Middle School Topics Model Course III – Bundle 4
Changing Earth

This is the fourth bundle of the Middle School Topics Model Course III. Each bundle has connections to the other bundles in the course, as shown in the [Course Flowchart].

Bundle 1 Question: This bundle is assembled to address the question "What has the history of Earth looked like?"

Summary

The bundle organizes performance expectations with a focus on helping students build understanding of how Earth has evolved over time. Instruction developed from this bundle should always maintain the three-dimensional nature of the standards, and is not limited to the practices and concepts directly linked with any of the bundle performance expectations.

Connections between bundle DCIs

Earth and its solar system are part of the Milky Way galaxy, which is one of many galaxies in the universe (ESS1.A as in MS-ESS1-2). The solar system consists of the sun and a collection of objects, including planets, their moons, and asteroids that are held in orbit around the sun by its gravitational pull on them (ESS1.B as in MS-ESS1-2, MS-ESS1-3). Models of the solar system can be used to explain patterns of the apparent motion of the sun, the moon, and stars in the sky (ESS1.A as in MS-ESS1-1) including eclipses of the sun and the moon, the Earth's spin axis, and seasons (ESS1.B as in MS-ESS1-1).

Earth and its solar system appear to have been formed from a disk of dust and gas, drawn together by gravity (ESS1.B as in MS-ESS1-2). The geologic time scale interpreted from rock strata provides a way to organize Earth's history, including its formation and the fossil record (ESS1.C as in MS-ESS1-4). The fossil record documents the existence, diversity, extinction, and change of many life forms throughout the history of life on Earth (LS4.A as in MS-LS4-1). Similarities and differences between various organisms living today and between them and organisms in the fossil record, enable the reconstruction of evolutionary history and the inference of lines of evolutionary descent (LS4.A as in MS-LS4-2).

Earth is still changing today, and as human populations and per-capita consumption of natural resources increase, so do the negative impacts on Earth unless the activities and technologies involved are engineered otherwise (ESS3.C as in MS-ESS3-4). The engineering design ideas that there are systematic processes for evaluating solutions with respect to how well they meet the criteria and constraints of a problem (ETS1.B as in MS-ETS1-3) and that identifying the characteristics of the design that performed the best in each test can provide useful information for the new design (ETS1.C as in MS-ETS1-3) could connect to many different science ideas, such as that seasons are caused by the differential intensity of sunlight on different areas of Earth across the year (ESS1.B as in MS-ESS1-1), or that as human populations and per-capita consumption of natural resources increase, so do the negative impacts on Earth (ESS3.C as in MS-ESS3-4). Connections could be made through evaluating solutions such as how to maximize energy capture of solar cells, maximize photosynthesis for plants based on the angle of a greenhouse roof, decrease the amount of human garbage that is generated each year, or develop alternative sources of energy to minimize the negative impacts on Earth.

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 (MS-ESS1-1 and MS-ESS1-2); analyzing and interpreting data (MS-LS4-1, MS-ESS1-3, and MS-ETS1-3); constructing explanations (MS-LS4-2 and MS-ESS1-4); and engaging in argument (MS-ESS3-4). 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 Patterns (MS-LS4-2, MS-LS4-1, and MS-ESS1-1); Cause and Effect (MS-ESS3-4); Scale, Proportion, and Quantity (MS-ESS1-3 and MS-ESS1-4); and Systems and System Models (MS-ESS1-2). Many other crosscutting concept elements can be used in instruction.

