High School Modified Domains Model Course II - Physics
Bundle 3: What Happens When Energy Moves from One Place to Another?

This is the third bundle of the High School Domains Model Course II - Physics. 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 "what happens when energy moves from one place to another?"
Summary The bundle organizes performance expectations with a focus on helping students understand forces and energy transfer when objects interact. 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** Energy is a quantitative property of a system that depends on the motion and interactions of matter and radiation within that system. That there is a single quantity called energy is due to the fact that a system's total energy is conserved, even as within the system, energy is continually transferred from one object to another, and between its various possible forms (PS3.A as in HS-PS3-1). These ideas connect to the concept that energy cannot be created or destroyed, but it can be transported from one place to another and transferred between systems (PS3.B as in HS-PS3-1 and HS-PS3-4). This also connects to the idea that at the macroscopic scale, energy manifests itself in multiple ways, such as in motion, sound, light, and thermal energy (PS3.A as in HS-PS3-3) and although energy cannot be destroyed, it can be converted to less useful forms—for example, to thermal energy in the surrounding environment (PS3.D as in HS-PS3-3 and HS-PS3-4), and also to the idea that mathematical expressions, which quantify how the stored energy in a system depends on its configuration and how kinetic energy depends on mass and speed, allow the concept of conservation of energy to be used to predict and describe system behavior (PS3.B as in HS-PS3-1). The availability of energy limits what can occur in any system and uncontrolled systems always evolve toward more stable states (PS3.B as in HS-PS3-4). These ideas about energy and systems connect to the ideas about Earth's systems and their transfer of energy, including that the foundation for Earth's global climate systems is the electromagnetic radiation from the sun, as well as its reflection, absorption, storage, and redistribution among the atmosphere, ocean, and land systems, and this energy's re-radiation into space (ESS2.D as in HS-ESS2-2 and HS-ESS2-4); the abundance of liquid water on Earth's surface and its unique combination of physical and chemical properties are central to the planet's dynamics (ESS2.C as in HS-ESS2-5); Earth's systems, being dynamic and interacting, cause feedback effects that can increase or decrease the original changes (ESS2.A as in HS-ESS2-1 and HS-ESS2-2); the radioactive decay of unstable isotopes continually generates new energy within Earth's crust and mantle, providing the primary source of heat that drives mantle convection (ESS2.B as in HS-ESS2-3); motions of the Earth's mantle and its plates occur primarily through thermal convection, which involves the cycling of matter due to the outward flow of energy form Earth's interior and gravitational movement of denser materials toward the interior (ESS2.A as in HS-ESS2-3); the geological record shows that changes to global and regional climate can be caused by interactions among changes in the sun's energy output or Earth's orbit, tectonic events, ocean circulation, volcanic activity, glaciers, vegetation, and human activities (ESS2.A as in HS-ESS2-4); and that changes in the atmosphere due to human activity have increased carbon dioxide concentrations and thus affect climate (ESS2.D as in HS-ESS2-4). The engineering design concepts that criteria may need to be broken down into simpler ones that can be approached systematically, and decisions about the priority of certain criteria over others may be needed (ETS1.C as in HS-ETS1-2) could be applied to many different science ideas, including how the foundation for Earth's global climate systems is the electromagnetic radiation from the sun, as well as its reflection, absorption, storage, and redistribution among the atmosphere, ocean, and land systems, and this energy's re-radiation into space (ESS2.D as in HS-ESS2-2 and HS-ESS2-4) or how changes in the atmosphere due to human activity have increased carbon dioxide concentrations and thus affect climate (ESS2.D as in HS-ESS2-4). Connections could be made through an engineering design task

such as breaking criteria down into simpler ones to develop systems of transportation that emit less carbon, or designing artificial climate control systems for a greenhouse or school.

Bundle Science and Engineering Practices
Instruction leading to this bundle of PEs will help students build toward proficiency in elements of the practices of developing and using models (HS-ESS2-1, HS-ESS2-3, and HS-ESS2-4), planning and conducting investigations (HS-PS3-4 and HS-ESS2-5), analyzing data (HS-ESS2-2), using mathematics and computational thinking (HS-PS3-1), and constructing explanations and designing solutions (HS-PS3-3 and HS-ETS1-2). 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 (HS-ESS2-4); Systems and System Models (HS-PS3-4 and HS-PS3-1); Energy and Matter (HS-PS3-3 and HS-ESS2-3); Structure and Function (HS-ESS2-5); and Stability and Change (HS-ESS2-1 and HS-ESS2-2). Many other crosscutting concept elements can be used in instruction.

All instruction should be three-dimensional.

