Middle School Topics Model Course 1-Bundle 3
Energy Transfer

This is the third bundle of the Topics Model Course 1. Each bundle has connections to the other bundles in the course, as shown in the Course Flowchart.

Bundle 3 Question: This bundle is assembled to address the question of "How can we measure the flow of energy in a system?"

Summary

The bundle organizes performance expectations around the theme of energy flows in systems. Instruction leading to this bundle provides the energy transfer knowledge students will need for a deeper understanding of the concepts in bundle 4. 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

Temperature is a measure of the average kinetic energy of particles in matter. The relationship between the temperature and the total energy of a system depends on the types, states, and amounts of matter present (PS3.A as in MS-PS3-3, MS-PS3-4) and when the motion energy of an object changes, there is inevitably some other change in energy at the same time (PS3.B as in MS-PS3-5). These ideas 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.B as in MS-PS3-4), which also connects to the idea that since temperature is a measure of the average kinetic energy (energy of motion) of particles in matter, energy is spontaneously transferred out of hotter regions or objects and into colder ones (PS3.B as in MS-PS3-3).

There are systematic processes for evaluating solutions with respect to how well they meet the criteria and constraints of a problem (ETS1.B as in MS-ETS1-3) and although the design may not perform the best across all tests, identifying the characteristics of the design that performed the best in each test can provide useful information for the redesign process (ETS1.C as in MS-ETS1-3). These concepts could connect to how energy is spontaneously transferred out of hotter regions or objects and into colder ones (PS3.B as in MS-PS3-3) or for how the amount of energy transfer needed to change the temperature of matter depends on the nature of the matter, the size of the sample, and the environment (PS3.B as in MS-PS3-4). Connections could be made through an engineering design task such as evaluating how well a design meets the criteria and constraints for a device that either increases or decreases the temperature of food for human consumption or in selecting materials to insulate a dog house or other animal shelter.

Bundle Science and Engineering Practices

Instruction leading to this bundle of PEs will help students build toward proficiency in elements of the practices of designing solutions (MS-PS3-3), planning an investigation (MS-PS3-4), engaging in argumentation (MS-PS3-5), and analyzing and interpreting data (MS-ETS1-3). 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 Scale, Proportion, and Quantity (MS-PS3-4), and Energy and Matter (MS-PS3-3 and MS-PS3-5). Many other crosscutting concept elements can be used in instruction.

All instruction should be three-dimensional.

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Performance Expectations	MS-PS3-3 **Apply scientific principles to design, construct, and test a device that either minimizes or maximizes thermal energy transfer.*** [Clarification Statement: Examples of devices could include an insulated box, a solar cooker, and a Styrofoam cup.] [Assessment Boundary: Assessment does not include calculating the total amount of thermal energy transferred.] MS-PS3-4 **Plan an investigation to determine the relationships among the energy transferred, the type of matter, the mass, and the change in the average kinetic energy of the particles as measured by the temperature of the sample.** [Clarification Statement: Examples of experiments could include comparing final water temperatures after different masses of ice melted in the same volume of water with the same initial temperature, the temperature change of samples of different materials with the same mass as they cool or heat in the environment, or the same material with different masses when a specific amount of energy is added.] [Assessment Boundary: Assessment does not include calculating the total amount of thermal energy transferred.] MS-PS3-5 **Construct, use, and present arguments to support the claim that when the kinetic energy of an object changes, energy is transferred to or from the object.** [Clarification Statement: Examples of empirical evidence used in arguments could include an inventory or other representation of the energy before and after the transfer in the form of temperature changes or motion of object.] [Assessment Boundary: Assessment does not include calculations of energy.] MS-ETS1-3 **Analyze data from tests to determine similarities and differences among several design solutions to identify the best characteristics of each that can be combined into a new solution to better meet the criteria for success.**
Example Phenomena	At the same temperature, metal feels colder to the touch than wood. A solar oven using only the sun's energy can get hot enough to bake a cake.
Additional Practices Building to the PEs	**Asking Questions and Defining Problems** • Ask questions to clarify and/or refine a model, an explanation, or an engineering problem. Students could *ask questions to clarify an explanation* [for how] **energy is spontaneously transferred out of hotter regions or objects and into colder ones.** MS-PS3-4 **Developing and Using Models** • Develop and/or revise a model to show the relationships among variables, including those that are not observable but predict observable phenomena. Students could *develop a model to show* [that] ***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 and MS-PS3-4 **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 *revise the experimental design of an investigation* [that focuses on collecting] *data* [about how] ***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***. MS-PS3-4

