2. A substance to change state from a solid to a liquid or from a liquid to a gas.
		ii. The motion of molecules in a gaseous state increases, causing the moving molecules in the gas to have greater kinetic energy, thereby colliding with molecules in surrounding materials with greater force (i.e., the pressure of the system increases).
	d	Students use their model to provide a causal account of what happens when thermal energy is transferred from a substance, including that:
		i. Decreased kinetic energy of the particles can cause:
		1. A decrease in the temperature of the system as the motion of the particles relative to each other decreases, or
		2. A substance to change state from a gas to a liquid or from a liquid to a solid.
		ii. The pressure that a gas exerts decreases because the kinetic energy of the gas molecules decreases, and the slower molecules exert less force in collisions with other molecules in surrounding materials.
	e	Students use their model to provide a causal account for the relationship between changes in pressure of a system and changes of the states of materials in the system.
		i. With a decrease in pressure, a smaller addition of thermal energy is required for particles of a liquid to change to gas because particles in the gaseous state are colliding with the surface of the liquid less frequently and exerting less force on the particles in the liquid, thereby allowing the particles in the liquid to break away and move into the gaseous state with the addition of less energy.
		ii. With an increase in pressure, a greater addition of thermal energy is required for particles of a liquid to change to gas because particles in the gaseous state are colliding with the surface of the liquid more frequently and exerting greater force on the particles in the liquid, thereby limiting the movement of particles from the liquid to gaseous state.

MS-PS3-3 Energy

Students who demonstrate understanding can:

MS-PS3-3. Apply scientific principles to design, construct, and test a device that either minimizes or maximizes thermal energy transfer.* [Clarification Statement: Examples of devices could include an insulated box, a solar cooker, and a Styrofoam cup.] [*Assessment Boundary: Assessment does not include calculating the total amount of thermal energy transferred.*]

The performance expectation above was developed using the following elements from the NRC document *A Framework for K-12 Science Education*:

Science and Engineering Practices

Constructing Explanations and Designing Solutions
Constructing explanations and designing solutions in 6–8 builds on K–5 experiences and progresses to include constructing explanations and designing solutions supported by multiple sources of evidence consistent with scientific ideas, principles, and theories.

- Apply scientific ideas or principles to design, construct, and test a design of an object, tool, process or system.

Disciplinary Core Ideas

PS3.A: Definitions of Energy

- Temperature is a measure of the average kinetic energy of particles of matter. The relationship between the temperature and the total energy of a system depends on the types, states, and amounts of matter present.

PS3.B: Conservation of Energy and Energy Transfer

- Energy is spontaneously transferred out of hotter regions or objects and into colder ones.

ETS1.A: Defining and Delimiting an Engineering Problem

- The more precisely a design task's criteria and constraints can be defined, the more likely it is that the designed solution will be successful. Specification of constraints includes consideration of scientific principles and other relevant knowledge that is likely to limit possible solutions.*(secondary)*

ETS1.B: Developing Possible Solutions

- A solution needs to be tested, and then modified on the basis of the test results in order to improve it. There are systematic processes for evaluating solutions with respect to how well they meet criteria and constraints of a problem. *(secondary)*

Crosscutting Concepts

Energy and Matter

- The transfer of energy can be tracked as energy flows through a designed or natural system.

Observable features of the student performance by the end of the course:

1	Using scientific knowledge to generate design solutions		
	a	Given a problem to solve that requires either minimizing or maximizing thermal energy transfer, students design and build a solution to the problem. In the designs, students:	
		i.	Identify that thermal energy is transferred from hotter objects to colder objects.
		ii.	Describe* different types of materials used in the design solution and their properties (e.g., thickness, heat conductivity, reflectivity) and how these materials will be used to minimize or maximize thermal energy transfer.
		iii.	Specify how the device will solve the problem.
2	Describing* criteria and constraints, including quantification when appropriate		
	a	Students describe* the given criteria and constraints that will be taken into account in the design solution:	
		i.	Students describe* criteria, including:

		1. The minimum or maximum temperature difference that the device is required to maintain.
		2. The amount of time that the device is required to maintain this difference.
		3. Whether the device is intended to maximize or minimize the transfer of thermal energy.
		ii. Students describe* constraints, which may include:
		1. Materials.
		2. Safety.
		3. Time.
		4. Cost.
3	Evaluating potential solutions	
	a	Students test the device to determine its ability to maximize or minimize the flow of thermal energy, using the rate of temperature change as a measure of success.
	b	Students use their knowledge of thermal energy transfer and the results of the testing to evaluate the design systematically against the criteria and constraints.

