

High School Conceptual Progressions Model III – Bundle 1

Evolution of Earth

This is the first bundle of the High School Conceptual Progressions 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 evidence do we have that the Earth is different now than it used to be?”

Summary

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

Connections between bundle DCIs

Although active geologic processes, such as plate tectonics and erosion, have destroyed or altered most of the very early rock record on Earth, other objects in the solar system, such as lunar rocks, asteroids, and meteorites, have changed little over billions of years. Studying these objects can provide information about Earth’s formation and early history (ESS1.C as in HS-ESS1-6).

Geologists use seismic waves and their reflection at interfaces between layers to probe structures deep in the planet (PS4.A as in HS-ESS2-3). This evidence along with 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.A as in HS-ESS2-3). The radioactive decay of unstable isotopes continually generates new energy within Earth’s crust and mantle, providing the primary source of the heat that drives this mantle convection. Plate tectonics can be viewed as the surface expression of mantle convection (ESS2.B as in HS-ESS2-3) and plate tectonics is the unifying theory that explains the past and current movements of the rocks on Earth’s surface and provides a framework for understanding its geologic history (ESS2.B as in HS-ESS1-5).

Because spontaneous radioactive decays follow a characteristic exponential decay law. Nuclear lifetimes allow radiometric dating to be used to determine the ages of rocks and other materials (PS1.C as in HS-ESS1-6). For example, continental rocks, which can be older than 4 billion years, are generally much older than the rocks of the ocean floor, which are less than 200 million years old (ESS1.C as in HS-ESS1-5). We can also use radiometric dating to gather information about the co-evolution of Earth’s surface and the life that exists on it (ESS2.E as in HS-ESS2-7), including the gradual atmospheric changes due to plants and other organisms that captured carbon dioxide and released oxygen (ESS2.D as in HS-ESS2-7).

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 models (HS-ESS2-3), constructing explanations (HS-ESS1-6), and engaging in argument (HS-ESS1-5 and HS-ESS2-7). 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 (HS-ESS1-5), Energy and Matter (HS-ESS2-3), and Stability and Change (HS-ESS1-6 and HS-ESS2-7). Many other crosscutting concept elements can be used in instruction.

<i>All instruction should be three-dimensional.</i>	
Performance Expectations HS-ESS2-3 and HS-ESS2-7 are partially assessable	<p>HS-ESS1-5. Evaluate evidence of the past and current movements of continental and oceanic crust and the theory of plate tectonics to explain the ages of crustal rocks. [Clarification Statement: Emphasis is on the ability of plate tectonics to explain the ages of crustal rocks. Examples include evidence of the ages oceanic crust increasing with distance from mid-ocean ridges (a result of plate spreading) and the ages of North American continental crust increasing with distance away from a central ancient core (a result of past plate interactions).]</p> <p>HS-ESS1-6. Apply scientific reasoning and evidence from ancient Earth materials, meteorites, and other planetary surfaces to construct an account of Earth’s formation and early history. [Clarification Statement: Emphasis is on using available evidence within the solar system to reconstruct the early history of Earth, which formed along with the rest of the solar system 4.6 billion years ago. Examples of evidence include the absolute ages of ancient materials (obtained by radiometric dating of meteorites, moon rocks, and Earth’s oldest minerals), the sizes and compositions of solar system objects, and the impact cratering record of planetary surfaces.]</p> <p>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.]</p> <p>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 of 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.]</p>
Example Phenomena	<p>Ocean maps show that some parts of the ocean are much deeper than others.</p> <p>The moon appears to be pock-marked with many craters.</p>
Additional Practices Building to the PEs	<p>Asking Questions and Defining Problems</p> <ul style="list-style-type: none"> Ask questions that arise from careful observation of phenomena, or unexpected results, to clarify and/or seek additional information. <p>Students could <i>ask questions that arise from careful observation to seek additional information</i> [about how] <i>gradual atmospheric changes were due to plants and other organisms that captured carbon dioxide and released oxygen.</i> HS-ESS2-7</p> <p>Developing and Using Models</p> <ul style="list-style-type: none"> Develop and/or use multiple types of models to provide mechanistic accounts and/or predict phenomena, and move flexibly between model types based on merits and limitations. <p>Students could <i>use multiple types of models to provide mechanistic accounts</i> [of why] <i>continental rocks are generally much older than the rocks of the ocean floor, and [choose different] model types based on merits and limitations.</i> HS-ESS1-5</p>

Additional Practices Building to the PEs (Continued)

Planning and Carrying Out Investigations

- Plan an investigation or test a design individually and collaboratively to produce data to serve as the basis for evidence as part of building and revising models, supporting explanations for phenomena, or testing solutions to problems. Consider possible confounding variables or effects and evaluate the investigation's design to ensure variables are controlled.

