High School Science Domains Model Course 1-Chemistry-Bundle 3
The Flow of Energy

This is the third bundle of the High School Domains Model Course 1-Chemistry. Each bundle has connections to the other bundles in the course, as shown in the Course Flowchart.

Bundle 3 Question: This bundle is assembled to address the question of "How can we get energy to flow from one place to another?"	
Summary The bundle organizes performance expectations with a focus on helping students understand *energy flows*. 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). This idea of energy is expanded by the concept 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). These ideas of energy and its forms then connect to ideas about the transfer of energy, which can occur through fields (PS2.B as in HS-PS2-5). Finally, the concept of energy connects to the idea of conservation of energy (PS3.B as in HS-PS3-4) and the conversion of energy in chemical reactions (PS3.D as in HS-PS3-4). **Bundle Science and Engineering Practices** Instruction leading to this bundle of PEs will help students build toward proficiency in elements of the practices of planning and conducting investigations (HS-PS2-5 and HS-PS3-4), creating a computational model (HS-PS3-1), and designing, evaluating, and/or refining a solution (HS-PS3-3). Many other practice elements can be used in instruction. **Bundle Crosscutting Concepts** Instruction leading to this bundle of PEs will help students build toward proficiency in elements of the crosscutting concepts of Cause and Effect (HS-PS2-5), Systems and System Models (HS-PS3-1 and HS-PS3-4), and Energy and Matter (HS-PS3-3). Many other crosscutting concept elements can be used in instruction. *All instruction should be three-dimensional.*	
Performance Expectations	HS-PS2-5. **Plan and conduct an investigation to provide evidence that an electric current can produce a magnetic field and that a changing magnetic field can produce an electric current.** **[*Assessment Boundary: Assessment is limited to designing and conducting investigations with provided materials and tools.*]** 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.*]**
Example Phenomena	Windmills can generate electricity. When the brakes are pressed in a hybrid car, the battery is recharged. To cool off the house on a hot day, I run the air conditioner. When my refrigerator is running, I feel warm air being blown on my feet.
Additional Practices Building to the PEs	**Asking Questions and Defining Problems** ● Define a design problem that involves the development of a process or system with interacting components and criteria and constraints that may include social, technical, and/or environmental considerations. Students could *define a design problem that involves the development of a process* [for the] **transfer of energy between systems.**. HS-PS3-1 **Developing and Using Models** ● Develop, revise, and/or use a model based on evidence to illustrate and/or predict the relationships between systems or between components of a system. Student could develop a model to illustrate the relationships between components in a system that **transports energy from one place to another**. HS-PS3-4 **Planning and Carrying Out Investigations** ● Manipulate variables and collect data about a complex model of a proposed process or system to identify failure points or improve performance relative to criteria for success or other variables. Students could *manipulate variables and collect data about a complex model of a system* [in which] **energy is converted to less useful forms—for example, to thermal energy in the surrounding environment** [in order to] *to improve performance relative to criteria for success.* HS-PS3-3 **Analyzing and Interpreting 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. Students could *collect and analyze data from a computational model of the* **energy in a system**, *in order to make valid and reliable scientific claims* [about how] **energy is continually transferred from one object to another and between its various possible forms.** HS-PS3-1