MS-PS3-4 Energy

Students who demonstrate understanding can:

MS-PS3-4. **Plan an investigation to determine the relationships among the energy transferred, the type of matter, the mass, and the change in the average kinetic energy of the particles as measured by the temperature of the sample.** [Clarification Statement: Examples of experiments could include comparing final water temperatures after different masses of ice melted in the same volume of water with the same initial temperature, the temperature change of samples of different materials with the same mass as they cool or heat in the environment, or the same material with different masses when a specific amount of energy is added.] [*Assessment Boundary: Assessment does not include calculating the total amount of thermal energy transferred.*]

The performance expectation above was developed using the following elements from the NRC document *A Framework for K-12 Science Education*:

Science and Engineering Practices

Planning and Carrying Out Investigations
Planning and carrying out investigations to answer questions or test solutions to problems in 6–8 builds on K–5 experiences and progresses to include investigations that use multiple variables and provide evidence to support explanations or design solutions.

- Plan an investigation individually and collaboratively, and in the design: identify independent and dependent variables and controls, what tools are needed to do the gathering, how measurements will be recorded, and how many data are needed to support a claim.

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Connections to Nature of Science

Scientific Knowledge is Based on Empirical Evidence

- Science knowledge is based upon logical and conceptual connections between evidence and explanations

Disciplinary Core Ideas

PS3.A: Definitions of Energy

- Temperature is a measure of the average kinetic energy of particles of matter. The relationship between the temperature and the total energy of a system depends on the types, states, and amounts of matter present.

PS3.B: Conservation of Energy and Energy Transfer

- The amount of energy transfer needed to change the temperature of a matter sample by a given amount depends on the nature of the matter, the size of the sample, and the environment.

Crosscutting Concepts

Scale, Proportion, and Quantity

- Proportional relationships (e.g. speed as the ratio of distance traveled to time taken) among different types of quantities provide information about the magnitude of properties and processes.

Observable features of the student performance by the end of the course:			
1	Identifying the phenomenon under investigation		
	a	Students identify the phenomenon under investigation involving thermal energy transfer.	
	b	Students describe* the purpose of the investigation, including determining the relationships among the following factors:	
		i.	The transfer of thermal energy.
		ii.	The type of matter.
		iii.	The mass of the matter involved in thermal energy transfer.
		iv.	The change in the average kinetic energy of the particles.
2	Identifying the evidence to address the purpose of the investigation		
	a	Individually or collaboratively, students develop an investigation plan that describes* the data to be collected and the evidence to be derived from the data, including:	
		i.	That the following data are to be collected:
			1. Initial and final temperatures of the materials used in the investigation.
			2. Types of matter used in the investigation.
			3. Mass of matter used in the investigation.
		ii.	How the collected data will be used to:

		1. Provide evidence of proportional relationships between changes in temperature of materials and the mass of those materials.
		2. Relate the changes in temperature in the sample to the types of matter and to the change in the average kinetic energy of the particles.
3	Planning the investigation	
	a	In the investigation plan, students describe*:
		i. How the mass of the materials are to be measured and in what units.
		ii. How and when the temperatures of the materials are to be measured and in what units.
		iii. Details of the experimental conditions that will allow the appropriate data to be collected to address the purpose of the investigation (e.g., time between temperature measurements, amounts of sample used, types of materials used), including appropriate independent and dependent variables and controls.

MS-ESS2-4 Earth's Systems

Students who demonstrate understanding can:

MS-ESS2-4. Develop a model to describe the cycling of water through Earth's systems driven by energy from the sun and the force of gravity. [Clarification Statement: Emphasis is on the ways water changes its state as it moves through the multiple pathways of the hydrologic cycle. Examples of models can be conceptual or physical.] [*Assessment Boundary: A quantitative understanding of the latent heats of vaporization and fusion is not assessed.*]

The performance expectation above was developed using the following elements from the NRC document *A Framework for K-12 Science Education*:

Science and Engineering Practices	Disciplinary Core Ideas	Crosscutting Concepts
Developing and Using Models Modeling in 6–8 builds on K–5 experiences and progresses to developing, using, and revising models to describe, test, and predict more abstract phenomena and design systems. • Develop a model to describe unobservable mechanisms.	**ESS2.C: The Roles of Water in Earth's Surface Processes** • Water continually cycles among land, ocean, and atmosphere via transpiration, evaporation, condensation and crystallization, and precipitation, as well as downhill flows on land. • Global movements of water and its changes in form are propelled by sunlight and gravity.	**Energy and Matter** • Within a natural or designed system, the transfer of energy drives the motion and/or cycling of matter.