Students could *plan an investigation to serve as the basis for evidence* [that] ***plants capture carbon dioxide and release oxygen, [therefore causing] gradual atmospheric changes.*** HS-ESS2-7

Analyzing and Interpreting Data

- Analyze data using tools, technologies, and/or models (e.g., computational, mathematical) in order to make valid and reliable scientific claims or determine an optimal design solution.

Students could *analyze data in order to make valid and reliable scientific claims* [about how] ***studying plate tectonics, erosion, lunar rocks, asteroids, and meteorites can provide information about Earth's formation and early history.*** HS-ESS1-6

Using Mathematical and Computational Thinking

- Use mathematical, computational, and/or algorithmic representations of phenomena or design solutions to describe and/or support claims and/or explanations.

Students could *use computational representations of phenomena to describe the explanation* [that] ***motions of the Earth's 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.*** HS-ESS2-3

Constructing Explanations and Designing Solutions

- Construct and revise an explanation based on valid and reliable evidence obtained from a variety of sources (including students' own investigations, models, theories, simulations, peer review) 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.

Students could *construct an explanation based on valid and reliable evidence obtained from a variety of sources* [for how] ***gradual atmospheric changes were*** [caused by] ***plants and other organisms that captured carbon dioxide and released oxygen.*** HS-ESS2-7

Engaging in Argument from Evidence

- Make and defend a claim based on evidence about the natural world or the effectiveness of a design solution that reflects scientific knowledge, and student-generated evidence.

Students could *defend a claim based on evidence* [that] ***plate tectonics can be viewed as the surface expression of mantle convection.*** HS-ESS2-3

<p>Additional Practices Building to the PEs (Continued)</p>	<p>Obtaining, Evaluating, and Communicating Information</p> <ul style="list-style-type: none"> Gather, read, and evaluate scientific and/or technical information from multiple authoritative sources, assessing the evidence and usefulness of each source. <p>Students could gather, read, and evaluate scientific information from multiple authoritative sources [about how] <i>studying plate tectonics can provide information about Earth's formation and early history</i>. HS-ESS1-6</p>
<p>Additional Crosscutting Concepts Building to the PEs</p>	<p>Patterns</p> <ul style="list-style-type: none"> Different patterns may be observed at each of the scales at which a system is studied and can provide evidence for causality in explanations of phenomena. <p>Students could evaluate and communicate information about how <i>different patterns may be observed at different scales, and the patterns can provide evidence for causality</i> [about how] <i>plate tectonics can be viewed as the surface expression of mantle convection</i>. HS-ESS2-3</p> <p>Cause and Effect</p> <ul style="list-style-type: none"> Empirical evidence is required to differentiate between cause and correlation and make claims about specific causes and effects. <p>Students could construct an argument for how <i>empirical evidence is required to differentiate between cause and correlation</i> [between] <i>the evolution of Earth's surface and the evolution of the life that exists on it</i>. HE-ESS2-7</p> <p>Stability and Change</p> <ul style="list-style-type: none"> Changes and rates of change can be quantified and modeled over very short or very long periods of time. Some system changes are irreversible. <p>Students could construct an argument for how <i>changes and rates of change</i> [in] <i>the movements of the rocks at Earth's surface can be quantified and modeled over very short or very long periods of time</i>. HS-ESS1-5</p>
<p>Additional Connections to Nature of Science</p>	<p>Scientific Investigations Use a Variety of Methods</p> <ul style="list-style-type: none"> Scientific investigations use a variety of methods, tools, and techniques to revise and produce new knowledge. <p>Students could construct an argument for how <i>scientific investigations use a variety of methods, tools, and techniques to revise and produce new knowledge</i> [about how] <i>continental rocks, which can be older than 4 billion years, are generally much older than the rocks of the ocean floor, which are less than 200 million years old</i>. HS-ESS1-5</p> <p>Scientific Knowledge Assumes an Order and Consistency in Natural Systems</p> <ul style="list-style-type: none"> Scientific knowledge is based on the assumption that natural laws operate today as they did in the past and they will continue to do so in the future. <p>Students could construct an argument for how <i>scientific knowledge is based on the assumption that natural laws operate today as they did in the past and they will continue to do so in the future</i> [using as an example our knowledge about the] <i>continual coevolution of Earth's surface and the life that exists on it</i>. HS-ESS2-7</p>