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All instruction should be three-dimensional.	
Performance Expectations MS-LS4-1 and MS-LS4-2 are partially assessable.	MS-LS4-1. **Analyze and interpret data for patterns in the fossil record that document the existence, diversity, extinction, and change of life forms throughout the history of life on Earth under the assumption that natural laws operate today as in the past.** [Clarification Statement: Emphasis is on finding patterns of changes in the level of complexity of anatomical structures in organisms and the chronological order of fossil appearance in the rock layers.] [Assessment Boundary: Assessment does not include the names of individual species or geological eras in the fossil record.] MS-LS4-2. **Apply scientific ideas to construct an explanation for the anatomical similarities and differences among modern organisms and between modern and fossil organisms to infer evolutionary relationships.** [Clarification Statement: Emphasis is on explanations of the evolutionary relationships among organisms in terms of similarity or differences of the gross appearance of anatomical structures.] MS-ESS1-1. **Develop and use a model of the Earth-sun-moon system to describe the cyclic patterns of lunar phases, eclipses of the sun and moon, and seasons.** [Clarification Statement: Examples of models can be physical, graphical, or conceptual.] MS-ESS1-2. **Develop and use a model to describe the role of gravity in the motions within galaxies and the solar system.** [Clarification Statement: Emphasis for the model is on gravity as the force that holds together the solar system and Milky Way galaxy and controls orbital motions within them. Examples of models can be physical (such as the analogy of distance along a football field or computer visualizations of elliptical orbits) or conceptual (such as mathematical proportions relative to the size of familiar objects such as students' school or state).] [Assessment Boundary: Assessment does not include Kepler's Laws of orbital motion or the apparent retrograde motion of the planets as viewed from Earth.] MS-ESS1-3. **Analyze and interpret data to determine scale properties of objects in the solar system.** [Clarification Statement: Emphasis is on the analysis of data from Earth-based instruments, space-based telescopes, and spacecraft to determine similarities and differences among solar system objects. Examples of scale properties include the sizes of an object's layers (such as crust and atmosphere), surface features (such as volcanoes), and orbital radius. Examples of data include statistical information, drawings and photographs, and models.] [Assessment Boundary: Assessment does not include recalling facts about properties of the planets and other solar system bodies.] MS-ESS1-4. **Construct a scientific explanation based on evidence from rock strata for how the geologic time scale is used to organize Earth's 4.6-billion-year-old history.** [Clarification Statement: Emphasis is on how analyses of rock formations and the fossils they contain are used to establish relative ages of major events in Earth's history. Examples of Earth's major events could range from being very recent (such as the last Ice Age or the earliest fossils of homo sapiens) to very old (such as the formation of Earth or the earliest evidence of life). Examples can include the formation of mountain chains and ocean basins, the evolution or extinction of particular living organisms, or significant volcanic eruptions.] [Assessment Boundary: Assessment does not include recalling the names of specific periods or epochs and events within them.] MS-ESS3-4. **Construct an argument supported by evidence for how increases in human population and per-capita consumption of natural resources impact Earth's systems.** [Clarification Statement: Examples of evidence include grade-appropriate databases on human populations and the rates of consumption of food and natural resources (such as freshwater, mineral, and energy). Examples of impacts can include changes to the appearance, composition, and structure of Earth's systems as well as the rates at which they change. The consequences of increases in human populations and consumption of natural resources are described by science, but science does not make the decisions for the actions society takes.] MS-ETS1-3. **Analyze data from tests to determine similarities and differences among several design solutions to identify the best characteristics of each that can be combined into a new solution to better meet the criteria for success.**
Example Phenomena	The island of Surtsey was formed in 1963 after a volcanic eruption from beneath the sea. Dinosaurs don't roam the Earth today.

Additional Practices Building to the PEs	**Asking Questions and Defining Problems** • Ask questions to identify and/or clarify evidence and/or the premise(s) of an argument. Students could *ask questions to identify evidence* [that] ***the fossil record documents the existence, diversity, extinction, and change of many life forms throughout the history of life on Earth***. MS-LS4-1 **Developing and Using Models** • Develop a model to describe unobservable mechanisms. Students could *develop a model to describe* [that] ***typically as human populations and per-capita consumption of natural resources increase, so do the negative impacts on Earth***. MS-ESS3-4 **Planning and Carrying Out Investigations** • Evaluate the accuracy of various methods for collecting data. Students could *evaluate the accuracy of various methods for collecting data* [on the effects of] ***gravity*** [on the] ***formation*** [of] ***the solar system***. MS-ESS1-2 **Analyzing and Interpreting Data** • Distinguish between causal and correlational relationships in data. Students could *distinguish between causal and correlational relationships in data* [on] ***the increase of per-capita consumption of natural resources and the increase of negative impacts on Earth***. MS-ESS3-4 **Using Mathematical and Computational Thinking** • Use mathematical representations to describe and/or support scientific conclusions and design solutions. Students could *use mathematical representations to support scientific conclusions* [about how] ***the seasons are caused by the differential intensity of sunlight on different areas of Earth across the year***. MS-ESS1-1 **Constructing Explanations and Designing Solutions** • Construct an explanation using models or representations. Students could *construct an explanation using models or representations* [of how] ***the seasons are a result of the Earth's tilt relative to its orbit around the sun***. MS-ESS1-1 **Engaging in Argument from Evidence** • Compare and critique two arguments on the same topic and analyze whether they emphasize similar or different evidence and/or interpretation of facts. Students could *critique two arguments and analyze whether they emphasize similar or different evidence* [about] ***anatomical similarities and differences between various organisms living today and organisms in the fossil record.*** MS-LS4-2