Observable features of the student performance by the end of the course:			
1	Components of the model		
	a	To make sense of a phenomenon, students develop a model in which they identify the relevant components:	
		i.	Water (liquid, solid, and in the atmosphere).
		ii.	Energy in the form of sunlight.
		iii.	Gravity.
		iv.	Atmosphere.
		v.	Landforms.
		vi.	Plants and other living things.
2	Relationships		
	a	In their model, students describe* the relevant relationships between components, including:	
		i.	Energy transfer from the sun warms water on Earth, which can evaporate into the atmosphere.
		ii.	Water vapor in the atmosphere forms clouds, which can cool and condense to produce precipitation that falls to the surface of Earth.
		iii.	Gravity causes water on land to move downhill (e.g., rivers and glaciers) and much of it eventually flows into oceans.
		iv.	Some liquid and solid water remains on land in the form of bodies of water and ice sheets.
		v.	Some water remains in the tissues of plants and other living organisms, and this water is released when the tissues decompose.
3	Connections		
	a	Students use the model to account for both energy from light and the force of gravity driving water cycling between oceans, the atmosphere, and land, including that:	
		i.	Energy from the sun drives the movement of water from the Earth (e.g., oceans, landforms, plants) into the atmosphere through transpiration and evaporation.
		ii.	Water vapor in the atmosphere can cool and condense to form rain or crystallize to form snow or ice, which returns to Earth when pulled down by gravity.
		iii.	Some rain falls back into the ocean, and some rain falls on land. Water that falls on land can:

		1. Be pulled down by gravity to form surface waters such as rivers, which join together and generally flow back into the ocean.
		2. Evaporate back into the atmosphere.
		3. Be taken up by plants, which release it through transpiration and also eventually through decomposition.
		4. Be taken up by animals, which release it through respiration and also eventually through decomposition.
		5. Freeze (crystallize) and/or collect in frozen form, in some cases forming glaciers or ice sheets.
		6. Be stored on land in bodies of water or below ground in aquifers.
	b	Students use the model to describe* that the transfer of energy between water and its environment drives the phase changes that drive water cycling through evaporation, transpiration, condensation, crystallization, and precipitation.
	c	Students use the model to describe* how gravity interacts with water in different phases and locations to drive water cycling between the Earth's surface and the atmosphere.

MS-ESS2-5 Earth's Systems

Students who demonstrate understanding can:

MS-ESS2-5. Collect data to provide evidence for how the motions and complex interactions of air masses results in changes in weather conditions. [Clarification Statement: Emphasis is on how air masses flow from regions of high pressure to low pressure, causing weather (defined by temperature, pressure, humidity, precipitation, and wind) at a fixed location to change over time, and how sudden changes in weather can result when different air masses collide. Emphasis is on how weather can be predicted within probabilistic ranges. Examples of data can be provided to students (such as weather maps, diagrams, and visualizations) or obtained through laboratory experiments (such as with condensation).] [*Assessment Boundary: Assessment does not include recalling the names of cloud types or weather symbols used on weather maps or the reported diagrams from weather stations.*]

The performance expectation above was developed using the following elements from the NRC document *A Framework for K-12 Science Education*:

Science and Engineering Practices	Disciplinary Core Ideas	Crosscutting Concepts
Planning and Carrying Out Investigations Planning and carrying out investigations in 6-8 builds on K-5 experiences and progresses to include investigations that use multiple variables and provide evidence to support explanations or solutions. • Collect data to produce data to serve as the basis for evidence to answer scientific questions or test design solutions under a range of conditions.	**ESS2.C: The Roles of Water in Earth's Surface Processes** • The complex patterns of the changes and the movement of water in the atmosphere, determined by winds, landforms, and ocean temperatures and currents, are major determinants of local weather patterns. **ESS2.D: Weather and Climate** • Because these patterns are so complex, weather can only be predicted probabilistically.	**Cause and Effect** • Cause and effect relationships may be used to predict phenomena in natural or designed systems.