Performance Expectations	HS-PS3-1. **Create a computational model to calculate the change in the energy of one component in a system when the change in energy of the other component(s) and energy flows in and out of the system are known.** [Clarification Statement: Emphasis is on explaining the meaning of mathematical expressions used in the model.] [Assessment Boundary: Assessment is limited to basic algebraic expressions or computations; to systems of two or three components; and to thermal energy, kinetic energy, and/or the energies in gravitational, magnetic, or electric fields.] HS-PS3-3. **Design, build, and refine a device that works within given constraints to convert one form of energy into another form of energy.*** [Clarification Statement: Emphasis is on both qualitative and quantitative evaluations of devices. Examples of devices could include Rube Goldberg devices, wind turbines, solar cells, solar ovens, and generators. Examples of constraints could include use of renewable energy forms and efficiency.] [Assessment Boundary: Assessment for quantitative evaluations is limited to total output for a given input. Assessment is limited to devices constructed with materials provided to students.] HS-PS3-4. **Plan and conduct an investigation to provide evidence that the transfer of thermal energy when two components of different temperature are combined within a closed system results in a more uniform energy distribution among the components in the system (second law of thermodynamics).** [Clarification Statement: Emphasis is on analyzing data from student investigations and using mathematical thinking to describe the energy changes both quantitatively and conceptually. Examples of investigations could include mixing liquids at different initial temperatures or adding objects at different temperatures to water.] [Assessment Boundary: Assessment is limited to investigations based on materials and tools provided to students.] HS-ESS2-1. **Develop a model to illustrate how Earth's internal and surface processes operate at different spatial and temporal scales to form continental and ocean-floor features.** [Clarification Statement: Emphasis is on how the appearance of land features (such as mountains, valleys, and plateaus) and sea-floor features (such as trenches, ridges, and seamounts) are a result of both constructive forces (such as volcanism, tectonic uplift, and orogeny) and destructive mechanisms (such as weathering, mass wasting, and coastal erosion).] [Assessment Boundary: Assessment does not include memorization of the details of the formation of specific geographic features of Earth's surface.]

Performance Expectations (Continued)	HS-ESS2-2. **Analyze geoscience data to make the claim that one change to Earth's surface can create feedbacks that cause changes to other Earth's systems.** [Clarification Statement: Examples should include climate feedbacks, such as how an increase in greenhouse gases causes a rise in global temperatures that melts glacial ice, which reduces the amount of sunlight reflected from Earth's surface, increasing surface temperatures and further reducing the amount of ice. Examples could also be taken from other system interactions, such as how the loss of ground vegetation causes an increase in water runoff and soil erosion; how dammed rivers increase groundwater recharge, decrease sediment transport, and increase coastal erosion; or how the loss of wetlands causes a decrease in local humidity that further reduces the wetland extent.] HS-ESS2-3. **Develop a model based on evidence of Earth's interior to describe the cycling of matter by thermal convection.** [Clarification Statement: Emphasis is on both a one-dimensional model of Earth, with radial layers determined by density, and a three-dimensional model, which is controlled by mantle convection and the resulting plate tectonics. Examples of evidence include maps of Earth's three-dimensional structure obtained from seismic waves, records of the rate of change of Earth's magnetic field (as constraints on convection in the outer core), and identification of the composition of Earth's layers from high-pressure laboratory experiments.] HS-ESS2-4. **Use a model to describe how variations in the flow of energy into and out of Earth's systems result in changes in climate.** [Clarification Statement: Examples of the causes of climate change differ by timescale, over 1-10 years: large volcanic eruption, ocean circulation; 10-100s of years: changes in human activity, ocean circulation, solar output; 10-100s of thousands of years: changes to Earth's orbit and the orientation of its axis; and 10-100s of millions of years: long-term changes in atmospheric composition.] [Assessment Boundary: Assessment of the results of changes in climate is limited to changes in surface temperatures, precipitation patterns, glacial ice volumes, sea levels, and biosphere distribution.] HS-ESS2-5. **Plan and conduct an investigation of the properties of water and its effects on Earth materials and surface processes.** [Clarification Statement: Emphasis is on mechanical and chemical investigations with water and a variety of solid materials to provide the evidence for connections between the hydrologic cycle and system interactions commonly known as the rock cycle. Examples of mechanical investigations include stream transportation and deposition using a stream table, erosion using variations in soil moisture content, or frost wedging by the expansion of water as it freezes. Examples of chemical investigations include chemical weathering and recrystallization (by testing the solubility of different materials) or melt generation (by examining how water lowers the melting temperature of most solids).] HS-ETS1-2. **Design a solution to a complex real-world problem by breaking it down into smaller, more manageable problems that can be solved through engineering.**
Example Phenomena	A solar oven can get hot enough to cook food. When hot and cold water are mixed together, they reach a final temperature that is between each of the original temperatures.
Additional Practices Building to the PEs	**Asking Questions and Defining Problems** • Ask and/or evaluate questions that challenge the premise(s) of an argument, the interpretation of a data set, or the suitability of a design. Students could *evaluate questions that challenge the premise(s) of an argument* [about how] ***interactions among changes in the Earth's orbit and ocean circulation change global and regional climate***. HS-ESS2-4 **Developing and Using Models** • Design a test of a model to ascertain its reliability. Students could *design a test of a model* [of how] ***energy can be converted to less useful forms*** *to ascertain its reliability*. HS-PS3-3