Additional Practices Building to the PEs (Continued)	**Obtaining, Evaluating, and Communicating Information** • Critically read scientific texts adapted for classroom use to determine the central ideas and/or obtain scientific and/or technical information to describe patterns in and/or evidence about the natural and designed world(s). Students could *critically read texts to obtain scientific information* [about why scientists think that] ***the solar system consists of the sun and a collection of objects including planets, their moons, and asteroids that are held in orbit around the sun by its gravitational pull on them***. MS-ESS1-2 and MS-ESS1-3
Additional Crosscutting Concepts Building to the PEs	**Systems and System Models** • Systems may interact with other systems; they may have sub-systems and be a part of larger complex systems. Students could obtain and evaluate information about ***the Milky Way galaxy,*** [including that it] *may interact with other systems* [as well as] *have* [interacting] *sub-systems*. MS-ESS1-2 **Structure and Function** • Complex and microscopic structures and systems can be visualized, modeled, and used to describe how their function depends on the shapes, composition, and relationships among its parts; therefore, complex natural and designed structures/systems can be analyzed to determine how they function. Students could construct an explanation *to describe how the structure of* ***the solar system*** *can be analyzed to determine how it functions*. MS-ESS1-1 **Stability and Change** • Stability might be disturbed either by sudden events or gradual changes that accumulate over time. Students could obtain, evaluate, and communicate information for how the *stability* [of Earth's systems] *might be disturbed either by sudden events or by gradual changes that accumulate over time* [when either] ***human populations*** [or] ***per-capita consumption of natural resources increase***. MS-ESS3-4
Additional Connections to Nature of Science	**Scientific Knowledge is Open to Revision in Light of New Evidence** • Scientific explanations are subject to revision and improvement in light of new evidence. Students could evaluate and communicate information about why *scientific explanations,* [such as that] ***solar system objects are held in orbit around the sun by its gravitational pull on them,*** *are subject to revision and improvement in light of new evidence*. MS-ESS1-2 and MS-ESS1-3 **Science is a Human Endeavor** • Scientists and engineers rely on human qualities such as persistence, precision, reasoning, logic, imagination and creativity. Students could construct an argument for why *scientists have relied on human qualities such as persistence, precision, reasoning, logic, imagination and creativity* [to help them explain] ***patterns of the apparent motion of the sun***. MS-ESS1-1

MS-LS4-1 Biological Evolution: Unity and Diversity

Students who demonstrate understanding can:

MS-LS4-1. Analyze and interpret data for patterns in the fossil record that document the existence, diversity, extinction, and change of life forms throughout the history of life on Earth under the assumption that natural laws operate today as in the past. [Clarification Statement: Emphasis is on finding patterns of changes in the level of complexity of anatomical structures in organisms and the chronological order of fossil appearance in the rock layers.] [Assessment Boundary: Assessment does not include the names of individual species or geological eras in the fossil record.]

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

Science and Engineering Practices

Analyzing and Interpreting Data
Analyzing data in 6–8 builds on K–5 experiences and progresses to extending quantitative analysis to investigations, distinguishing between correlation and causation, and basic statistical techniques of data and error analysis.

- Analyze and interpret data to determine similarities and differences in findings.

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Connections to Nature of Science

Scientific Knowledge is Based on Empirical Evidence

- Science knowledge is based upon logical and conceptual connections between evidence and explanations.

Disciplinary Core Ideas

LS4.A: Evidence of Common Ancestry and Diversity

- The collection of fossils and their placement in chronological order (e.g., through the location of the sedimentary layers in which they are found or through radioactive dating) is known as the fossil record. It documents the existence, diversity, extinction, and change of many life forms throughout the history of life on Earth.

Crosscutting Concepts

Patterns

- Graphs, charts, and images can be used to identify patterns in data.

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Connections to Nature of Science

Scientific Knowledge Assumes an Order and Consistency in Natural Systems

- Science assumes that objects and events in natural systems occur in consistent patterns that are understandable through measurement and observation.

Observable features of the student performance by the end of the course:			
1	Organizing data		
	a	Students organize the given data (e.g., using tables, graphs, charts, images), including the appearance of specific types of fossilized organisms in the fossil record as a function of time, as determined by their locations in the sedimentary layers or the ages of rocks.	
	b	Students organize the data in a way that allows for the identification, analysis, and interpretation of similarities and differences in the data.	
2	Identifying relationships		
	a	Students identify:	
		i.	Patterns between any given set of sedimentary layers and the relative ages of those layers.
		ii.	The time period(s) during which a given fossil organism is present in the fossil record.
		iii.	Periods of time for which changes in the presence or absence of large numbers of organisms or specific types of organisms can be observed in the fossil record (e.g., a fossil layer with very few organisms immediately next to a fossil layer with many types of organisms).
		iv.	Patterns of changes in the level of complexity of anatomical structures in organisms in the fossil record, as a function of time.
3	Interpreting data		
	a	Students analyze and interpret the data to determine evidence for the existence, diversity, extinction, and change in life forms throughout the history of Earth, using the assumption that natural laws operate today as they would have in the past. Students use similarities and differences in the observed patterns to provide evidence for:	
		i.	When mass extinctions occurred.
		ii.	When organisms or types of organisms emerged, went extinct, or evolved.
		iii.	The long-term increase in the diversity and complexity of organisms on Earth.

MS-LS4-2 Biological Evolution: Unity and Diversity

Students who demonstrate understanding can:

MS-LS4-2. Apply scientific ideas to construct an explanation for the anatomical similarities and differences among modern organisms and between modern and fossil organisms to infer evolutionary relationships. [Clarification Statement: Emphasis is on explanations of the evolutionary relationships among organisms in terms of similarity or differences of the gross appearance of anatomical structures.]

