High School Conceptual Progressions Model Course 1 - Bundle 3
Forces, Energy, and Motion

*This is the third bundle of the High School Conceptual Progressions 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 "What is energy? How can one predict an object's continued motion, changes in motion, or stability?"*
Summary The bundle organizes performance expectations with a focus on helping students understand the relationships between *energy, motion, changes in motion, and stability*. 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. (PS3.A as in HS-PS3-2; PS3.B as in HS-PS3-4; PS3.D as in HS-PS3-4). This concept of energy connects to ideas about energy from Earth's interior, and the outward flow of that energy due to thermal convection (ESS2.A as in HS-ESS2-3). 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. Plate tectonics can be viewed as the surface expression of mantle convection (ESS2.B as in HS-ESS2-3). The concepts of motion and interactions of matter within a system connect to the idea of momentum and changes in momentum. (PS2.A as in HS-PS2-2). (PS2.A as in HS-PS2-2, HS-PS2-3). Finally, an understanding of energy, motion, changes in motion, and stability is essential for the engineering of solutions to problems [about how] the total momentum of the system can change, but any change is balanced by changes in the momentum of objects outside the system (PS2.A as in HS-PS2-2, HS-PS2-3) and [about how] uncontrolled systems always evolve toward more stable states (PS3.B as in HS-PS3-4). Connections could be made through an engineering design task such as designing a car or a package to minimize the force on an object during a collision (PS2.A as in HS-PS2-3). Criteria and constraints include satisfying requirements set by society (ETS1.A as in HS-ETS1-1) and sometimes, 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) such as reducing risk to humans traveling in a car or minimizing damage to a piece of artwork or a plant packaged in a box for shipment from one location to another. **Bundle Science and Engineering Practices** Instruction leading to this bundle of PEs will help students build toward proficiency in elements of the practices of defining problems (HS-ETS1-1), developing and using a model (HS-PS3-2, HS-ESS2-3), planning and conducting an investigation (HS-PS3-4), using mathematical representations (HS-PS2-2), and designing solutions (HS-PS2-3, 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-PS2-3), Systems and System Models (HS-PS2-2, HS-PS3-4), and Energy and Matter (HS-PS3-2, HS-ESS2-3). Many other CCC elements can be used in instruction. *All instruction should be three-dimensional.*

Performance Expectations HS-ESS2-3, HS-ETS1-1, and HS-ETS1-2 are partially assessable.	HS-PS2-2. **Use mathematical representations to support the claim that the total momentum of a system of objects is conserved when there is no net force on the system.** [Clarification Statement: Emphasis is on the quantitative conservation of momentum in interactions and the qualitative meaning of this principle.] [Assessment Boundary: Assessment is limited to systems of two macroscopic bodies moving in one dimension.] HS-PS2-3. **Apply scientific and engineering ideas to design, evaluate, and refine a device that minimizes the force on a macroscopic object during a collision.*** [Clarification Statement: Examples of evaluation and refinement could include determining the success of the device at protecting an object from damage and modifying the design to improve it. Examples of a device could include a football helmet or a parachute.] [Assessment Boundary: Assessment is limited to qualitative evaluations and/or algebraic manipulations.] HS-PS3-2. **Develop and use models to illustrate that energy at the macroscopic scale can be accounted for as a combination of energy associated with the motions of particles (objects) and energy associated with the relative position of particles (objects).** [Clarification Statement: Examples of phenomena at the macroscopic scale could include the conversion of kinetic energy to thermal energy, the energy stored due to position of an object above the earth, and the energy stored between two electrically-charged plates. Examples of models could include diagrams, drawings, descriptions, and computer simulations.] 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-ESS2-3. **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-ETS1-1. **Analyze a major global challenge to specify qualitative and quantitative criteria and constraints for solutions that account for societal needs and wants.** 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	When a baseball bat hits a baseball, both the bat and ball feel warmer. Cars have crumple zones.
Additional Practices Building to the PEs	**Asking Questions and Defining Problems** • Ask questions that can be investigated within the scope of the school laboratory, research facilities, or field (e.g., outdoor environment) with available resources and, when appropriate, frame a hypothesis based on a model or theory. Students could *ask questions that can be investigated* [to support the claim that] ***if a system interacts with objects outside itself, any such change is balanced by changes in the momentum of objects outside the system***. HS-PS2-2 and HS-PS2-3 **Developing and Using Models** • Evaluate merits and limitations of two different models of the same proposed tool, process, mechanism, or system in order to select or revise a model that best fits the evidence or design criteria. Students could *evaluate merits and limitations of two different models* [for] ***the energy distribution*** [over time in] ***uncontrolled systems.*** HS-PS3-4