Additional Practices Building to the PEs (Continued)	**Planning and Carrying Out Investigations** • Plan an investigation individually and collaboratively to produce data to serve as the basis for evidence as part of supporting explanations for phenomena. Consider possible confounding variables or effects and evaluate the investigation's design to ensure variables are controlled. Students could *plan an investigation to produce data* [that could] *serve as the basis for evidence* [for the claim that] ***the foundation for Earth's global climate systems is the electromagnetic radiation from the sun***. HS-ESS2-2 and HS-ESS2-4 **Analyzing and Interpreting Data** • Apply concepts of statistics and probability (including determining function fits to data, slope, intercept, and correlation coefficient for linear fits) to scientific and engineering questions and problems, using digital tools when feasible. Students could *apply concepts of statistics and probability* [to analyze whether] ***Earth's systems cause feedback effects***. HS-ESS2-2 **Using Mathematical and Computational Thinking** • Use mathematical, computational, and/or algorithmic representations of phenomena or design solutions to describe and/or support claims and/or explanations. Students could *use mathematical representations to describe and support the claim* [that] ***in a system the total energy is conserved, even as, within the system, energy is continually transferred from one object to another and between its various possible forms***. HS-PS3-1 **Constructing Explanations and Designing Solutions** • Apply scientific reasoning, theory, and/or models to link evidence to the claims to assess the extent to which the reasoning and data support the explanation or conclusion. Students could *apply scientific reasoning and models to assess the extent to which the reasoning and data support an explanation* [for how] ***Earth's systems cause feedback effects***. HS-ESS2-2 **Engaging in Argument from Evidence** • Evaluate the claims, evidence, and/or reasoning behind currently accepted explanations or solutions to determine the merits of arguments. Students could *evaluate the evidence, and reasoning behind currently accepted explanations* [for how] ***evidence from deep probes and seismic waves, reconstructions of historical changes in Earth's surface and its magnetic field, and an understanding of physical and chemical processes lead to a model of Earth with a hot but solid inner core, a liquid outer core, a solid mantle and crust***. HS-ESS2-3 **Obtaining, Evaluating, and Communicating Information** • Compare, integrate and evaluate sources of information presented in different media or formats (e.g., visually, quantitatively) as well as in words in order to address a scientific question or solve a problem. Students could *evaluate sources of information presented in different formats* [about how] ***the total change of energy in any system is always equal to the total energy transferred into or out of the system***. HS-PS3-1

Additional Crosscutting Concepts Building to the PEs	**Cause and Effect** • Cause and effect relationships can be suggested and predicted for complex natural and human designed systems by examining what is known about smaller scale mechanisms within the system. Students could construct an argument from evidence for how *cause and effect relationships can be suggested and predicted* [for the relationship between] ***human activity*** [and] ***increased carbon dioxide concentrations***. HS-ESS2-4 **Systems and System Models** • Models (e.g., physical, mathematical, computer models) can be used to simulate systems and interactions—including energy, matter, and information flows—within and between systems at different scales. Students could describe *models that simulate systems and interactions within and between systems at different scales*, [including the interactions between the Earth's] ***mantle convection and the radioactive decay of unstable isotopes within Earth's crust and mantle***. HS-ESS2-3 **Energy and Matter** • Changes of energy and matter in a system can be described in terms of energy and matter flows into, out of and within that system. Students could develop a model of *energy and matter flows into, out of and within a system* [to describe that] ***energy cannot be created or destroyed, but it can be transported form one place to another and transferred between systems***. HS-PS3-1 and HS-PS3-4
Additional Connections to Nature of Science	**Science Models, Laws, Mechanisms, and Theories Explain Natural Phenomena** • Laws are statements or descriptions of the relationships among observable phenomena. Students could construct an argument for how *laws are statements or descriptions of the relationships among observable phenomena*, [including how] ***the total change of energy in any system is always equal to the total energy transferred into or out of the system***. HS-PS3-1 **Scientific Knowledge Assumes an Order and Consistency in Natural Systems** • Scientific knowledge is based on the assumption that natural laws operate today as they did in the past and they will continue to do so in the future. Students could construct an argument for how *scientific knowledge, [such as the causes of]* ***global and regional climate****, is based on the assumption that natural laws operate today as they did in the past and they will continue to do so in the future*. HS-ESS2-4

HS-PS3-1

Students who demonstrate understanding can:

HS-PS3-1. **Create a computational model to calculate the change in the energy of one component in a system when the change in energy of the other component(s) and energy flows in and out of the system are known.** [Clarification Statement: Emphasis is on explaining the meaning of mathematical expressions used in the model.] [*Assessment Boundary: Assessment is limited to basic algebraic expressions or computations; to systems of two or three components; and to thermal energy, kinetic energy, and/or the energies in gravitational, magnetic, or electric fields.*]

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

Science and Engineering Practices

Using Mathematics and Computational Thinking
Mathematical and computational thinking at the 9–12 level builds on K–8 and progresses to using algebraic thinking and analysis; a range of linear and nonlinear functions including trigonometric functions, exponentials and logarithms; and computational tools for statistical analysis to analyze, represent, and model data. Simple computational simulations are created and used based on mathematical models of basic assumptions.

- Create a computational model or simulation of a phenomenon, designed device, process, or system.

Disciplinary Core Ideas

PS3.A: Definitions of Energy

- Energy is a quantitative property of a system that depends on the motion and interactions of matter and radiation within that system. That there is a single quantity called energy is due to the fact that a system's total energy is conserved, even as, within the system, energy is continually transferred from one object to another and between its various possible forms.

PS3.B: Conservation of Energy and Energy Transfer

- Conservation of energy means that the total change of energy in any system is always equal to the total energy transferred into or out of the system.
- Energy cannot be created or destroyed, but it can be transported from one place to another and transferred between systems.
- Mathematical expressions, which quantify how the stored energy in a system depends on its configuration (e.g., relative positions of charged particles, compression of a spring) and how kinetic energy depends on mass and speed, allow the concept of conservation of energy to be used to predict and describe system behavior.
- The availability of energy limits what can occur in any system.

Crosscutting Concepts

Systems and System Models

- Models can be used to predict the behavior of a system, but these predictions have limited precision and reliability due to the assumptions and approximations inherent in models.

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Connections to Nature of Science

Scientific Knowledge Assumes an Order and Consistency in Natural Systems

- Science assumes the universe is a vast single system in which basic laws are consistent.