Additional Practices Building to the PEs (Continued)	**Using Mathematics and Computational Thinking** ● Use simple limit cases to test mathematical expressions, computer programs, algorithms, or simulations of a process or system to see if a model "makes sense" by comparing the outcomes with what is known about the real world. Students could *compare the results of an algorithm of* [the amount of] **energy transferred from one object to another within a system** *to what is known about* **energy transfer** [in] *the real world*. HS-PS3-1 **Constructing Explanations and Designing Solutions** ● Apply scientific ideas, principles, and/or evidence to provide an explanation of phenomena and solve design problems, taking into account possible unanticipated effects. Students could *apply evidence about* [the amount of] **energy transferred from one object to another within a system** *to solve design problems*. HS-PS3-1 **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. economic, societal, environmental, ethical considerations). Considering competing design solutions, students could *evaluate the design solutions for their effectiveness using scientific knowledge* [of the] **transfer of thermal energy.** HS-PS3-4 **Obtaining, Evaluating, and Communicating Information** ● Communicate scientific and/or technical information or ideas (e.g. about phenomena and/or the process of development and the design and performance of a proposed process or system) in multiple formats (i.e., orally, graphically, textually, mathematically). Students could *communicate scientific information* [about the way that] **energy is transported from one place to another** *in multiple formats (i.e., orally, graphically, textually, mathematically)*. HS-PS3-4
Additional Crosscutting Concepts Building to the PEs	**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. When evaluating the **energy of a system**, students could describe how they take into account that *energy cannot be created or destroyed*. HS-PS3-1 and HS-PS3-3 **Patterns** ● Mathematical representations are needed to identify some patterns. Students could use *mathematical representations of* [data in order to identify] *patterns* [caused by] **forces** [acting] **at a distance.** HS-PS2-5 **Systems and Systems 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. Students could *define the boundaries and initial conditions of a system* [where] **energy is transported from one place to another** [and then] *analyze the inputs and outputs* [of that system] *using models*. HS-PS3-4

Additional Connections to Nature of Science	**Scientific Phenomena is Based on Empirical Evidence** ● Science knowledge is based on empirical evidence. Students could describe [the use of] *empirical evidence* [to make claims about how] **energy is transported from one place to another**. HS-PS3-4 **Science is a Human Endeavor** ● Technological advances have influenced the progress of science and science has influenced advances in technology. Students could investigate the development of devices made to **transport energy from one place to another** [to find information about how] *technological advances have influenced the progress of science and science has influenced advances in technology.* HS-PS3-4

HS-PS2-5

Students who demonstrate understanding can:

HS-PS2-5. **Plan and conduct an investigation to provide evidence that an electric current can produce a magnetic field and that a changing magnetic field can produce an electric current.** [*Assessment Boundary: Assessment is limited to designing and conducting investigations with provided materials and tools.*]

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

PS2.B: Types of Interactions

- Newton's law of universal gravitation and Coulomb's law provide the mathematical models to describe and predict the effects of gravitational and electrostatic forces between distant objects. (HS-PS2-4)
- Forces at a distance are explained by fields (gravitational, electric, and magnetic) permeating space that can transfer energy through space. Magnets or electric currents cause magnetic fields; electric charges or changing magnetic fields cause electric fields.

PS3.A: Definitions of Energy

- "Electrical energy" may mean energy stored in a battery or energy transmitted by electric currents. *(secondary)*

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	Identifying the phenomenon to be investigated		
	a	Students describe* the phenomenon under investigation, which includes the following idea: that an electric current produces a magnetic field and that a changing magnetic field produces an electric current.	
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 about 1) an observable effect of a magnetic field that is uniquely related to the presence of an electric current in the circuit, and 2) an electric current in the circuit that is uniquely related to the presence of a changing magnetic field near the circuit. Students describe* why these effects seen must be causal and not correlational, citing specific cause-effect relationships.	
3	Planning for the investigation		
	a	In the investigation plan, students include:	
		i.	The use of an electric circuit through which electric current can flow, a source of electrical energy that can be placed in the circuit, the shape and orientation of the wire, and the types and positions of detectors;
		ii.	A means to indicate or measure when electric current is flowing through the circuit;
		iii.	A means to indicate or measure the presence of a local magnetic field near the circuit; and

		iv. A design of a system to change the magnetic field in a nearby circuit and a means to indicate or measure when the magnetic field is changing.
	b	In the plan, students state whether the investigation will be conducted individually or collaboratively.
4	Collecting the data	
	a	Students measure and record electric currents and magnetic fields.
5	Refining the design	
	a	Students evaluate their investigation, including an evaluation of:
		i. The accuracy and precision of the data collected, as well as limitations of the investigation; and
		ii. The ability of the data to provide the evidence required.
	b	If necessary, students refine the investigation plan to produce more accurate, precise, and useful data such that the measurements or indicators of the presence of an electric current in the circuit and a magnetic field near the circuit can provide the required evidence.

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.

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.