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

Science and Engineering Practices

Constructing Explanations and Designing Solutions

Constructing explanations and designing solutions in 6–8 builds on K–5 experiences and progresses to include constructing explanations and designing solutions supported by multiple sources of evidence consistent with scientific ideas, principles, and theories.

- Apply scientific ideas to construct an explanation for real-world phenomena, examples, or events.

Disciplinary Core Ideas

LS4.A: Evidence of Common Ancestry and Diversity

- Anatomical similarities and differences between various organisms living today and between them and organisms in the fossil record, enable the reconstruction of evolutionary history and the inference of lines of evolutionary descent.

Crosscutting Concepts

Patterns

- Patterns can be used to identify cause and effect relationships.

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Connections to Nature of Science

Scientific Knowledge Assumes an Order and Consistency in Natural Systems

- Science assumes that objects and events in natural systems occur in consistent patterns that are understandable through measurement and observation.

Observable features of the student performance by the end of the course:		
1	Articulating the explanation of phenomena	
	a	Students articulate a statement that relates a given phenomenon to scientific ideas, including the following ideas about similarities and differences in organisms and their evolutionary relationships:
		i. Anatomical similarities and differences among organisms can be used to infer evolutionary relationships, including:
		1. Among modern organisms.
		2. Between modern and fossil organisms.
	b	Students use evidence and reasoning to construct an explanation for the given phenomenon.
2	Evidence	
	a	Students identify and describe* evidence (e.g., from students' own investigations, observations, reading material, archived data, simulations) necessary for constructing the explanation, including similarities and differences in anatomical patterns in and between:
		i. Modern, living organisms (e.g., skulls of modern crocodiles, skeletons of birds; features of modern whales and elephants).
		ii. Fossilized organisms (e.g., skulls of fossilized crocodiles, fossilized dinosaurs).
3	Reasoning	
	a	Students use reasoning to connect the evidence to support an explanation. Students describe* the following chain of reasoning for the explanation:
		i. Organisms that share a pattern of anatomical features are likely to be more closely related than are organisms that do not share a pattern of anatomical features, due to the cause-and-effect relationship between genetic makeup and anatomy (e.g., although birds and insects both have wings, the organisms are structurally very different and not very closely related; the wings of birds and bats are structurally similar, and the organisms are more closely related; the limbs of horses and zebras are structurally very similar, and they are more closely related than are birds and bats or birds and insects).
		ii. Changes over time in the anatomical features observable in the fossil record can be used to infer lines of evolutionary descent by linking extinct organisms to living organisms through a series of fossilized organisms that share a basic set of anatomical features.

MS-ESS1-1 Earth's Place in the Universe

Students who demonstrate understanding can:

MS-ESS1-1. Develop and use a model of the Earth-sun-moon system to describe the cyclic patterns of lunar phases, eclipses of the sun and moon, and seasons. [Clarification Statement: Examples of models can be physical, graphical, or conceptual.]

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

Science and Engineering Practices

Developing and Using Models
Modeling in 6–8 builds on K–5 experiences and progresses to developing, using, and revising models to describe, test, and predict more abstract phenomena and design systems.

- Develop and use a model to describe phenomena.

Disciplinary Core Ideas

ESS1.A: The Universe and Its Stars

- Patterns of the apparent motion of the sun, the moon, and stars in the sky can be observed, described, predicted, and explained with models.

ESS1.B: Earth and the Solar System

- This model of the solar system can explain eclipses of the sun and the moon. Earth's spin axis is fixed in direction over the short-term but tilted relative to its orbit around the sun. The seasons are a result of that tilt and are caused by the differential intensity of sunlight on different areas of Earth across the year.

Crosscutting Concepts

Patterns

- Patterns can be used to identify cause-and-effect relationships.

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Connections to Nature of Science

Scientific Knowledge Assumes an Order and Consistency in Natural Systems

- Science assumes that objects and events in natural systems occur in consistent patterns that are understandable through measurement and observation.

Observable features of the student performance by the end of the course:			
1	Components of the model		
	a	To make sense of a given phenomenon involving, students develop a model (e.g., physical, conceptual, graphical) of the Earth-moon-sun system in which they identify the relevant components, including:	
		i.	Earth, including the tilt of its axis of rotation.
		ii.	Sun.
		iii.	Moon.
		iv.	Solar energy.
	b	Students indicate the accuracy of size and distance (scale) relationships within the model, including any scale limitations within the model.	
2	Relationships		
	a	In their model, students describe* the relationships between components, including:	
		i.	Earth rotates on its tilted axis once an Earth day.
		ii.	The moon rotates on its axis approximately once a month.
		iii.	Relationships between Earth and the moon:
			1. The moon orbits Earth approximately once a month.
			2. The moon rotates on its axis at the same rate at which it orbits Earth so that the side of the moon that faces Earth remains the same as it orbits.
			3. The moon's orbital plane is tilted with respect to the plane of the Earth's orbit around the sun.
		iv.	Relationships between the Earth-moon system and the sun:
			1. Earth-moon system orbits the sun once an Earth year.