Observable features of the student performance by the end of the course:			
1	Representation		
	a	Students identify and describe* the components to be computationally modeled, including:	
		i.	The boundaries of the system and that the reference level for potential energy = 0 (the potential energy of the initial or final state does not have to be zero);
		ii.	The initial energies of the system's components (e.g., energy in fields, thermal energy, kinetic energy, energy stored in springs — all expressed as a total amount of Joules in

			each component), including a quantification in an algebraic description to calculate the total initial energy of the system;
		iii.	The energy flows in or out of the system, including a quantification in an algebraic description with flow into the system defined as positive; and
		iv.	The final energies of the system components, including a quantification in an algebraic description to calculate the total final energy of the system.
2	Computational Modeling		
	a	Students use the algebraic descriptions of the initial and final energy state of the system, along with the energy flows to create a computational model (e.g., simple computer program, spreadsheet, simulation software package application) that is based on the principle of the conservation of energy.	
	b	Students use the computational model to calculate changes in the energy of one component of the system when changes in the energy of the other components and the energy flows are known.	
3	Analysis		
	a	Students use the computational model to predict the maximum possible change in the energy of one component of the system for a given set of energy flows.	
	b	Students identify and describe* the limitations of the computational model, based on the assumptions that were made in creating the algebraic descriptions of energy changes and flows in the system.	

HS-PS3-3

Students who demonstrate understanding can:

HS-PS3-3. **Design, build, and refine a device that works within given constraints to convert one form of energy into another form of energy.*** [Clarification Statement: Emphasis is on both qualitative and quantitative evaluations of devices. Examples of devices could include Rube Goldberg devices, wind turbines, solar cells, solar ovens, and generators. Examples of constraints could include use of renewable energy forms and efficiency.] [*Assessment Boundary: Assessment for quantitative evaluations is limited to total output for a given input. Assessment is limited to devices constructed with materials provided to students.*]

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

Science and Engineering Practices

Constructing Explanations and Designing Solutions

Constructing explanations and designing solutions in 9–12 builds on K–8 experiences and progresses to explanations and designs that are supported by multiple and independent student-generated sources of evidence consistent with scientific ideas, principles, and theories.

- Design, evaluate, and/or refine a solution to a complex real-world problem based on scientific knowledge, student-generated sources of evidence, prioritized criteria, and tradeoff considerations.

Disciplinary Core Ideas

PS3.A: Definitions of Energy

- At the macroscopic scale, energy manifests itself in multiple ways, such as in motion, sound, light, and thermal energy.

PS3.D: Energy in Chemical Processes

- Although energy cannot be destroyed, it can be converted to less useful forms — for example, to thermal energy in the surrounding environment.

ETS1.A: Defining and Delimiting an Engineering Problem

- Criteria and constraints also include satisfying any requirements set by society, such as taking issues of risk mitigation into account, and they should be quantified to the extent possible and stated in such a way that one can tell if a given design meets them. *(secondary)*

Crosscutting Concepts

Energy and Matter

- Changes of energy and matter in a system can be described in terms of energy and matter flows into, out of, and within that system.

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Connections to Engineering, Technology, and Applications of Science

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

- Modern civilization depends on major technological systems. Engineers continuously modify these technological systems by applying scientific knowledge and engineering design practices to increase benefits while decreasing costs and risks.

Observable features of the student performance by the end of the course:			
1	Using scientific knowledge to generate the design solution		
	a	Students design a device that converts one form of energy into another form of energy.	
	b	Students develop a plan for the device in which they:	
		i.	Identify what scientific principles provide the basis for the energy conversion design;
		ii.	Identify the forms of energy that will be converted from one form to another in the designed system;
		iii.	Identify losses of energy by the design system to the surrounding environment;
		iv.	Describe* the scientific rationale for choices of materials and structure of the device, including how student-generated evidence influenced the design; and
		v.	Describe* that this device is an example of how the application of scientific knowledge and engineering design can increase benefits for modern civilization while decreasing costs and risk.
2	Describing criteria and constraints, including quantification when appropriate		

	a	Students describe* and quantify (when appropriate) prioritized criteria and constraints for the design of the device, along with the tradeoffs implicit in these design solutions. Examples of constraints to be considered are cost and efficiency of energy conversion.
3	Evaluating potential solutions	
	a	Students build and test the device according to the plan.
	b	Students systematically and quantitatively evaluate the performance of the device against the criteria and constraints.
4	Refining and/or optimizing the design solution	
	a	Students use the results of the tests to improve the device performance by increasing the efficiency of energy conversion, keeping in mind the criteria and constraints, and noting any modifications in tradeoffs.

HS-PS3-4

Students who demonstrate understanding can:

HS-PS3-4. **Plan and conduct an investigation to provide evidence that the transfer of thermal energy when two components of different temperature are combined within a closed system results in a more uniform energy distribution among the components in the system (second law of thermodynamics).** [Clarification Statement: Emphasis is on analyzing data from student investigations and using mathematical thinking to describe the energy changes both quantitatively and conceptually. Examples of investigations could include mixing liquids at different initial temperatures or adding objects at different temperatures to water.] [*Assessment Boundary: Assessment is limited to investigations based on materials and tools provided to students.*]

The performance expectation above was developed using the following elements from *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 9–12 builds on K–8 experiences and progresses to include investigations that provide evidence for and test conceptual, mathematical, physical, and empirical models.

- Plan and conduct an investigation individually and collaboratively to produce data to serve as the basis for evidence, and in the design: decide on types, how much, and accuracy of data needed to produce reliable measurements and consider limitations on the precision of the data (e.g., number of trials, cost, risk, time), and refine the design accordingly.

Disciplinary Core Ideas

PS3.B: Conservation of Energy and Energy Transfer

- Energy cannot be created or destroyed, but it can be transported from one place to another and transferred between systems.
- Uncontrolled systems always evolve toward more stable states—that is, toward more uniform energy distribution (e.g., water flows downhill, objects hotter than their surrounding environment cool down).

