

### Unit Summary

#### ***How can one explain and predict interactions between Earth materials and within Earth systems?***

In this unit of study, *planning and carrying out investigations, analyzing and interpreting data, developing and using models, and engaging in arguments from evidence* are key practices to explore the dynamic nature of Earth systems. Students apply these practices to illustrate how Earth's interacting systems cause feedback effects on other Earth systems, to investigate the properties of water and its effects on Earth materials and surface processes, and to model the cycling of carbon through all of the Earth's spheres. Students seek evidence to construct arguments about the simultaneous co-evolution of the Earth's systems and life on Earth. The crosscutting concepts of *energy and matter, structure and function, and stability and change* are called out as organizing concepts for these disciplinary core ideas.

This unit is based on HS-ESS2-2, HS-ESS2-5, HS-ESS2-6, and HS-ESS2-7. *[Note: The disciplinary core ideas, science and engineering practices, and crosscutting concepts can be taught in either this course or in a high school chemistry course.]*

### Student Learning Objectives

**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.]* ([HS-ESS2-2](#))

**Plan and conduct an investigation of the properties of water and its effects on Earth materials and surface processes.** *[Clarification Statement: Emphasis is on mechanical and chemical investigations with water and a variety of solid materials to provide the evidence for connections between the hydrologic cycle and system interactions commonly known as the rock cycle. Examples of mechanical investigations include stream transportation and deposition using a stream table, erosion using variations in soil moisture content, or frost wedging by the expansion of water as it freezes. Examples of chemical investigations include chemical weathering and recrystallization (by testing the solubility of different materials) or melt generation (by examining how water lowers the melting temperature of most solids).]* ([HS-ESS2-5](#))

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

**Construct an argument based on evidence about the simultaneous co-evolution 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.]* ([HS-ESS2-7](#))

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Part A: How do changes in the geosphere affect the atmosphere?	
Concepts	Formative Assessment
<ul style="list-style-type: none"> <li>• Earth’s systems, being dynamic and interacting, cause feedback effects that can increase or decrease the original changes.</li> <li>• 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.</li> <li>• Feedback (negative or positive) can stabilize or destabilize a system.</li> </ul>	<p><i>Students who understand the concepts are able to:</i></p> <ul style="list-style-type: none"> <li>• Analyze geoscience data using tools, technologies, and/or models (e.g., computational, mathematical) to make the claim that one change to Earth’s surface can create feedbacks that cause changes to other Earth systems.</li> </ul>

Part B: How do the properties and movements of water shape Earth's surface and affect its systems?	
Concepts	Formative Assessment
<ul style="list-style-type: none"> <li>• 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.</li> <li>• The 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.</li> </ul>	<p><i>Students who understand the concepts are able to:</i></p> <ul style="list-style-type: none"> <li>• Plan and conduct an investigation of the properties of water and its effects on Earth materials and surface processes.</li> </ul>

Part C: How does carbon cycle among the hydrosphere, atmosphere, geosphere, and biosphere?
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Concepts	Formative Assessment
<ul style="list-style-type: none"> <li>Gradual atmospheric changes were due to plants and other organisms that captured carbon dioxide and released oxygen.</li> <li>Changes in the atmosphere due to human activity have increased carbon dioxide concentrations and thus affect climate.</li> <li>The total amount of energy and matter in closed systems is conserved.</li> <li>The total amount of carbon cycling among and between the hydrosphere, atmosphere, geosphere, and biosphere is conserved.</li> </ul>	<p><i>Students who understand the concepts are able to:</i></p> <ul style="list-style-type: none"> <li>Develop a model based on evidence to describe the cycling of carbon among the hydrosphere, atmosphere, geosphere, and biosphere.</li> <li>Develop a model based on evidence to illustrate the biogeochemical cycles that include the cycling of carbon through the ocean, atmosphere, soil, and biosphere, providing the foundation for living organisms.</li> </ul>