Observable features of the student performance by the end of the course:			
1	Identifying the phenomenon under investigation		
	a	From the given investigation plan, students describe* the phenomenon under investigation, which includes the relationships between air mass interactions and weather conditions.	
	b	Students identify the purpose of the investigation, which includes providing evidence to answer questions about how motions and complex interactions of air masses result in changes in weather conditions [note: expectations of students regarding mechanisms are limited to relationships between patterns of activity of air masses and changes in weather].	
2	Identifying the evidence to address the purpose of the investigation		
	a	From a given investigation plan, students describe* the data to be collected and the evidence to be derived from the data that would indicate relationships between air mass movement and changes in weather, including:	
		i.	Patterns in weather conditions in a specific area (e.g., temperature, air pressure, humidity, wind speed) over time.
		ii.	The relationship between the distribution and movement of air masses and landforms, ocean temperatures, and currents.

		iii. The relationship between observed, large-scale weather patterns and the location or movement of air masses, including patterns that develop between air masses (e.g., cold fronts may be characterized by thunderstorms).
	b	Students describe* how the evidence to be collected will be relevant to determining the relationship between patterns of activity of air masses and changes in weather conditions.
	c	Students describe* that because weather patterns are so complex and have multiple causes, weather can be predicted only probabilistically.
3	Planning the investigation	
	a	Students describe* the tools and methods used in the investigation, including how they are relevant to the purpose of the investigation.
4	Collecting the data	
	a	According to the provided investigation plan, students make observations and record data, either firsthand and/or from professional weather monitoring services.

MS-ESS2-6 Earth's Systems

Students who demonstrate understanding can:

MS-ESS2-6. Develop and use a model to describe how unequal heating and rotation of the Earth cause patterns of atmospheric and oceanic circulation that determine regional climates. [Clarification Statement: Emphasis is on how patterns vary by latitude, altitude, and geographic land distribution. Emphasis of atmospheric circulation is on the sunlight-driven latitudinal banding, the Coriolis effect, and resulting prevailing winds; emphasis of ocean circulation is on the transfer of heat by the global ocean convection cycle, which is constrained by the Coriolis effect and the outlines of continents. Examples of models can be diagrams, maps and globes, or digital representations.] [*Assessment Boundary: Assessment does not include the dynamics of the Coriolis effect.*]

The performance expectation above was developed using the following elements from the NRC document *A Framework for K-12 Science Education*:

Science and Engineering Practices	Disciplinary Core Ideas	Crosscutting Concepts
Developing and Using Models Modeling in 6–8 builds on K–5 experiences and progresses to developing, using, and revising models to describe, test, and predict more abstract phenomena and design systems. • Develop and use a model to describe phenomena.	**ESS2.C: The Roles of Water in Earth's Surface Processes** • Variations in density due to variations in temperature and salinity drive a global pattern of interconnected ocean currents. **ESS2.D: Weather and Climate** • Weather and climate are influenced by interactions involving sunlight, the ocean, the atmosphere, ice, landforms, and living things. These interactions vary with latitude, altitude, and local and regional geography, all of which can affect oceanic and atmospheric flow patterns. • The ocean exerts a major influence on weather and climate by absorbing energy from the sun, releasing it over time, and globally redistributing it through ocean currents.	**Systems and System Models** • Models can be used to represent systems and their interactions—such as inputs, processes and outputs—and energy, matter, and information flows within systems.

Observable features of the student performance by the end of the course:			
1	Components of the model		
	a	To make sense of a phenomenon, students develop a model in which they identify the relevant components of the system, with inputs and outputs, including:	
		i.	The rotating Earth.
		ii.	The atmosphere.
		iii.	The ocean, including the relative rate of thermal energy transfer of water compared to land or air.
		iv.	Continents and the distribution of landforms on the surface of Earth.
		v.	Global distribution of ice.
		vi.	Distribution of living things.
		vii.	Energy.
			1. Radiation from the sun as an input.
			2. Thermal energy that exists in the atmosphere, water, land, and ice (as represented by temperature).