Additional Practices Building to the PEs (Continued)	**Planning and Carrying Out Investigations** • Select appropriate tools to collect, record, analyze, and evaluate data. Students could [discuss how to collect data and what] *tools are necessary to collect, record, analyze, and evaluate data* [to support the claim that] ***if a system interacts with objects outside itself, any such change is balanced by changes in the momentum of objects outside the system***. HS-PS2-3 **Analyzing and Interpreting Data** • Consider limitations of data analysis (e.g., measurement error, sample selection) when analyzing and interpreting data. Students could *consider limitations of data analysis* [to support the claim that] ***if a system interacts with objects outside itself, any such change is balanced by changes in the momentum of objects outside the system.*** HS-PS2-3 **Using Mathematical and Computational Thinking** • Create and/or revise a computational model or simulation of a phenomenon, designed device, process, or system. Students could *revise a computational model* [that describes that] ***motions of the mantle and its plates occur primarily through thermal convection.*** HS-ESS2-3 **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 *assess the extent to which reasoning and data support the explanation* [that] ***energy cannot be created or destroyed, but it can be transported from one place to another and transferred between systems.*** HS-PS3-4 **Engaging in Argument from Evidence** • Evaluate competing design solutions to a real-world problem based on scientific ideas and principles, empirical evidence, and/or logical arguments regarding relevant factors (e.g. economical, societal, environmental, ethical considerations). Students could *evaluate competing design solutions to a problem based on scientific ideas* [about how] ***energy can be converted to less useful forms such as thermal energy being released into the environment.*** HS-PS3-4 **Obtaining, Evaluating, and Communicating Information** • Gather, read, and evaluate scientific and/or technical information from multiple authoritative sources, assessing the evidence and usefulness of each source. Students could *evaluate scientific information from multiple authoritative sources, assessing the evidence and usefulness of each source* [to describe how] ***the total momentum of a system can change if the system interacts with objects outside itself, but any such change is balanced by changes in the momentum of objects outside the system.*** HS-PS2-3

Additional Crosscutting Concepts Building to the PEs	**Scale, Proportion, and Quantity** • The significance of a phenomenon is dependent on the scale, proportion, and quantity at which it occurs. Students could describe the ***flow of energy (momentum, force, thermal***) within a variety of systems at *different scales*. HS-PS2-2, HS-PS2-3, HS-PS3-4, and HS-ESS2-3 **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 *use models to simulate systems and interactions within and between systems* [for how] ***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***. HS-ESS2-3 **Energy and Matter** • The total amount of energy and matter in closed systems is conserved. Students could develop a model [for how] *the total amount of energy in a closed system is conserved* [including that] ***uncontrolled system always evolve toward more stable states or toward more uniform energy distribution***. HS-PS3-4
Additional Connections to Nature of Science	**Scientific Phenomena is Based on Empirical Evidence (SEP):** • Science arguments are strengthened by multiple lines of evidence supporting a single explanation. Students could construct an argument for how *science arguments are strengthened by multiple lines of evidence supporting the explanation* [for how] ***the total momentum of a system can change if the system interacts with objects outside itself*** [and how] ***any such change is balanced by changes in the momentum of objects outside the system***. HS-PS2-2 and HS-PS2-3 **Science is a Human Endeavor (CCC):** • Science and engineering are influenced by society and society is influenced by science and engineering. Students could describe how *science and engineering influence society and how society is influenced by science and engineering* [for example, when] ***designing a device, criteria and constraints include taking issues of risk mitigation into account***. HS-PS2-3, HS-ETS1-1, and HS-ETS1-2

HS-PS2-2

Students who demonstrate understanding can:

HS-PS2-2. **Use mathematical representations to support the claim that the total momentum of a system of objects is conserved when there is no net force on the system.** [Clarification Statement: Emphasis is on the quantitative conservation of momentum in interactions and the qualitative meaning of this principle.] [*Assessment Boundary: Assessment is limited to systems of two macroscopic bodies moving in one dimension.*]

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.

- Use mathematical representations of phenomena to describe explanations.

