High School Conceptual Progressions Model Course II – Bundle 2
Matter and Energy in the Environment

This is the second bundle of the High School Conceptual Progressions Model Course II. Each bundle has connections to the other bundles in the course, as shown in the [Course Flowchart](#).

Bundle 2 Question: This bundle is assembled to address the question "how much is Earth constantly changing?"

Summary

The bundle organizes performance expectations with a focus on helping students understand matter and energy flows in Earth systems. 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

Earth's systems, being dynamic and interacting, cause feedback effects that can increase or decrease changes (ESS2.A as in HS-ESS2-1 and HS-ESS2-2). This concept forms the foundation of the bundle, and connects to the idea that the geological record shows that changes to global and regional climate can be caused by interactions among many different factors, and these changes can occur on a variety of time scales (ESS2.A as in HS-ESS2-4).

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-ESS2-4). This concept connects to the idea that the 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 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 (ESS1.B as in HS-ESS2-4).

Changes to climate caused by volcanic activity (ESS2.A as in HS-ESS2-4) connects to the concepts of plate tectonic movements being responsible for most continental and ocean-floor features and for the distribution of most rocks and minerals within Earth's crust (ESS2.A as in HS-ESS2-1). These ideas also connect to the concept that the abundance of liquid water on Earth's surface and its unique combination of physical and chemical properties—including 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—are central to the planet's dynamics (ESS2.C as in HS-ESS2-5).

The idea that, as Earth evolved, gradual atmospheric changes were due to plants and other organisms that captured carbon dioxide and released oxygen (ESS2.D as in HS-ESS2-6) connects to the concept that changes in the atmosphere due to human activity are increasing carbon dioxide concentrations (ESS2.D as in HS-ESS2-6, HS-ESS2-4). These ideas connect to the concept that chemical elements that make up the molecules of an organism pass through food webs and into and out of the atmosphere and soil, and they are combined and recombined in different ways, and that at each of these transitions in an ecosystem, matter and energy are conserved (LS2.B as in HS-LS2-4).

The engineering design concept that criteria may need to be broken down into simpler ones that can be approached systematically (ETS1.C as in HS-ETS1-2) could be applied to several bundle DCIs, such as that at each link upward in a food web, only a small fraction of the matter consumed at the lower level is transferred upward (LS2.B as in HS-LS2-4) and 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 (ESS2.D as in HS-ESS2-2). Students could make connections through an engineering design task such as creating their own food web and developing the criteria that the highest level of the web needs to be optimized for energy efficiency, and the students could break down each criterion into smaller pieces in order to address them. Alternately, when designing a solution with the criterion that changes the absorption rate of electromagnetic radiation from the sun into the ocean, the students could break down the criterion into smaller pieces in order to address them.

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-ESS2-4, and HS-ESS2-6), planning and conducting investigations (HS-ESS2-5), analyzing data (HS-ESS2-2), and using mathematical thinking (HS-LS2-4). 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); Energy and Matter (HS-LS2-4 and HS-ESS2-6); 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-LS2-4. **Use mathematical representations to support claims for the cycling of matter and flow of energy among organisms in an ecosystem.** [Clarification Statement: Emphasis is on using a mathematical model of stored energy in biomass to describe the transfer of energy from one trophic level to another and that matter and energy are conserved as matter cycles and energy flows through ecosystems. Emphasis is on atoms and molecules such as carbon, oxygen, hydrogen and nitrogen being conserved as they move through an ecosystem.] [Assessment Boundary: Assessment is limited to proportional reasoning to describe the cycling of matter and flow of energy.] 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.] 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-ESS2-4. **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.]