2	Relationships		
	a	In the model, students identify and describe* the relationships between components of the system, including:	
		i.	Differences in the distribution of solar energy and temperature changes, including:
			1. Higher latitudes receive less solar energy per unit of area than do lower latitudes, resulting in temperature differences based on latitude.
			2. Smaller temperature changes tend to occur in oceans than on land in the same amount of time.
			3. In general, areas at higher elevations have lower average temperatures than do areas at lower elevations.
			4. Features on the Earth's surface, such as the amount of solar energy reflected back into the atmosphere or the absorption of solar energy by living things, affect the amount of solar energy transferred into heat energy.
		ii.	Motion of ocean waters and air masses (matter):
			1. Fluid matter (i.e., air, water) flows from areas of higher density to areas of lower density (due to temperature or salinity). The density of a fluid can vary for several different reasons (e.g., changes in salinity and temperature of water can each cause changes in density). Differences in salinity and temperature can, therefore, cause fluids to move vertically and, as a result of vertical movement, also horizontally because of density differences.
		iii.	Factors affecting the motion of wind and currents:
			1. The Earth's rotation causes oceanic and atmospheric flows to curve when viewed from the rotating surface of Earth (Coriolis force).
			2. The geographical distribution of land limits where ocean currents can flow.
			3. Landforms affect atmospheric flows (e.g., mountains deflect wind and/or force it to higher elevation).
		iv.	Thermal energy transfer:
			1. Thermal energy moves from areas of high temperature to areas of lower temperature either through the movement of matter, via radiation, or via conduction of heat from warmer objects to cooler objects.
			2. Absorbing or releasing thermal energy produces a more rapid change in temperature on land compared to in water.
			3. Absorbing or releasing thermal energy produces a more rapid change in temperature in the atmosphere compared to either on land or in water so the atmosphere is warmed or cooled by being in contact with land or the ocean.
3	Connections		
	a	Students use the model to describe*:	
		i.	The general latitudinal pattern in climate (higher average annual temperatures near the equator and lower average annual temperatures at higher latitudes) caused by more direct light (greater energy per unit of area) at the equator (more solar energy) and less direct light at the poles (less solar energy).
		ii.	The general latitudinal pattern of drier and wetter climates caused by the shift in the amount of air moisture during precipitation from rising moisture-rich air and the sinking of dry air.
		iii.	The pattern of differing climates in continental areas as compared to the oceans. Because water can absorb more solar energy for every degree change in temperature compared to land, there is a greater and more rapid temperature change on land than in the ocean. At the centers of landmasses, this leads to conditions typical of continental climate patterns.
		iv.	The pattern that climates near large water bodies, such as marine coasts, have comparatively smaller changes in temperature relative to the center of the landmass. Land near the oceans can exchange thermal energy through the air, resulting in smaller changes in temperature. At the edges of landmasses, this leads to marine climates.
		v.	The pattern that climates at higher altitudes have lower temperatures than climates at lower altitudes. Because of the direct relationship between temperature and pressure, given the same amount of thermal energy, air at lower pressures (higher altitudes) will have lower temperatures than air at higher pressures (lower altitudes).

		vi. Regional patterns of climate (e.g., temperature or moisture) related to a specific pattern of water or air circulation, including the role of the following in contributing to the climate pattern:
		1. Air or water moving from areas of high temperature, density, and/or salinity to areas of low temperature, density, and/or salinity.
		2. The Earth's rotation, which affects atmospheric and oceanic circulation.
		3. The transfer of thermal energy with the movement of matter.
		4. The presence of landforms (e.g., the rain shadow effect).
	b	Students use the model to describe* the role of each of its components in producing a given regional climate.

MS-ETS1-4 Engineering Design

Students who demonstrate understanding can:

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

The performance expectation above was developed using the following elements from the NRC document *A Framework for K-12 Science Education*:

Science and Engineering Practices	Disciplinary Core Ideas	Crosscutting Concepts
Developing and Using Models Modeling in 6–8 builds on K–5 experiences and progresses to developing, using, and revising models to describe, test, and predict more abstract phenomena and design systems. • Develop a model to generate data to test ideas about designed systems, including those representing inputs and outputs.	**ETS1.B: Developing Possible Solutions** • A solution needs to be tested, and then modified on the basis of the test results, in order to improve it. • Models of all kinds are important for testing solutions. **ETS1.C: Optimizing the Design Solution** • The iterative process of testing the most promising solutions and modifying what is proposed on the basis of the test results leads to greater refinement and ultimately to an optimal solution.	

Observable features of the student performance by the end of the course:			
1	Components of the model		
	a	Students develop a model in which they identify the components relevant to testing ideas about the designed system, including:	
		i.	The given problem being solved, including criteria and constraints.
		ii.	The components of the given proposed solution (e.g., object, tools, or process), including inputs and outputs of the designed system.
2	Relationships		
	a	Students identify and describe* the relationships between components, including:	
		i.	The relationships between each component of the proposed solution and the functionality of the solution.
		ii.	The relationship between the problem being solved and the proposed solution.
		iii.	The relationship between each of the components of the given proposed solution and the problem being solved.
		iv.	The relationship between the data generated by the model and the functioning of the proposed solution.
3	Connections		
	a	Students use the model to generate data representing the functioning of the given proposed solution and each of its iterations as components of the model are modified.	
	b	Students identify the limitations of the model with regards to representing the proposed solution.	
	c	Students describe* how the data generated by the model, along with criteria and constraints that the proposed solution must meet, can be used to optimize the design solution through iterative testing and modification.	