Disciplinary Core Ideas

PS2.A: Forces and Motion

- Momentum is defined for a particular frame of reference; it is the mass times the velocity of the object.
- If a system interacts with objects outside itself, the total momentum of the system can change; however, any such change is balanced by changes in the momentum of objects outside the system.

Crosscutting Concepts

Systems and System Models

- When investigating or describing a system, the boundaries and initial conditions of the system need to be defined.

Observable features of the student performance by the end of the course:		
1	Representation	
	a	Students clearly define the system of the two interacting objects that is represented mathematically, including boundaries and initial conditions.
	b	Students identify and describe* the momentum of each object in the system as the product of its mass and its velocity, $p = mv$ (p and v are restricted to one-dimensional vectors), using the mathematical representations.
	c	Students identify the claim, indicating that the total momentum of a system of two interacting objects is constant if there is no net force on the system.
2	Mathematical modeling	
	a	Students use the mathematical representations to model and describe* the physical interaction of the two objects in terms of the change in the momentum of each object as a result of the interaction.
	b	Students use the mathematical representations to model and describe* the total momentum of the system by calculating the vector sum of momenta of the two objects in the system.
3	Analysis	
	a	Students use the analysis of the motion of the objects before the interaction to identify a system with essentially no net force on it.
	b	Based on the analysis of the total momentum of the system, students support the claim that the momentum of the system is the same before and after the interaction between the objects in the system, so that momentum of the system is constant.
	c	Students identify that the analysis of the momentum of each object in the system indicates that any change in momentum of one object is balanced by a change in the momentum of the other object, so that the total momentum is constant.

HS-PS2-3

Students who demonstrate understanding can:

HS-PS2-3. **Apply scientific and engineering ideas to design, evaluate, and refine a device that minimizes the force on a macroscopic object during a collision.*** [Clarification Statement: Examples of evaluation and refinement could include determining the success of the device at protecting an object from damage and modifying the design to improve it. Examples of a device could include a football helmet or a parachute.] [*Assessment Boundary: Assessment is limited to qualitative evaluations and/or algebraic manipulations.*]

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.

- Apply scientific ideas to solve a design problem, taking into account possible unanticipated effects.

Disciplinary Core Ideas

PS2.A: Forces and Motion

- If a system interacts with objects outside itself, the total momentum of the system can change; however, any such change is balanced by changes in the momentum of objects outside the system.

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)*

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. *(secondary)*

Crosscutting Concepts

Cause and Effect

- Systems can be designed to cause a desired effect.

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 minimizes the force on a macroscopic object during a collision. In the design, students:	
		i.	Incorporate the concept that for a given change in momentum, force in the direction of the change in momentum is decreased by increasing the time interval of the collision ($F\Delta t = m\Delta v$); and
		ii.	Explicitly make use of the principle above so that the device has the desired effect of reducing the net force applied to the object by extending the time the force is applied to the object during the collision.
	b	In the design plan, students describe* the scientific rationale for their choice of materials and for the structure of the device.	
2	Describing criteria and constraints, including quantification when appropriate		

	a	Students describe* and quantify (when appropriate) the criteria and constraints, along with the tradeoffs implicit in these design solutions. Examples of constraints to be considered are cost, mass, the maximum force applied to the object, and requirements set by society for widely used collision-mitigation devices (e.g., seatbelts, football helmets).
3	Evaluating potential solutions	
	a	Students systematically evaluate the proposed device design or design solution, including describing* the rationales for the design and comparing the design to the list of criteria and constraints.
	b	Students test and evaluate the device based on its ability to minimize the force on the test object during a collision. Students identify any unanticipated effects or design performance issues that the device exhibits.
4	Refining and/or optimizing the design solution	
	a	Students use the test results to improve the device performance by extending the impact time, reducing the device mass, and/or considering cost-benefit analysis.

HS-PS3-2

Students who demonstrate understanding can:

HS-PS3-2. **Develop and use models to illustrate that energy at the macroscopic scale can be accounted for as a combination of energy associated with the motions of particles (objects) and energy associated with the relative positions of particles (objects).** [Clarification Statement: Examples of phenomena at the macroscopic scale could include the conversion of kinetic energy to thermal energy, the energy stored due to position of an object above the earth, and the energy stored between two electrically-charged plates. Examples of models could include diagrams, drawings, descriptions, and computer simulations.]