PS3.D: Energy in Chemical Processes

- Although energy cannot be destroyed, it can be converted to less useful forms — for example, to thermal energy in the surrounding environment.

Crosscutting Concepts

Systems and System Models

- When investigating or describing a system, the boundaries and initial conditions of the system need to be defined and their inputs and outputs analyzed and described using models.

Observable features of the student performance by the end of the course:			
1	Identifying the phenomenon to be investigated		
	a	Students describe* the purpose of the investigation, which includes the following idea, that the transfer of thermal energy when two components of different temperature are combined within a closed system results in a more uniform energy distribution among the components in the system (second law of thermodynamics).	
2	Identifying the evidence to answer this question		
	a	Students develop an investigation plan and describe* the data that will be collected and the evidence to be derived from the data, including:	
		i.	The measurement of the reduction of temperature of the hot object and the increase in temperature of the cold object to show that the thermal energy lost by the hot object is equal to the thermal energy gained by the cold object and that the distribution of thermal energy is more uniform after the interaction of the hot and cold components; and
		ii.	The heat capacity of the components in the system (obtained from scientific literature).
3	Planning for the investigation		
	a	In the investigation plan, students describe*:	
		i.	How a nearly closed system will be constructed, including the boundaries and initial

		conditions of the system;
		ii. The data that will be collected, including masses of components and initial and final temperatures; and
		iii. The experimental procedure, including how the data will be collected, the number of trials, the experimental set up, and equipment required.
4	Collecting the data	
	a	Students collect and record data that can be used to calculate the change in thermal energy of each of the two components of the system.
5	Refining the design	
	a	Students evaluate their investigation, including:
		i. The accuracy and precision of the data collected, as well as the limitations of the investigation; and
		ii. The ability of the data to provide the evidence required.
	b	If necessary, students refine the plan to produce more accurate, precise, and useful data that address the experimental question.
	c	Students identify potential causes of the apparent loss of energy from a closed system (which should be zero in an ideal system) and adjust the design of the experiment accordingly.

HS-ESS2-1

Students who demonstrate understanding can:

HS-ESS2-1. **Develop a model to illustrate how Earth's internal and surface processes operate at different spatial and temporal scales to form continental and ocean-floor features.** [Clarification Statement: Emphasis is on how the appearance of land features (such as mountains, valleys, and plateaus) and sea-floor features (such as trenches, ridges, and seamounts) are a result of both constructive forces (such as volcanism, tectonic uplift, and orogeny) and destructive mechanisms (such as weathering, mass wasting, and coastal erosion).] [*Assessment Boundary: Assessment does not include memorization of the details of the formation of specific geographic features of Earth's surface.*]

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

Science and Engineering Practices

Developing and Using Models
Modeling in 9–12 builds on K–8 experiences and progresses to using, synthesizing, and developing models to predict and show relationships among variables between systems and their components in the natural and designed world(s).

- Develop a model based on evidence to illustrate the relationships between systems or between components of a system.

Disciplinary Core Ideas

ESS2.A: Earth Materials and Systems

- Earth's systems, being dynamic and interacting, cause feedback effects that can increase or decrease the original changes.

ESS2.B: Plate Tectonics and Large-Scale System Interactions

- Plate tectonics is the unifying theory that explains the past and current movements of the rocks at Earth's surface and provides a framework for understanding its geologic history. Plate movements are responsible for most continental and ocean-floor features and for the distribution of most rocks and minerals within Earth's crust. *(ESS2.B Grade 8 GBE)*

Crosscutting Concepts

Stability and Change

- Change and rates of change can be quantified and modeled over very short or very long periods of time. Some system changes are irreversible.

Observable features of the student performance by the end of the course:			
1	Components of the model		
	a	Students use evidence to develop a model in which they identify and describe* the following components:	
		i.	Descriptions* and locations of specific continental features and specific ocean-floor features;
		ii.	A geographic scale, showing the relative sizes/extents of continental and/or ocean-floor features;
		iii.	Internal processes (such as volcanism and tectonic uplift) and surface processes (such as weathering and erosion); and
		iv.	A temporal scale showing the relative times over which processes act to produce continental and/or ocean-floor features.
2	Relationships		
	a	In the model, students describe* the relationships between components, including:	
		i.	Specific internal processes, mainly volcanism, mountain building or tectonic uplift, are identified as causal agents in building up Earth's surface over time.
		ii.	Specific surface processes, mainly weathering and erosion, are identified as causal agents in wearing down Earth's surface over time.

		iii. Interactions and feedbacks between processes are identified (e.g., mountain-building changes weather patterns that then change the rate of erosion of mountains).
		iv. The rate at which the features change is related to the time scale on which the processes operate. Features that form or change slowly due to processes that act on long time scales (e.g., continental positions due to plate drift) and features that form or change rapidly due to processes that act on short time scales (e.g., volcanic eruptions) are identified.
3	Connections	
	a	Students use the model to illustrate the relationship between 1) the formation of continental and ocean floor features and 2) Earth's internal and surface processes operating on different temporal or spatial scales.

HS-ESS2-2

Students who demonstrate understanding can:

HS-ESS2-2. **Analyze geoscience data to make the claim that one change to Earth's surface can create feedbacks that cause changes to other Earth systems.** [Clarification Statement: Examples should include climate feedbacks, such as how an increase in greenhouse gases causes a rise in global temperatures that melts glacial ice, which reduces the amount of sunlight reflected from Earth's surface, increasing surface temperatures and further reducing the amount of ice. Examples could also be taken from other system interactions, such as how the loss of ground vegetation causes an increase in water runoff and soil erosion; how dammed rivers increase groundwater recharge, decrease sediment transport, and increase coastal erosion; or how the loss of wetlands causes a decrease in local humidity that further reduces the wetland extent.]