Part D: How do living organisms alter Earth's processes and structures?	
Concepts	Formative Assessment
<ul style="list-style-type: none"> <li>The many dynamic and delicate feedbacks between the biosphere and other Earth systems cause a continual co-evolution of Earth's surface and the life that exists on it.</li> </ul>	<p><i>Students who understand the concepts are able to:</i></p> <ul style="list-style-type: none"> <li>Construct an argument based on evidence about the simultaneous co-evolution of Earth's systems and life on Earth.</li> </ul>

What It Looks Like in the Classroom
<p>After students have an understanding of the structure and formation of Earth’s surface, they examine how changes to Earth’s surface create feedback. Students also consider what changes to other Earth systems are caused by that feedback. Students analyze data, using tools, technologies, and models to make claims about relationships between changes to Earth’s surface and feedback. Students examine data from the Earth’s weather patterns to model how some weather patterns and Earth events are related to the use of natural resources. Examples of feedback include how an increase in greenhouse gases causes a rise in global temperatures that melts glacial ice, thus reducing the amount of sunlight reflected from Earth’s surface, which in turn increases surface temperatures and further reduces the amount of ice. Other system interactions include 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 wetlands’ extent. Students then provide and explain examples (such as CO<sub>2</sub> emissions, ozone depletion, changing weather patterns, etc.) of the negative and positive feedback that can stabilize and destabilize the environment. Students cite examples of new technologies (such as gasoline cars, hydrogen-fuel-cell cars, biofuel cars, solar power, alternative energy, etc.) and consider their impacts on society and the environment. Students also consider the inorganic carbon cycle and geologic processes. For example, climate feedback could be modeled by understanding relationships between sediments containing carbon (calcium carbonate made by marine organisms) on the seafloor in subduction zones and carbon dioxide released through volcanoes.</p> <p>Students actively explore the properties of water and its effects on Earth materials and surface properties by planning and conducting investigations. Initially they identify evidence needed to answer a question related to the properties of water and its effects on Earth materials and surface properties. The evidence may be related to the properties, such as heat capacity of water, density of water in its liquid and solid states, and the polar nature of a water molecule due to its molecular</p>

structure. The evidence may be related to the effect of the properties of water on energy transfer that causes patterns of temperature, the movement of air, the movement and availability of water at Earth's surface. The evidence may be related to mechanical effects of water on Earth's materials that can be used to infer the effect of water on Earth's surface properties. Some examples include stream transportation and deposition, erosion using variations in soil moisture content, and expansion of water as it freezes. Finally, the evidence may be related to the chemical effects of water on Earth materials that can be used to infer the effect of water on Earth's surface processes. This may include the properties of solubility, the reaction of water on iron, and the properties of water that lower the melting temperature of most solids, and decreases the viscosity of melted rock. Next, students plan out their investigation to align their data collection methods with the evidence they are seeking. For example, they may decide to investigate the mechanical nature of running water on sediment transport and deposition by changing the slope of a stream table. Once their protocol has been designed, they run their investigation and collect data. They analyze and interpret the data, and if necessary, they modify the protocol and run the investigation again.

Students will continue their study of Earth's systems by examining the history of the atmosphere. Students should research the early atmospheric components and the changes that occurred due to plants and other organisms removing carbon dioxide and releasing oxygen. By studying the carbon cycle, students should revisit the idea that matter and energy within a closed system are conserved among the hydrosphere, atmosphere, geosphere, and biosphere. Students should extend their understanding of how human activity affects the concentration of carbon dioxide in the environment and therefore climate. Students' experiences should include synthesizing information from multiple sources and developing quantitative models based on evidence to describe the cycling of carbon among the ocean, atmosphere, soil, and biosphere. Students should understand how biogeochemical cycles provide the foundation for living organisms. Once again, students might use a jigsaw activity to illustrate the relationships between these systems.