Performance Expectations (Continued)	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-ESS2-6. **Develop a quantitative model to describe the cycling of carbon among the hydrosphere, atmosphere, geosphere, and biosphere.** [Clarification Statement: Emphasis is on modeling biogeochemical cycles that include the cycling of carbon through the ocean, atmosphere, soil, and biosphere (including humans), providing the foundation for living organisms.] 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	Ice forms in the winter, but melts in the spring. The temperature is higher inside cities than in the countryside surrounding them.
Additional Practices Building to the PEs	**Asking Questions and Defining Problems** • Ask questions that arise from examining models or a theory, to clarify and/or seek additional information and relationships. Students could *ask questions to clarify and/or seek additional information* [about how] ***gradual atmospheric changes were due to plants and other organisms that captured carbon dioxide and released oxygen***. HS-ESS2-6 **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 how] ***at each link upward in a food web, only a small fraction of the matter consumed at the lower level is transferred upward***. HS-LS2-4 **Planning and Carrying Out Investigations** • Make directional hypotheses that specify what happens to a dependent variable when an independent variable is manipulated. Students could *make directional hypotheses* [about how] ***changes in the atmosphere due to human activity have increased carbon dioxide concentrations***. HS-ESS2-4 and HS-ESS2-6 **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 when interpreting data* [about] ***feedback effects*** [from one] ***Earth system that increase or decrease changes*** [in another] ***Earth system***. HS-ESS2-1 and HS-ESS2-2

Additional Practices Building to the PEs (Continued)	**Using Mathematical and Computational Thinking** • Apply techniques of algebra and functions to represent and solve scientific and engineering problems. Students could *apply techniques of algebra and functions* [to describe how] ***changes in the atmosphere due to human activity have increased carbon dioxide concentrations***. HS-ESS2-4 and HS-ESS2-6 **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 to link evidence to claims* [about how] ***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***. HS-ESS2-4 **Engaging in Argument from Evidence** • Construct, use, and/or present an oral and written argument or counter-arguments based on data and evidence. Students could *construct a counter-argument based on evidence* [that] ***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***. HS-ESS2-5 **Obtaining, Evaluating, and Communicating Information** • Critically read scientific literature adapted for classroom use to determine the central ideas or conclusions and/or to obtain scientific and/or technical information to summarize complex evidence, concepts, processes, or information presented in a text by paraphrasing them in simpler but still accurate terms. Students could *critically read scientific literature to determine the central ideas* [of how] ***Earth's systems cause feedback effects that can increase or decrease the original changes***. HS-ESS2-1 and HS-ESS2-2
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 *suggesting and predicting the cause and effect relationships* [between] ***the planet's dynamics and the unique physical and chemical properties of liquid water***. HS-ESS2-5 **Scale, Proportion, and Quantity** • The significance of a phenomenon is dependent on the scale, proportion, and quantity at which it occurs. Students could develop and use a model [for how] ***water's properties include its 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*** [and how these properties are] *dependent on the scale, proportion, and quantity at which they occur*. HS-ESS2-5

Additional Crosscutting Concepts Building to the PEs (Continued)	**Stability and Change** • Much of science deals with constructing explanations of how things change and how they remain stable. Students could construct an argument for how *much of science deals with constructing explanations of how things change and how they remain stable,* [including as evidence that scientists study] ***interactions among changes in the sun's energy output or Earth's orbit, tectonic events, ocean circulation, volcanic activity, glaciers, vegetation, and human activities***. HS-ESS2-4
Additional Connections to Nature of Science	**Scientific Knowledge is Open to Revision in Light of New Evidence (SEP):** • Scientific argumentation is a mode of logical discourse used to clarify the strength of relationships between ideas and evidence that may result in revision of an explanation. Students could describe evidence that *scientific argumentation is a mode of logical discourse used to clarify the strength of relationships between ideas and evidence,* [including about how] ***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***. HS-ESS2-4 **Scientific Knowledge Assumes an Order and Consistency in Natural Systems (CCC):** • Science assumes the universe is a vast single system in which basic laws are consistent. Students could ask questions about how the principle that *science assumes the universe is a vast single system in which basic laws are consistent* [affects our understanding of] ***interactions among changes in the sun's energy output or Earth's orbit, tectonic events, ocean circulation, volcanic activity, glaciers, vegetation, and human activities.*** HS-ESS2-4

HS-LS2-4

Students who demonstrate understanding can:

HS-LS2-4. **Use mathematical representations to support claims for the cycling of matter and flow of energy among organisms in an ecosystem.** [Clarification Statement: Emphasis is on using a mathematical model of stored energy in biomass to describe the transfer of energy from one trophic level to another and that matter and energy are conserved as matter cycles and energy flows through ecosystems. Emphasis is on atoms and molecules such as carbon, oxygen, hydrogen and nitrogen being conserved as they move through an ecosystem.] [*Assessment Boundary: Assessment is limited to proportional reasoning to describe the cycling of matter and flow of energy.*]

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
Using Mathematical and Computational Thinking Mathematical and computational thinking in 9-12 builds on K-8 experiences 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 or design solutions to support claims.	**LS2.B: Cycles of Matter and Energy Transfer in Ecosystems** • Plants or algae form the lowest level of the food web. At each link upward in a food web, only a small fraction of the matter consumed at the lower level is transferred upward, to produce growth and release energy in cellular respiration at the higher level. Given this inefficiency, there are generally fewer organisms at higher levels of a food web. Some matter reacts to release energy for life functions, some matter is stored in newly made structures, and much is discarded. The chemical elements that make up the molecules of organisms pass through food webs and into and out of the atmosphere and soil, and they are combined and recombined in different ways. At each link in an ecosystem, matter and energy are conserved.	**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	Representation	
	a	Students identify and describe* the components in the mathematical representations that are relevant to supporting the claims. The components could include relative quantities related to organisms, matter, energy, and the food web in an ecosystem.
	b	Students identify the claims about the cycling of matter and energy flow among organisms in an ecosystem.
2	Mathematical modeling	
	a	Students describe* how the claims can be expressed as a mathematical relationship in the mathematical representations of the components of an ecosystem
	b	Students use the mathematical representation(s) of the food web to:
		i. Describe* the transfer of matter (as atoms and molecules) and flow of energy upward between organisms and their environment;

		ii. Identify the transfer of energy and matter between tropic levels; and
		iii. Identify the relative proportion of organisms at each trophic level by correctly identifying producers as the lowest trophic level having the greatest biomass and energy and consumers decreasing in numbers at higher trophic levels.
3	Analysis	
	a	Students use the mathematical representation(s) to support the claims that include the idea that matter flows between organisms and their environment.
	b	Students use the mathematical representation(s) to support the claims that include the idea that energy flows from one trophic level to another as well as through the environment.
	c	Students analyze and use the mathematical representation(s) to account for the energy not transferred to higher trophic levels but which is instead used for growth, maintenance, or repair, and/or transferred to the environment, and the inefficiencies in transfer of matter and energy.

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	Disciplinary Core Ideas	Crosscutting Concepts
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.	**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)*	**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-ESS2-4

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.

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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-ESS2-6

Students who demonstrate understanding can:

HS-ESS2-6. **Develop a quantitative model to describe the cycling of carbon among the hydrosphere, atmosphere, geosphere, and biosphere.** [Clarification Statement: Emphasis is on modeling biogeochemical cycles that include the cycling of carbon through the ocean, atmosphere, soil, and biosphere (including humans), providing the foundation for living organisms.]

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 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.	**ESS2.D: Weather and Climate** • Gradual atmospheric changes were due to plants and other organisms that captured carbon dioxide and released oxygen. • Changes in the atmosphere due to human activity have increased carbon dioxide concentrations and thus affect climate.	**Energy and Matter** • The total amount of energy and matter in closed systems is conserved.

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:	
		i.	Identify the relative concentrations of carbon present in the hydrosphere, atmosphere, geosphere and biosphere; and
		ii.	Represent carbon cycling from one sphere to another.
2	Relationships		
	a	In the model, students represent and describe* the following relationships between components of the system, including:	
		i.	The biogeochemical cycles that occur as carbon flows from one sphere to another;
		ii.	The relative amount of and the rate at which carbon is transferred between spheres;
		iii.	The capture of carbon dioxide by plants; and
		iv.	The increase in carbon dioxide concentration in the atmosphere due to human activity and the effect on climate.
3	Connections		
	a	Students use the model to explicitly identify the conservation of matter as carbon cycles through various components of Earth's systems.	
	b	Students identify the limitations of the model in accounting for all of Earth's carbon.	

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.