Additional Practices Building to the PEs (Continued)	**Analyzing and Interpreting Data** • Distinguish between causal and correlational relationships in data. Students could *distinguish between causal and correlational relationships in data* [about] ***the relationship between the temperature and the total energy of a system***. MS-PS3-3 and MS-PS3-4 **Using Mathematical and Computational Thinking** • Use digital tools (e.g., computers) to analyze very large data sets for patterns and trends. Students could *use digital tools to analyze very large data sets for patterns and trends* [about how] ***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***. MS-PS3-4 **Constructing Explanations and Designing Solutions** • Construct an explanation that includes qualitative and quantitative relationships between variables that predict(s) and/or describe(s) phenomena. Students could *construct an explanation that includes* ***the relationship between the temperature and the total energy of a system***. MS-PS3-3 and MS-PS3-4 **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 provide critiques about* [experimental] *procedures* [that tested whether] ***energy is spontaneously transferred out of hotter regions or objects and into colder ones*** *by citing relevant evidence and posing questions*. MS-PS3-3 **Obtaining, Evaluating, and Communicating Information** • 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 technical information in writing* [for how well the] *proposed* ***design solution meets the criteria and constraints*** [related to the] ***spontaneous transfer of energy out of hotter regions or objects and into colder ones***. MS-PS3-3 and MS-ETS1-3
Additional Crosscutting Concepts Leading to PE	**Cause and Effect** • Cause and effect relationships may be used to predict phenomena in natural or designed systems. Students could identify *cause and effect relationships* for the ***characteristics of the design that performed the best in each test*** [of slowing the] ***energy transfer*** [between objects of different temperatures]. MS-PS3-3 and MS-ETS1-3

Additional Crosscutting Concepts Leading to PE (Continued)	**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. Students could construct a *model to represent the systems and their interactions, such as inputs, processes and outputs* [involved in] ***the relationship between the temperature and the total energy of a system, which depends on the types, states, and amounts of matter present***. MS-PS3-3 and MS-PS3-4 **Energy and Matter** • Matter is conserved because atoms are conserved in physical and chemical processes. Students could construct a model of how *matter is conserved* [even when] ***the kinetic energy of particles of matter*** [changes]. MS-PS3-4
Additional Connections to Nature of Science	**Scientific Knowledge is Open to Revision in Light of New Evidence (SEP):** • Scientific explanations are subject to revision and improvement in light of new evidence. Students could *revise an explanation in light of new evidence* [for how] ***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***. MS-PS3-4 **Science is a Human Endeavor(CCC):** • Scientists and engineers rely on human qualities such as persistence, precision, reasoning, logic, imagination, and creativity. Students could construct an argument for why *scientists and engineers rely on human qualities such as persistence, precision, reasoning, logic, imagination, and creativity* [in order to] ***evaluate solutions*** [to problems of] ***energy transfer with respect to how well they meet the criteria and constrains of a problem***. MS-PS3-3 and MS-ETS1-3

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-PS3-5 Energy

Students who demonstrate understanding can:

MS-PS3-5. **Construct, use, and present arguments to support the claim that when the kinetic energy of an object changes, energy is transferred to or from the object.** [Clarification Statement: Examples of empirical evidence used in arguments could include an inventory or other representation of the energy before and after the transfer in the form of temperature changes or motion of object.] [*Assessment Boundary: Assessment does not include calculations of energy.*]

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

Engaging in Argument from Evidence

Engaging in argument from evidence in 6–8 builds on K–5 experiences and progresses to constructing a convincing argument that supports or refutes claims for either explanations or solutions about the natural and designed worlds.