		2. Solar energy travels in a straight line from the sun to Earth and the moon so that the side of Earth or the moon that faces the sun is illuminated.
		3. Solar energy reflects off of the side of the moon that faces the sun and can travel to Earth.
		4. The distance between Earth and the sun stays relatively constant throughout the Earth's orbit.
		5. Solar energy travels in a straight line from the sun and hits different parts of the curved Earth at different angles — more directly at the equator and less directly at the poles.
		6. The Earth's rotation axis is tilted with respect to its orbital plane around the sun. Earth maintains the same relative orientation in space, with its North Pole pointed toward the North Star throughout its orbit.
3	Connections	
	a	Students use patterns observed from their model to provide causal accounts for events, including:
		i. Moon phases:
		1. Solar energy coming from the sun bounces off of the moon and is viewed on Earth as the bright part of the moon.
		2. The visible proportion of the illuminated part of the moon (as viewed from Earth) changes over the course of a month as the location of the moon relative to Earth and the sun changes.
		3. The moon appears to become more fully illuminated until "full" and then less fully illuminated until dark, or "new," in a pattern of change that corresponds to what proportion of the illuminated part of the moon is visible from Earth.
		ii. Eclipses:
		1. Solar energy is prevented from reaching the Earth during a solar eclipse because the moon is located between the sun and Earth.
		2. Solar energy is prevented from reaching the moon (and thus reflecting off of the moon to Earth) during a lunar eclipse because Earth is located between the sun and moon.
		3. Because the moon's orbital plane is tilted with respect to the plane of the Earth's orbit around the sun, for a majority of time during an Earth month, the moon is not in a position to block solar energy from reaching Earth, and Earth is not in a position to block solar energy from reaching the moon.
		iii. Seasons:
		1. Because the Earth's axis is tilted, the most direct and intense solar energy occurs over the summer months, and the least direct and intense solar energy occurs over the winter months.
		2. The change in season at a given place on Earth is directly related to the orientation of the tilted Earth and the position of Earth in its orbit around the sun because of the change in the directness and intensity of the solar energy at that place over the course of the year.
		a. Summer occurs in the Northern Hemisphere at times in the Earth's orbit when the northern axis of Earth is tilted toward the sun. Summer occurs in the Southern Hemisphere at times in the Earth's orbit when the southern axis of Earth is tilted toward the sun.
		b. Winter occurs in the Northern Hemisphere at times in the Earth's orbit when the northern axis of Earth is tilted away from the sun. Summer occurs in the Southern Hemisphere at times in the Earth's orbit when the southern axis of Earth is tilted away from the sun.
	b	Students use their model to predict:
		i. The phase of the moon when given the relative locations of the Earth, sun, and moon.
		ii. The relative positions of the Earth, sun, and moon when given a moon phase.
		iii. Whether an eclipse will occur, given the relative locations of the Earth, sun, and moon and a position on Earth from which the moon or sun can be viewed (depending on the type of eclipse).
		iv. The relative positions of the Earth, sun, and moon, given a type of eclipse and a position on Earth from which the moon/sun can be viewed.

		v.	The season on Earth, given the relative positions of Earth and the sun (including the orientation of the Earth’s axis) and a position on Earth.
		vi.	The relative positions of Earth and the sun when given a season and a relative position (e.g. far north, far south, equatorial) on Earth.

MS-ESS1-2 Earth's Place in the Universe

Students who demonstrate understanding can:

MS-ESS1-2. Develop and use a model to describe the role of gravity in the motions within galaxies and the solar system. [Clarification Statement: Emphasis for the model is on gravity as the force that holds together the solar system and Milky Way galaxy and controls orbital motions within them. Examples of models can be physical (such as the analogy of distance along a football field or computer visualizations of elliptical orbits) or conceptual (such as mathematical proportions relative to the size of familiar objects such as students' school or state).] [*Assessment Boundary: Assessment does not include Kepler's Laws of orbital motion or the apparent retrograde motion of the planets as viewed from Earth.*]

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

Science and Engineering Practices

Developing and Using Models
Modeling in 6–8 builds on K–5 experiences and progresses to developing, using, and revising models to describe, test, and predict more abstract phenomena and design systems.

- Develop and use a model to describe phenomena.

Disciplinary Core Ideas

ESS1.A: The Universe and Its Stars

- Earth and its solar system are part of the Milky Way galaxy, which is one of many galaxies in the universe.

ESS1.B: Earth and the Solar System

- The solar system consists of the sun and a collection of objects, including planets, their moons, and asteroids that are held in orbit around the sun by its gravitational pull on them.
- The solar system appears to have formed from a disk of dust and gas, drawn together by gravity.

Crosscutting Concepts

Systems and System Models

- Models can be used to represent systems and their interactions.