HS-ESS1-5

Students who demonstrate understanding can:

HS-ESS1-5. Evaluate evidence of the past and current movements of continental and oceanic crust and the theory of plate tectonics to explain the ages of crustal rocks. [Clarification Statement: Emphasis is on the ability of plate tectonics to explain the ages of crustal rocks. Examples include evidence of the ages of oceanic crust increasing with distance from mid-ocean ridges (a result of plate spreading) and the ages of North American continental crust decreasing with distance away from a central ancient core of the continental plate (a result of past plate interactions).]

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
<p>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.</p> <ul style="list-style-type: none"> Evaluate evidence behind currently accepted explanations or solutions to determine the merits of arguments. 	<p>ESS1.C: The History of Planet Earth</p> <ul style="list-style-type: none"> Continental rocks, which can be older than 4 billion years, are generally much older than the rocks of the ocean floor, which are less than 200 million years old. <p>ESS2.B: Plate Tectonics and Large-Scale System Interactions</p> <ul style="list-style-type: none"> 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. (<i>ESS2.B Grade 8 GBE</i>) (<i>secondary</i>) <p>PS1.C: Nuclear Processes</p> <ul style="list-style-type: none"> Spontaneous radioactive decays follow a characteristic exponential decay law. Nuclear lifetimes allow radiometric dating to be used to determine the ages of rocks and other materials. (<i>secondary</i>) 	<p>Patterns</p> <ul style="list-style-type: none"> Empirical evidence is needed to identify patterns.

Observable features of the student performance by the end of the course:

1	Identifying the given explanation and the supporting evidence
a	Students identify the given explanation, which includes the following idea: that crustal materials of different ages are arranged on Earth's surface in a pattern that can be attributed to plate tectonic activity and formation of new rocks from magma rising where plates are moving apart.
b	Students identify the given evidence to be evaluated.
2	Identifying any potential additional evidence that is relevant to the evaluation
a	Students identify and describe* additional relevant evidence (in the form of data, information, models, or other appropriate forms) that was not provided but is relevant to the explanation and to evaluating the given evidence, including:
i.	Measurement of the ratio of parent to daughter atoms produced during radioactive decay as a means for determining the ages of rocks;
ii.	Ages and locations of continental rocks;
iii.	Ages and locations of rocks found on opposite sides of mid-ocean ridges; and

		iv. The type and location of plate boundaries relative to the type, age, and location of crustal rocks.
3	Evaluating and critiquing	
	a	Students use their additional evidence to assess and evaluate the validity of the given evidence.
	b	Students evaluate the reliability, strengths, and weaknesses of the given evidence along with its ability to support logical and reasonable arguments about the motion of crustal plates.
4	Reasoning/synthesis	
	a	Students describe* how the following patterns observed from the evidence support the explanation about the ages of crustal rocks:
		i. The pattern of the continental crust being older than the oceanic crust;
		ii. The pattern that the oldest continental rocks are located at the center of continents, with the ages decreasing from their centers to their margin; and
		iii. The pattern that the ages of oceanic crust are greatest nearest the continents and decrease in age with proximity to the mid-ocean ridges.
	b	Students synthesize the relevant evidence to describe* the relationship between the motion of continental plates and the patterns in the ages of crustal rocks, including that:
		i. At boundaries where plates are moving apart, such as mid-ocean ridges, material from the interior of the Earth must be emerging and forming new rocks with the youngest ages.
		ii. The regions furthest from the plate boundaries (continental centers) will have the oldest rocks because new crust is added to the edge of continents at places where plates are coming together, such as subduction zones.
		iii. The oldest crustal rocks are found on the continents because oceanic crust is constantly being destroyed at places where plates are coming together, such as subduction zones.

HS-ESS1-6

Students who demonstrate understanding can:

HS-ESS1-6. Apply scientific reasoning and evidence from ancient Earth materials, meteorites, and other planetary surfaces to construct an account of Earth's formation and early history. [Clarification Statement: Emphasis is on using available evidence within the solar system to reconstruct the early history of Earth, which formed along with the rest of the solar system 4.6 billion years ago. Examples of evidence include the absolute ages of ancient materials (obtained by radiometric dating of meteorites, moon rocks, and Earth's oldest minerals), the sizes and compositions of solar system objects, and the impact cratering record of planetary surfaces.]