- Construct, use, and present oral and written arguments supported by empirical evidence and scientific reasoning to support or refute an explanation or a model for a phenomenon.

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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.B: Conservation of Energy and Energy Transfer

- When the motion energy of an object changes, there is inevitably some other change in energy at the same time.

Crosscutting Concepts

Energy and Matter

- Energy may take different forms (e.g. energy in fields, thermal energy, energy of motion).

Observable features of the student performance by the end of the course:			
1	Supported claims		
	a	Students make a claim about a given explanation or model for a phenomenon. In their claim, students include idea that when the kinetic energy of an object changes, energy is transferred to or from that object.	
2	Identifying scientific evidence		
	a	Students identify and describe* the given evidence that supports the claim, including the following when appropriate:	
		i.	The change in observable features (e.g., motion, temperature, sound) of an object before and after the interaction that changes the kinetic energy of the object.
		ii.	The change in observable features of other objects or the surroundings in the defined system.
3	Evaluating and critiquing the evidence		
	a	Students evaluate the evidence and identify its strengths and weaknesses, including:	
		i.	Types of sources.
		ii.	Sufficiency, including validity and reliability, of the evidence to make and defend the claim.
		iii.	Any alternative interpretations of the evidence and why the evidence supports the given claim as opposed to any other claims.
4	Reasoning and synthesis		
	a	Students use reasoning to connect the necessary and sufficient evidence and construct the argument. Students describe* a chain of reasoning that includes:	
		i.	Based on changes in the observable features of the object (e.g., motion, temperature), the kinetic energy of the object changed.
		ii.	When the kinetic energy of the object increases or decreases, the energy (e.g., kinetic, thermal, potential) of other objects or the surroundings within the system increases or decreases, indicating that energy was transferred to or from the object.
	b	Students present oral or written arguments to support or refute the given explanation or model for the phenomenon.	

MS-ETS1-3 Engineering Design

Students who demonstrate understanding can:

MS-ETS1-3. Analyze data from tests to determine similarities and differences among several design solutions to identify the best characteristics of each that can be combined into a new solution to better meet the criteria for success.

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
Analyzing and Interpreting Data Analyzing data in 6–8 builds on K–5 experiences and progresses to extending quantitative analysis to investigations, distinguishing between correlation and causation, and basic statistical techniques of data and error analysis. • Analyze and interpret data to determine similarities and differences in findings.	**ETS1.B: Developing Possible Solutions** • There are systematic processes for evaluating solutions with respect to how well they meet the criteria and constraints of a problem. • Sometimes parts of different solutions can be combined to create a solution that is better than any of its predecessors. **ETS1.C: Optimizing the Design Solution** • Although one design may not perform the best across all tests, identifying the characteristics of the design that performed the best in each test can provide useful information for the redesign process—that is, some of those characteristics may be incorporated into the new design.	

Observable features of the student performance by the end of the course:		
1	Organizing data	
	a	Students organize given data (e.g., via tables, charts, or graphs) from tests intended to determine the effectiveness of three or more alternative solutions to a problem.
2	Identifying relationships	
	a	Students use appropriate analysis techniques (e.g., qualitative or quantitative analysis; basic statistical techniques of data and error analysis) to analyze the data and identify relationships within the datasets, including relationships between the design solutions and the given criteria and constraints.
3	Interpreting data	
	a	Students use the analyzed data to identify evidence of similarities and differences in features of the solutions.
	b	Based on the analyzed data, students make a claim for which characteristics of each design best meet the given criteria and constraints.
	c	Students use the analyzed data to identify the best features in each design that can be compiled into a new (improved) redesigned solution.