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Connections to Nature of Science

Scientific Knowledge Assumes an Order and Consistency in Natural Systems

- Science assumes that objects and events in natural systems occur in consistent patterns that are understandable through measurement and observation.

Observable features of the student performance by the end of the course:			
1	Components of the model		
	a	To make sense of a given phenomenon, students develop a model in which they identify the relevant components of the system, including:	
		i.	Gravity.
		ii.	The solar system as a collection of bodies, including the sun, planets, moons, and asteroids.
		iii.	The Milky Way galaxy as a collection of stars (e.g., the sun) and their associated systems of objects.
		iv.	Other galaxies in the universe
	b	Students indicate the relative spatial scales of solar systems and galaxies in the model.	
2	Relationships		
	a	Students describe* the relationships and interactions between components of the solar and galaxy systems, including:	
		i.	Gravity as an attractive force between solar system and galaxy objects that:
			1. Increases with the mass of the interacting objects increases.
			2. Decreases as the distances between objects increases.
		ii.	The orbital motion of objects in our solar system (e.g., moons orbit around planets, all objects within the solar system orbit the sun).
		iii.	The orbital motion, in the form of a disk, of vast numbers of stars around the center of the Milky Way.
		iv.	That our solar system is one of many systems orbiting the center of the larger system of the Milky Way galaxy.

		v. The Milky Way is one of many galaxy systems in the universe.
3	Connections	
	a	Students use the model to describe* that gravity is a predominantly inward-pulling force that can keep smaller/less massive objects in orbit around larger/more massive objects.
	b	Students use the model to describe* that gravity causes a pattern of smaller/less massive objects orbiting around larger/more massive objects at all system scales in the universe, including that:
		i. Gravitational forces from planets cause smaller objects (e.g., moons) to orbit around planets.
		ii. The gravitational force of the sun causes the planets and other bodies to orbit around it, holding the solar system together.
		iii. The gravitational forces from the center of the Milky Way cause stars and stellar systems to orbit around the center of the galaxy.
		iv. The hierarchy pattern of orbiting systems in the solar system was established early in its history as the disk of dust and gas was driven by gravitational forces to form moon-planet and planet-sun orbiting systems.
	c	Students use the model to describe* that objects too far away from the sun do not orbit it because the sun's gravitational force on those objects is too weak to pull them into orbit.
	d	Students use the model to describe* what a given phenomenon might look like without gravity (e.g., smaller planets would move in straight paths through space, rather than orbiting a more massive body).

MS-ESS1-3 Earth's Place in the Universe

Students who demonstrate understanding can:

MS-ESS1-3. **Analyze and interpret data to determine scale properties of objects in the solar system.** [Clarification Statement: Emphasis is on the analysis of data from Earth-based instruments, space-based telescopes, and spacecraft to determine similarities and differences among solar system objects. Examples of scale properties include the sizes of an object's layers (such as crust and atmosphere), surface features (such as volcanoes), and orbital radius. Examples of data include statistical information, drawings and photographs, and models.] [*Assessment Boundary: Assessment does not include recalling facts about properties of the planets and other solar system bodies.*]

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

Science and Engineering Practices

Analyzing and Interpreting Data
Analyzing data in 6–8 builds on K–5 experiences and progresses to extending quantitative analysis to investigations, distinguishing between correlation and causation, and basic statistical techniques of data and error analysis.

- Analyze and interpret data to determine similarities and differences in findings.

Disciplinary Core Ideas

ESS1.B: Earth and the Solar System

- The solar system consists of the sun and a collection of objects, including planets, their moons, and asteroids that are held in orbit around the sun by its gravitational pull on them.

Crosscutting Concepts

Scale, Proportion, and Quantity

- Time, space, and energy phenomena can be observed at various scales using models to study systems that are too large or too small.

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Connections to Engineering,Technology, and Applications of Science

Interdependence of Science, Engineering, and Technology

- Engineering advances have led to important discoveries in virtually every field of science and scientific discoveries have led to the development of entire industries and engineered systems.

Observable features of the student performance by the end of the course:			
1	Organizing data		
	a	Students organize given data on solar system objects (e.g., surface features, object layers, orbital radii) from various Earth- and space-based instruments to allow for analysis and interpretation (e.g., transforming tabular data into pictures, diagrams, graphs, or physical models that illustrate changes in scale).	
	b	Students describe* that different representations illustrate different characteristics of objects in the solar system, including differences in scale.	
2	Identifying relationships		
	a	Students use quantitative analyses to describe* similarities and differences among solar system objects by describing* patterns of features of those objects at different scales, including:	
		i.	Distance from the sun.
		ii.	Diameter.
		iii.	Surface features (e.g., sizes of volcanoes).
		iv.	Structure.
		v.	Composition (e.g., ice versus rock versus gas).

	b	Students identify advances in solar system science made possible by improved engineering (e.g., knowledge of the evolution of the solar system from lunar exploration and space probes) and new developments in engineering made possible by advances in science (e.g., space-based telescopes from advances in optics and aerospace engineering).
3	Interpreting data	
	a	Students use the patterns they find in multiple types of data at varying scales to draw conclusions about the identifying characteristics of different categories of solar system objects (e.g., planets, meteors, asteroids, comets) based on their features, composition, and locations within the solar system (e.g., most asteroids are rocky bodies between Mars and Jupiter, while most comets reside in orbits farther from the sun and are composed mostly of ice).
	b	Students use patterns in data as evidence to describe* that two objects may be similar when viewed at one scale (e.g., types of surface features) but may appear to be quite different when viewed at a different scale (e.g., diameter or number of natural satellites).
	c	Students use the organization of data to facilitate drawing conclusions about the patterns of scale properties at more than one scale, such as those that are too large or too small to directly observe.