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

Science and Engineering Practices

Analyzing and Interpreting Data
Analyzing data in 9–12 builds on K–8 experiences and progresses to introducing more detailed statistical analysis, the comparison of data sets for consistency, and the use of models to generate and analyze data.

- Analyze data using tools, technologies, and/or models (e.g., computational, mathematical) in order to make valid and reliable scientific claims or determine an optimal design solution.

Disciplinary Core Ideas

ESS2.A: Earth Materials and Systems

- Earth's systems, being dynamic and interacting, cause feedback effects that can increase or decrease the original changes.

ESS2.D: Weather and Climate

- The foundation for Earth's global climate systems is the electromagnetic radiation from the sun, as well as its reflection, absorption, storage, and redistribution among the atmosphere, ocean, and land systems, and this energy's re-radiation into space.

Crosscutting Concepts

Stability and Change

- Feedback (negative or positive) can stabilize or destabilize a system.

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Connections to Engineering, Technology, and Applications of Science

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

- New technologies can have deep impacts on society and the environment, including some that were not anticipated. Analysis of costs and benefits is a critical aspect of decisions about technology.

Observable features of the student performance by the end of the course:			
1	Organizing data		
	a	Students organize data that represent measurements of changes in hydrosphere, cryosphere, atmosphere, biosphere, or geosphere in response to a change in Earth's surface.	
	b	Students describe* what each data set represents.	
2	Identifying relationships		
	a	Students use tools, technologies, and/or models to analyze the data and identify and describe* relationships in the datasets, including:	
		i.	The relationships between the changes in one system and changes in another (or within the same) Earth system; and
		ii.	Possible feedbacks, including one example of feedback to the climate.
	b	Students analyze data to identify effects of human activity and specific technologies on Earth's systems if present.	
3	Interpreting data		
	a	Students use the analyzed data to describe* a mechanism for the feedbacks between two of Earth's systems and whether the feedback is positive or negative, increasing (destabilizing) or decreasing (stabilizing) the original changes.	

	b	Students use the analyzed data to describe* a particular unanticipated or unintended effect of a selected technology on Earth's systems if present.
	c	Students include a statement regarding how variation or uncertainty in the data (e.g., limitations, accuracy, any bias in the data resulting from choice of sample, scale, instrumentation, etc.) may affect the interpretation of the data.

HS-ESS2-3

Students who demonstrate understanding can:

HS-ESS2-3. **Develop a model based on evidence of Earth's interior to describe the cycling of matter by thermal convection.** [Clarification Statement: Emphasis is on both a one-dimensional model of Earth, with radial layers determined by density, and a three-dimensional model, which is controlled by mantle convection and the resulting plate tectonics. Examples of evidence include maps of Earth's three-dimensional structure obtained from seismic waves, records of the rate of change of Earth's magnetic field (as constraints on convection in the outer core), and identification of the composition of Earth's layers from high-pressure laboratory experiments.]

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

Science and Engineering Practices

Developing and Using Models
Modeling in 9–12 builds on K–8 experiences and progresses to using, synthesizing, and developing models to predict and show relationships among variables between systems and their components in the natural and designed world(s).

- Develop a model based on evidence to illustrate the relationships between systems or between components of a system.

- -

Connections to Nature of Science

Scientific Knowledge is Based on Empirical Evidence

- Science knowledge is based on empirical evidence.
- Science disciplines share common rules of evidence used to evaluate explanations about natural systems.
- Science includes the process of coordinating patterns of evidence with current theory.

Disciplinary Core Ideas

ESS2.A: Earth Materials and Systems

- Evidence from deep probes and seismic waves, reconstructions of historical changes in Earth's surface and its magnetic field, and an understanding of physical and chemical processes lead to a model of Earth with a hot but solid inner core, a liquid outer core, a solid mantle and crust. Motions of the mantle and its plates occur primarily through thermal convection, which involves the cycling of matter due to the outward flow of energy from Earth's interior and gravitational movement of denser materials toward the interior.

ESS2.B: Plate Tectonics and Large-Scale System Interactions

- The radioactive decay of unstable isotopes continually generates new energy within Earth's crust and mantle, providing the primary source of the heat that drives mantle convection. Plate tectonics can be viewed as the surface expression of mantle convection.

Crosscutting Concepts

Energy and Matter
Energy drives the cycling of matter within and between systems.

- -

Connections to Engineering, Technology, and Applications of Science

Interdependence of Science, Engineering, and Technology

- Science and engineering complement each other in the cycle known as research and development (R&D). Many R&D projects may involve scientists, engineers, and others with wide ranges of expertise.