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
Developing and Using Models Modeling in 9–12 builds on K–8 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 worlds. • Develop and use a model based on evidence to illustrate the relationships between systems or between components of a system.	**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. • At the macroscopic scale, energy manifests itself in multiple ways, such as in motion, sound, light, and thermal energy. • These relationships are better understood at the microscopic scale, at which all of the different manifestations of energy can be modeled as a combination of energy associated with the motion of particles and energy associated with the configuration (relative position of the particles). In some cases the relative position energy can be thought of as stored in fields (which mediate interactions between particles). This last concept includes radiation, a phenomenon in which energy stored in fields moves across space.	**Energy and Matter** • Energy cannot be created or destroyed; it only moves between one place and another place, between objects and/or fields, or between systems.

Observable features of the student performance by the end of the course:			
1	Components of the model		
	a	Students develop models in which they identify and describe* the relevant components, including:	
		i.	All the components of the system and the surroundings, as well as energy flows between the system and the surroundings;
		ii.	Clearly depicting both a macroscopic and a molecular/atomic-level representation of the system; and

		iii. Depicting the forms in which energy is manifested at two different scales:
		a) Macroscopic , such as motion, sound, light, thermal energy, potential energy or energy in fields; and
		b) Molecular/atomic, such as motions (kinetic energy) of particles (e.g., nuclei and electrons), the relative positions of particles in fields (potential energy), and energy in fields.
2	Relationships	
	a	Students describe* the relationships between components in their models, including:
		i. Changes in the relative position of objects in gravitational, magnetic or electrostatic fields can affect the energy of the fields (e.g., charged objects moving away from each other change the field energy).
		ii. Thermal energy includes both the kinetic and potential energy of particle vibrations in solids or molecules and the kinetic energy of freely moving particles (e.g., inert gas atoms, molecules) in liquids and gases.
		iii. The total energy of the system and surroundings is conserved at a macroscopic and molecular/atomic level.
		iv. Chemical energy can be considered in terms of systems of nuclei and electrons in electrostatic fields (bonds).
		v. As one form of energy increases, others must decrease by the same amount as energy is transferred among and between objects and fields.
3	Connections	
	a	Students use their models to show that in closed systems the energy is conserved on both the macroscopic and molecular/atomic scales so that as one form of energy changes, the total system energy remains constant, as evidenced by the other forms of energy changing by the same amount or changes only by the amount of energy that is transferred into or out of the system.
	b	Students use their models to illustrate that energy at the macroscopic scale can be accounted for as a combination of energy associated with the motions of particles/objects and energy associated with the relative positions of particles/objects on both the macroscopic and microscopic scales.

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-ESS2-3

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-ETS1-1

Students who demonstrate understanding can:

HS-ETS1-1. Analyze a major global challenge to specify qualitative and quantitative criteria and constraints for solutions that account for societal needs and wants.

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

Science and Engineering Practices

Asking Questions and Defining Problems
Asking questions and defining problems in 9–12 builds on K–8 experiences and progresses to formulating, refining, and evaluating empirically testable questions and design problems using models and simulations.

- Analyze complex real-world problems by specifying criteria and constraints for successful solutions.

Disciplinary Core Ideas

ETS1.A: Defining and Delimiting Engineering Problems

- 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.
- Humanity faces major global challenges today, such as the need for supplies of clean water and food or for energy sources that minimize pollution, which can be addressed through engineering. These global challenges also may have manifestations in local communities.

Crosscutting Concepts

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Connections to Engineering, Technology, and Applications of Science

Influence of Science, Engineering, and Technology 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	Identifying the problem to be solved		
	a	Students analyze a major global problem. In their analysis, students:	
		i.	Describe* the challenge with a rationale for why it is a major global challenge;
		ii.	Describe*, qualitatively and quantitatively, the extent and depth of the problem and its major consequences to society and/or the natural world on both global and local scales if it remains unsolved; and
		iii.	Document background research on the problem from two or more sources, including research journals.
2	Defining the process or system boundaries, and the components of the process or system		
	a	In their analysis, students identify the physical system in which the problem is embedded, including the major elements and relationships in the system and boundaries so as to clarify what is and is not part of the problem.	
	b	In their analysis, students describe* societal needs and wants that are relative to the problem (e.g., for controlling CO_2 emissions, societal needs include the need for cheap energy).	
3	Defining the criteria and constraints		
	a	Students specify qualitative and quantitative criteria and constraints for acceptable solutions to the problem.	

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.