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
<p>Constructing Explanations and Designing Solutions</p> <p>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.</p> <ul style="list-style-type: none"> Apply scientific reasoning to link evidence to the claims to assess the extent to which the reasoning and data support the explanation or conclusion. <p>-----</p> <p>Connections to Nature of Science</p> <p>Science Models, Laws, Mechanisms, and Theories Explain Natural Phenomena</p> <ul style="list-style-type: none"> A scientific theory is a substantiated explanation of some aspect of the natural world, based on a body of facts that have been repeatedly confirmed through observation and experiment, and the science community validates each theory before it is accepted. If new evidence is discovered that the theory does not accommodate, the theory is generally modified in light of this new evidence. Models, mechanisms, and explanations collectively serve as tools in the development of a scientific theory. 	<p>ESS1.C: The History of Planet Earth</p> <ul style="list-style-type: none"> Although active geologic processes, such as plate tectonics and erosion, have destroyed or altered most of the very early rock record on Earth, other objects in the solar system, such as lunar rocks, asteroids, and meteorites, have changed little over billions of years. Studying these objects can provide information about Earth's formation and early history. <p>PS1.C: Nuclear Processes</p> <ul style="list-style-type: none"> Spontaneous radioactive decays follow a characteristic exponential decay law. Nuclear lifetimes allow radiometric dating to be used to determine the ages of rocks and other materials. (<i>secondary</i>) 	<p>Stability and Change</p> <ul style="list-style-type: none"> 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	Articulating the explanation of phenomena
a	Students construct an account of Earth's formation and early history that includes that:
i.	Earth formed along with the rest of the solar system 4.6 billion years ago.
ii.	The early Earth was bombarded by impacts just as other objects in the solar system were bombarded.
iii.	Erosion and plate tectonics on Earth have destroyed much of the evidence of this bombardment, explaining the relative scarcity of impact craters on Earth.

2	Evidence	
	a	Students include and describe* the following evidence in their explanatory account:
		i. The age and composition of Earth's oldest rocks, lunar rocks, and meteorites as determined by radiometric dating;
		ii. The composition of solar system objects;
		iii. Observations of the size and distribution of impact craters on the surface of Earth and on the surfaces of solar system objects (e.g., the moon, Mercury, and Mars); and
		iv. The activity of plate tectonic processes, such as volcanism, and surface processes, such as erosion, operating on Earth.
3	Reasoning	
	a	Students use reasoning to connect the evidence to construct the explanation of Earth's formation and early history, including that:
		i. Radiometric ages of lunar rocks, meteorites and the oldest Earth rocks point to an origin of the solar system 4.6 billion years ago, with the creation of a solid Earth crust about 4.4 billion years ago.
		ii. Other planetary surfaces and their patterns of impact cratering can be used to infer that Earth had many impact craters early in its history.
		iii. The relative lack of impact craters and the age of most rocks on Earth compared to other bodies in the solar system can be attributed to processes such as volcanism, plate tectonics, and erosion that have reshaped Earth's surface, and that this is why most of Earth's rocks are much younger than Earth itself.

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	Disciplinary Core Ideas	Crosscutting Concepts
<p>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).</p> <ul style="list-style-type: none"> Develop a model based on evidence to illustrate the relationships between systems or between components of a system. <p>-----</p> <p>Connections to Nature of Science</p> <p>Scientific Knowledge is Based on Empirical Evidence</p> <ul style="list-style-type: none"> 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. 	<p>ESS2.A: Earth Materials and Systems</p> <ul style="list-style-type: none"> 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. <p>ESS2.B: Plate Tectonics and Large-Scale System Interactions</p> <ul style="list-style-type: none"> 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. 	<p>Energy and Matter Energy drives the cycling of matter within and between systems.</p> <p>-----</p> <p>Connections to Engineering, Technology, and Applications of Science</p> <p>Interdependence of Science, Engineering, and Technology</p> <ul style="list-style-type: none"> 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: <ul style="list-style-type: none"> 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-ESS2-7

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	Disciplinary Core Ideas	Crosscutting Concepts
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. <ul style="list-style-type: none"> Construct an oral and written argument or counter-arguments based on data and evidence. 	ESS2.D: Weather and Climate <ul style="list-style-type: none"> Gradual atmospheric changes were due to plants and other organisms that captured carbon dioxide and released oxygen. ESS2.E Biogeology <ul style="list-style-type: none"> 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. 	Stability and Change <ul style="list-style-type: none"> 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: <ul style="list-style-type: none"> 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.