Observable features of the student performance by the end of the course:			
1	Components of the model		
	a	Students develop a model (i.e., graphical, verbal, or mathematical) in which they identify and describe* the components based on both seismic and magnetic evidence (e.g., the pattern of the geothermal gradient or heat flow measurements) from Earth's interior, including:	
		i.	Earth's interior in cross-section and radial layers (crust, mantle, liquid outer core, solid inner core) determined by density;

		ii.	The plate activity in the outer part of the geosphere;
		iii.	Radioactive decay and residual thermal energy from the formation of the Earth as a source of energy;
		iv.	The loss of heat at the surface of the earth as an output of energy; and
		v.	The process of convection that causes hot matter to rise (move away from the center) and cool matter to fall (move toward the center).
2	Relationships		
	a	Students describe* the relationships between components in the model, including:	
		i.	Energy released by radioactive decay in the Earth's crust and mantle and residual thermal energy from the formation of the Earth provide energy that drives the flow of matter in the mantle.
		ii.	Thermal energy is released at the surface of the Earth as new crust is formed and cooled.
		iii.	The flow of matter by convection in the solid mantle and the sinking of cold, dense crust back into the mantle exert forces on crustal plates that then move, producing tectonic activity.
		iv.	The flow of matter by convection in the liquid outer core generates the Earth's magnetic field.
		v.	Matter is cycled between the crust and the mantle at plate boundaries. Where plates are pushed together, cold crustal material sinks back into the mantle, and where plates are pulled apart, mantle material can be integrated into the crust, forming new rock.
3	Connections		
	a	Students use the model to describe* the cycling of matter by thermal convection in Earth's interior, including:	
		i.	The flow of matter in the mantle that causes crustal plates to move;
		ii.	The flow of matter in the liquid outer core that generates the Earth's magnetic field, including evidence of polar reversals (e.g., seafloor exploration of changes in the direction of Earth's magnetic field);
		iii.	The radial layers determined by density in the interior of Earth; and
		iv.	The addition of a significant amount of thermal energy released by radioactive decay in Earth's crust and mantle.

HS-ESS2-4

Students who demonstrate understanding can:

HS-ESS2-4. **Use a model to describe how variations in the flow of energy into and out of Earth's systems result in changes in climate.** [Clarification Statement: Examples of the causes of climate change differ by timescale, over 1-10 years: large volcanic eruption, ocean circulation; 10-100s of years: changes in human activity, ocean circulation, solar output; 10-100s of thousands of years: changes to Earth's orbit and the orientation of its axis; and 10-100s of millions of years: long-term changes in atmospheric composition.] [*Assessment Boundary: Assessment of the results of changes in climate is limited to changes in surface temperatures, precipitation patterns, glacial ice volumes, sea levels, and biosphere distribution.*]

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

Science and Engineering Practices

Developing and Using Models
Modeling in 9–12 builds on K–8 experiences and progresses to using, synthesizing, and developing models to predict and show relationships among variables between systems and their components in the natural and designed world(s).

- Use a model to provide mechanistic accounts of phenomena.

- -

Connections to Nature of Science

Scientific Knowledge is Based on Empirical Evidence

- Science arguments are strengthened by multiple lines of evidence supporting a single explanation.

Disciplinary Core Ideas

ESS1.B: Earth and the Solar System

- Cyclical changes in the shape of Earth's orbit around the sun, together with changes in the tilt of the planet's axis of rotation, both occurring over hundreds of thousands of years, have altered the intensity and distribution of sunlight falling on the earth. These phenomena cause a cycle of ice ages and other gradual climate changes. *(secondary)*

ESS2.A: Earth Materials and System

- The geological record shows that changes to global and regional climate can be caused by interactions among changes in the sun's energy output or Earth's orbit, tectonic events, ocean circulation, volcanic activity, glaciers, vegetation, and human activities. These changes can occur on a variety of time scales from sudden (e.g., volcanic ash clouds) to intermediate (ice ages) to very long-term tectonic cycles.

ESS2.D: Weather and Climate

- The foundation for Earth's global climate systems is the electromagnetic radiation from the sun, as well as its reflection, absorption, storage, and redistribution among the atmosphere, ocean, and land systems, and this energy's re-radiation into space.

Crosscutting Concepts

Cause and Effect

- Empirical evidence is required to differentiate between cause and correlation and make claims about specific causes and effects.

Observable features of the student performance by the end of the course:			
1	Components of the model:		
	a	From the given model, students identify and describe* the components of the model relevant for their mechanistic descriptions. Given models include at least one factor that affects the input of energy, at least one factor that affects the output of energy, and at least one factor that affects the storage and redistribution of energy. Factors are derived from the following list:	
		i.	Changes in Earth's orbit and the orientation of its axis;
		ii.	Changes in the sun's energy output;
		iii.	Configuration of continents resulting from tectonic activity;
		iv.	Ocean circulation;
		v.	Atmospheric composition (including amount of water vapor and CO_2);
		vi.	Atmospheric circulation;
		vii.	Volcanic activity;
		viii.	Glaciation;
		ix.	Changes in extent or type of vegetation cover; and
		x.	Human activities.
	b	From the given model, students identify the relevant different time scales on which the factors operate.	
2	Relationships		
	a	Students identify and describe* the relationships between components of the given model, and organize the factors from the given model into three groups:	
		i.	Those that affect the input of energy;
		ii.	Those that affect the output of energy; and
		iii.	Those that affect the storage and redistribution of energy
	b	Students describe* the relationships between components of the model as either causal or correlational.	
3	Connections		
	a	Students use the given model to provide a mechanistic account of the relationship between energy flow in Earth's systems and changes in climate, including:	
		i.	The specific cause and effect relationships between the factors and the effect on energy flow into and out of Earth's systems; and
		ii.	The net effect of all of the competing factors in changing the climate.

HS-ESS2-5

Students who demonstrate understanding can:

HS-ESS2-5. **Plan and conduct an investigation of the properties of water and its effects on Earth materials and surface processes.** [Clarification Statement: Emphasis is on mechanical and chemical investigations with water and a variety of solid materials to provide the evidence for connections between the hydrologic cycle and system interactions commonly known as the rock cycle. Examples of mechanical investigations include stream transportation and deposition using a stream table, erosion using variations in soil moisture content, or frost wedging by the expansion of water as it freezes. Examples of chemical investigations include chemical weathering and recrystallization (by testing the solubility of different materials) or melt generation (by examining how water lowers the melting temperature of most solids).]