MS-ESS1-4 Earth's Place in the Universe

Students who demonstrate understanding can:

MS-ESS1-4. Construct a scientific explanation based on evidence from rock strata for how the geologic time scale is used to organize Earth's 4.6-billion-year-old history. [Clarification Statement: Emphasis is on how analyses of rock formations and the fossils they contain are used to establish relative ages of major events in Earth's history. Examples of Earth's major events could range from being very recent (such as the last Ice Age or the earliest fossils of homo sapiens) to very old (such as the formation of Earth or the earliest evidence of life). Examples can include the formation of mountain chains and ocean basins, the evolution or extinction of particular living organisms, or significant volcanic eruptions.] [*Assessment Boundary: Assessment does not include recalling the names of specific periods or epochs and events within them.*]

The performance expectation above was developed using the following elements from the NRC document *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 6–8 builds on K–5 experiences and progresses to include constructing explanations and designing solutions supported by multiple sources of evidence consistent with scientific ideas, principles, and theories. • Construct a scientific explanation based on valid and reliable evidence obtained from sources (including the students' own experiments) and the assumption that theories and laws that describe the natural world operate today as they did in the past and will continue to do so in the future.	**ESS1.C: The History of Planet Earth** • The geologic time scale interpreted from rock strata provides a way to organize Earth's history. Analyses of rock strata and the fossil record provide only relative dates, not an absolute scale.	**Scale, Proportion, and Quantity** • Time, space, and energy phenomena can be observed at various scales using models to study systems that are too large or too small.

Observable features of the student performance by the end of the course:			
1	Articulating the explanation of phenomena		
	a	Students articulate a statement that relates the given phenomenon to a scientific idea, including how events in the Earth's 4.6 billion-year-old history are organized relative to one another using the geologic time scale.	
	b	Students use evidence and reasoning to construct an explanation. In their explanation, students describe* how the relative order of events is determined on the geologic time scale using:	
		i.	Rock strata and relative ages of rock units (e.g., patterns of layering).
		ii.	Major events in the Earth's history and/or specific changes in fossils over time (e.g., formation of mountain chains, formation of ocean basins, volcanic eruptions, glaciations, asteroid impacts, extinctions of groups of organism).
2	Evidence		
	a	Students identify and describe* the evidence necessary for constructing the explanation, including:	
		i.	Types and order of rock strata.
		ii.	The fossil record.
		iii.	Identification of and evidence for major event(s) in the Earth's history (e.g., volcanic eruptions, asteroid impacts, etc.).
	b	Students use multiple valid and reliable sources of evidence, which may include students' own experiments.	
	Reasoning		

3	a	Students use reasoning, along with the assumption that theories and laws that describe the natural world operate today as they did in the past and will continue to do so in the future, to connect the evidence and support an explanation for how the geologic time scale is used to construct a timeline of the Earth's history. Students describe* the following chain of reasoning for their explanation:	
		i.	Unless they have been disturbed by subsequent activity, newer rock layers sit on top of older rock layers, allowing for a relative ordering in time of the formation of the layers (i.e., older sedimentary rocks lie beneath younger sedimentary rocks).
		ii.	Any rocks or features that cut existing rock strata are younger than the rock strata that they cut (e.g., a younger fault cutting across older, existing rock strata).
		iii.	The fossil record can provide relative dates based on the appearance or disappearance of organisms (e.g., fossil layers that contain only extinct animal groups are usually older than fossil layers that contain animal groups that are still alive today, and layers with only microbial fossils are typical of the earliest evidence of life).
		iv.	Specific major events (e.g., extensive lava flows, volcanic eruptions, asteroid impacts) can be used to indicate periods of time that occurred before a given event from periods that occurred after it.
		v.	Using a combination of the order of rock layers, the fossil record, and evidence of major geologic events, the relative time ordering of events can be constructed as a model for Earth's history, even though the timescales involved are immensely vaster than the lifetimes of humans or the entire history of humanity.

MS-ESS3-4 Earth and Human Activity

Students who demonstrate understanding can:

MS-ESS3-4. Construct an argument supported by evidence for how increases in human population and per-capita consumption of natural resources impact Earth's systems. [Clarification Statement: Examples of evidence include grade-appropriate databases on human populations and the rates of consumption of food and natural resources (such as freshwater, mineral, and energy). Examples of impacts can include changes to the appearance, composition, and structure of Earth's systems as well as the rates at which they change. The consequences of increases in human populations and consumption of natural resources are described by science, but science does not make the decisions for the actions society takes.]

