NEXT GENERATION SCIENCE STANDARDS

**Unless otherwise specified, "descriptions" referenced in the evidence statements could include but are not limited to written, oral, pictorial, and kinesthetic descriptions.*

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-ESS2-3

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.

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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.

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Connections to Engineering, Technology, and Applications of Science

Interdependence of Science, Engineering, and Technology

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

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

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

HS-ESS2-4

Students who demonstrate understanding can:

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

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

Science and Engineering Practices

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

- Use a model to provide mechanistic accounts of phenomena.

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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

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

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

Disciplinary Core Ideas

ESS2.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.

Crosscutting Concepts

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-ESS2-7

Students who demonstrate understanding can:

HS-ESS2-7. **Construct an argument based on evidence about the simultaneous coevolution of Earth's systems and life on Earth.** [Clarification Statement: Emphasis is on the dynamic causes, effects, and feedbacks between the biosphere and Earth's other systems, whereby geoscience factors control the evolution of life, which in turn continuously alters Earth's surface. Examples include how photosynthetic life altered the atmosphere through the production of oxygen, which in turn increased weathering rates and allowed for the evolution of animal life; how microbial life on land increased the formation of soil, which in turn allowed for the evolution of land plants; or how the evolution of corals created reefs that altered patterns of erosion and deposition along coastlines and provided habitats for the evolution of new life forms.] [*Assessment Boundary: Assessment does not include a comprehensive understanding of the mechanisms of how the biosphere interacts with all of Earth's other systems.*]

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

Science and Engineering Practices

Engaging in Argument from Evidence
Engaging in argument from evidence in 9–12 builds on K–8 experiences and progresses to using appropriate and sufficient evidence and scientific reasoning to defend and critique claims and explanations about the natural and designed world(s). Arguments may also come from current scientific or historical episodes in science.

- Construct an oral and written argument or counter-arguments based on data and evidence.

Disciplinary Core Ideas

ESS2.D: Weather and Climate

- Gradual atmospheric changes were due to plants and other organisms that captured carbon dioxide and released oxygen.

ESS2.E Biogeology

- The many dynamic and delicate feedbacks between the biosphere and other Earth systems cause a continual coevolution of Earth's surface and the life that exists on it.

Crosscutting Concepts

Stability and Change

- Much of science deals with constructing explanations of how things change and how they remain stable.

Observable features of the student performance by the end of the course:			
1	Developing the claim		
	a	Students develop a claim, which includes the following idea: that there is simultaneous coevolution of Earth's systems and life on Earth. This claim is supported by generalizing from multiple sources of evidence.	
2	Identifying scientific evidence		
	a	Students identify and describe* evidence supporting the claim, including:	
		i.	Scientific explanations about the composition of Earth's atmosphere shortly after its formation;
		ii.	Current atmospheric composition;
		iii.	Evidence for the emergence of photosynthetic organisms;
		iv.	Evidence for the effect of the presence of free oxygen on evolution and processes in other Earth systems;
		v.	In the context of the selected example(s), other evidence that changes in the biosphere affect other Earth systems.
3	Evaluating and critiquing		
	a	Students evaluate the evidence and include the following in their evaluation:	

		i.	A statement regarding how variation or uncertainty in the data (e.g., limitations, low signal-to-noise ratio, collection bias, etc.) may affect the usefulness of the data as sources of evidence; and
		ii.	The ability of the data to be used to determine causal or correlational effects between changes in the biosphere and changes in Earth's other systems.
4	Reasoning and synthesis		
	a	Students use at least two examples to construct oral and written logical arguments. The examples:	
		i.	Include that the evolution of photosynthetic organisms led to a drastic change in Earth's atmosphere and oceans in which the free oxygen produced caused worldwide deposition of iron oxide formations, increased weathering due to an oxidizing atmosphere and the evolution of animal life that depends on oxygen for respiration; and
		ii.	Identify causal links and feedback mechanisms between changes in the biosphere and changes in Earth's other systems.