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

Science and Engineering Practices

Planning and Carrying Out Investigations
Planning and carrying out investigations in 9-12 builds on K-8 experiences and progresses to include investigations that provide evidence for and test conceptual, mathematical, physical, and empirical models.

- Plan and conduct an investigation individually and collaboratively to produce data to serve as the basis for evidence, and in the design: decide on types, how much, and accuracy of data needed to produce reliable measurements and consider limitations on the precision of the data (e.g., number of trials, cost, risk, time), and refine the design accordingly.

Disciplinary Core Ideas

ESS2.C: The Roles of Water in Earth's Surface Processes

- The abundance of liquid water on Earth's surface and its unique combination of physical and chemical properties are central to the planet's dynamics. These properties include water's exceptional capacity to absorb, store, and release large amounts of energy, transmit sunlight, expand upon freezing, dissolve and transport materials, and lower the viscosities and melting points of rocks.

Crosscutting Concepts

Structure and Function

- The functions and properties of natural and designed objects and systems can be inferred from their overall structure, the way their components are shaped and used, and the molecular substructures of its various materials.

Observable features of the student performance by the end of the course:		
1	Identifying the phenomenon to be investigated	
	a	Students describe* the phenomenon under investigation, which includes the following idea: a connection between the properties of water and its effects on Earth materials and surface processes.
2	Identifying the evidence to answer this question	
	a	Students develop an investigation plan and describe* the data that will be collected and the evidence to be derived from the data, including:
		i. Properties of water, including:
		a) The heat capacity of water;
		b) The density of water in its solid and liquid states; and
		c) The polar nature of the water molecule due to its molecular structure.
		ii. The effect of the properties of water on energy transfer that causes the patterns of temperature, the movement of air, and the movement and availability of water at Earth's surface.
		iii. Mechanical effects of water on Earth materials that can be used to infer the effect of water on Earth's surface processes. Examples can include:
		a) Stream transportation and deposition using a stream table, which can be used to infer the ability of water to transport and deposit materials;

		b)	Erosion using variations in soil moisture content, which can be used to infer the ability of water to prevent or facilitate movement of Earth materials; and
		c)	The expansion of water as it freezes, which can be used to infer the ability of water to break rocks into smaller pieces.
		iv.	Chemical effects of water on Earth materials that can be used to infer the effect of water on Earth's surface processes. Examples can include:
		a)	The solubility of different materials in water, which can be used to infer chemical weathering and recrystallization;
		b)	The reaction of iron to rust in water, which can be used to infer the role of water in chemical weathering;
		c)	Data illustrating that water lowers the melting temperature of most solids, which can be used to infer melt generation; and
		d)	Data illustrating that water decreases the viscosity of melted rock, affecting the movement of magma and volcanic eruptions.
	b		In their investigation plan, students describe* how the data collected will be relevant to determining the effect of water on Earth materials and surface processes.
3	Planning for the Investigation		
	a		In their investigation plan, students include a means to indicate or measure the predicted effect of water on Earth's materials or surface processes. Examples include:
		i.	The role of the heat capacity of water to affect the temperature, movement of air and movement of water at the Earth's surface;
		ii.	The role of flowing water to pick up, move and deposit sediment;
		iii.	The role of the polarity of water (through cohesion) to prevent or facilitate erosion;
		iv.	The role of the changing density of water (depending on physical state) to facilitate the breakdown of rock;
		v.	The role of the polarity of water in facilitating the dissolution of Earth materials;
		vi.	Water as a component in chemical reactions that change Earth materials; and
		vii.	The role of the polarity of water in changing the melting temperature and viscosity of rocks.
	b		In the plan, students state whether the investigation will be conducted individually or collaboratively.
4	Collecting the data		
	a		Students collect and record measurements or indications of the predicted effect of a property of water on Earth's materials or surface.
5	Refining the design		
	a		Students evaluate the accuracy and precision of the collected data.
	b		Students evaluate whether the data can be used to infer the effect of water on processes in the natural world.
	c		If necessary, students refine the plan to produce more accurate and precise data.

HS-ETS1-2

Students who demonstrate understanding can:

HS-ETS1-2. **Design a solution to a complex real-world problem by breaking it down into smaller, more manageable problems that can be solved through engineering.**

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

Science and Engineering Practices	Disciplinary Core Ideas	Crosscutting Concepts
Constructing Explanations and Designing Solutions Constructing explanations and designing solutions in 9–12 builds on K–8 experiences and progresses to explanations and designs that are supported by multiple and independent student-generated sources of evidence consistent with scientific ideas, principles and theories. • Design a solution to a complex real-world problem based on scientific knowledge, student-generated sources of evidence, prioritized criteria, and tradeoff considerations.	**ETS1.C: Optimizing the Design Solution** • Criteria may need to be broken down into simpler ones that can be approached systematically, and decisions about the priority of certain criteria over others (tradeoffs) may be needed.	

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

1	Using scientific knowledge to generate the design solution	
	a	Students restate the original complex problem into a finite set of two or more sub-problems (in writing or as a diagram or flow chart).
	b	For at least one of the sub-problems, students propose two or more solutions that are based on student-generated data and/or scientific information from other sources.
	c	Students describe* how solutions to the sub-problems are interconnected to solve all or part of the larger problem.
2	Describing criteria and constraints, including quantification when appropriate	
	a	Students describe* criteria and constraints for the selected sub-problem.
	b	Students describe* the rationale for the sequence of how sub-problems are to be solved, and which criteria should be given highest priority if tradeoffs must be made.