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

Science and Engineering Practices

Engaging in Argument from Evidence

Engaging in argument from evidence in 6–8 builds on K–5 experiences and progresses to constructing a convincing argument that supports or refutes claims for either explanations or solutions about the natural and designed world(s).

- Construct an oral and written argument supported by empirical evidence and scientific reasoning to support or refute an explanation or a model for a phenomenon or a solution to a problem.

Disciplinary Core Ideas

ESS3.C: Human Impacts on Earth Systems

- Typically as human populations and per-capita consumption of natural resources increase, so do the negative impacts on Earth unless the activities and technologies involved are engineered otherwise.

Crosscutting Concepts

Cause and Effect

- Cause and effect relationships may be used to predict phenomena in natural or designed systems.

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Connections to Engineering, Technology, and Applications of Science

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

- All human activity draws on natural resources and has both short and long-term consequences, positive as well as negative, for the health of people and the natural environment.

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Connections to Nature of Science

Science Addresses Questions About the Natural and Material World

- Scientific knowledge can describe the consequences of actions but does not necessarily prescribe the decisions that society takes.

Observable features of the student performance by the end of the course:		
1	Supported claims	
	a	Students make a claim, to be supported by evidence, to support or refute an explanation or model for a given phenomenon. Students include the following idea in their claim: that increases in the size of the human population and per-capita consumption of natural resources affect Earth systems.
2	Identifying scientific evidence	
	a	Students identify evidence to support the claim from the given materials, including:
		i. Changes in the size of human population(s) in a given region or ecosystem over a given timespan.

		ii.	Per-capita consumption of resources by humans in a given region or ecosystem over a given timespan.
		iii.	Changes in Earth systems in a given region or ecosystem over a given timespan.
		iv.	The ways engineered solutions have altered the effects of human activities on Earth's systems.
3	Evaluating and critiquing evidence		
	a	Students evaluate the evidence for its necessity and sufficiency for supporting the claim.	
	b	Students determine whether the evidence is sufficient to determine causal relationships between consumption of natural resources and the impact on Earth systems.	
	c	Students consider alternative interpretations of the evidence and describe* why the evidence supports the claim they are making, as opposed to any alternative claims.	
4	Reasoning and synthesis		
	a	Students use reasoning to connect the evidence and evaluation to the claim. In their arguments, students describe* a chain of reasoning that includes:	
		i.	Increases in the size of the human population or in the per-capita consumption of a given population cause increases in the consumption of natural resources.
		ii.	Natural resource consumption causes changes in Earth systems.
		iii.	Because human population growth affects natural resource consumption and natural resource consumption has an effect on Earth systems, changes in human populations have a causal role in changing Earth systems.
		iv.	Engineered solutions alter the effects of human populations on Earth systems by changing the rate of natural resource consumption or mitigating the effects of changes in Earth systems.

MS-ETS1-3 Engineering Design

Students who demonstrate understanding can:

MS-ETS1-3. Analyze data from tests to determine similarities and differences among several design solutions to identify the best characteristics of each that can be combined into a new solution to better meet the criteria for success.

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

Science and Engineering Practices	Disciplinary Core Ideas	Crosscutting Concepts
Analyzing and Interpreting Data Analyzing data in 6–8 builds on K–5 experiences and progresses to extending quantitative analysis to investigations, distinguishing between correlation and causation, and basic statistical techniques of data and error analysis. • Analyze and interpret data to determine similarities and differences in findings.	**ETS1.B: Developing Possible Solutions** • There are systematic processes for evaluating solutions with respect to how well they meet the criteria and constraints of a problem. • Sometimes parts of different solutions can be combined to create a solution that is better than any of its predecessors. **ETS1.C: Optimizing the Design Solution** • Although one design may not perform the best across all tests, identifying the characteristics of the design that performed the best in each test can provide useful information for the redesign process—that is, some of those characteristics may be incorporated into the new design.	

Observable features of the student performance by the end of the course:		
1	Organizing data	
	a	Students organize given data (e.g., via tables, charts, or graphs) from tests intended to determine the effectiveness of three or more alternative solutions to a problem.
2	Identifying relationships	
	a	Students use appropriate analysis techniques (e.g., qualitative or quantitative analysis; basic statistical techniques of data and error analysis) to analyze the data and identify relationships within the datasets, including relationships between the design solutions and the given criteria and constraints.
3	Interpreting data	
	a	Students use the analyzed data to identify evidence of similarities and differences in features of the solutions.
	b	Based on the analyzed data, students make a claim for which characteristics of each design best meet the given criteria and constraints.
	c	Students use the analyzed data to identify the best features in each design that can be compiled into a new (improved) redesigned solution.