Since the Earth formed there has been a co-evolution of Earth's systems and life on Earth. Students explore multiple lines of evidence found in scientific research papers that support this claim, such as the scientific explanations about the composition of the Earth's atmosphere shortly after its formation; current atmospheric composition; evidence for the emergence of photosynthetic organisms; evidence of the effect of the presence of free oxygen on evolution and processes in the other Earth systems; and other evidence that changes in the biosphere affect Earth systems. Students might use a jigsaw activity to explore selected research papers. While reading these papers students identify the methods employed by the scientists, and interpret the data and data visualizations provided in the papers. From this, they evaluate and critique the claims by the scientists. After investigating a variety of research papers, students select at least two examples to construct oral and written logical arguments about the evolution of photosynthetic organisms led to drastic changes 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; or identify causal links and feedback mechanisms between changes in the biosphere and changes in Earth's other systems.

*English Language Arts/Literacy*

- Research on feedbacks in the Earth system provides the venue for students to cite specific textual evidence to support analysis of science and technical texts, attending to important distinctions the author makes and to any gaps or inconsistencies in the account.
- While analyzing scientific research related to feedbacks in the Earth system, students determine the central ideas or conclusions of a text; summarize complex concepts, processes, or information presented in a text by paraphrasing them in simpler but still accurate terms.
- Conduct short as well as more sustained research projects to answer a question (including a self-generated question) about the effect of water on Earth's systems; narrow or broaden the inquiry when appropriate; synthesize multiple sources on the subject, demonstrating understanding of the subject under investigation.
- Write arguments focused on discipline-specific content related to the simultaneous co-evolution of Earth's systems and life on Earth.

*Mathematics*

- Reason abstractly and quantitatively while considering feedbacks in the Earth system, such as the feedback created from increased levels of carbon dioxide on global temperature by correlating atmospheric carbon dioxide data and temperature data.
- Use units as a way to understand problems and to guide the solution of multi-step problems related to Earth system feedbacks; choose and interpret units consistently in formulas; choose and interpret the scale and the origin in graphs and data displays.
- Choose a level of accuracy appropriate to limitations on measurement when reporting quantities when exploring Earth system feedbacks or the effects of water on Earth systems materials and processes.
- Represent symbolically the cycling of carbon among the hydrosphere, atmosphere, geosphere, and biosphere, and manipulate the representing symbols. Make sense of quantities and relationships in the cycling of carbon among the hydrosphere, atmosphere, geosphere, and biosphere.
- Use a mathematical model to describe the cycling of carbon among the hydrosphere, atmosphere, geosphere, and biosphere. Identify important quantities in the cycling of carbon among the hydrosphere, atmosphere, geosphere, and biosphere and map their relationships using tools. Analyze those relationships mathematically to draw conclusions, reflecting on the results and improving the model if it has not served its purpose.
- Use units as a way to understand the cycling of carbon among the hydrosphere, atmosphere, geosphere, and biosphere; choose and interpret units consistently in formulas representing the cycling of carbon among the hydrosphere, atmosphere, geosphere, and biosphere; choose and interpret the scale and the origin in graphs and data displays representing the cycling of carbon among the hydrosphere, atmosphere, geosphere, and biosphere.
- Define appropriate quantities for the purpose of descriptive modeling of the cycling of carbon among the hydrosphere, atmosphere, geosphere, and biosphere.
- Choose a level of accuracy appropriate to limitations on measurement when reporting quantities showing the cycling of carbon among the hydrosphere, atmosphere, geosphere, and biosphere.

**Modifications**

*(Note: Teachers identify the modifications that they will use in the unit. See NGSS Appendix D: [All Standards, All Students/Case Studies for vignettes and explanations of the modifications.](#))*

- Structure lessons around questions that are authentic, relate to students' interests, social/family background and knowledge of their community.
- Provide students with multiple choices for how they can represent their understandings (e.g. multisensory techniques-auditory/visual aids; pictures, illustrations, graphs, charts, data tables, multimedia, modeling).
- Provide opportunities for students to connect with people of similar backgrounds (e.g. conversations via digital tool such as SKYPE, experts from the community helping with a project, journal articles, and biographies).
- Provide multiple grouping opportunities for students to share their ideas and to encourage work among various backgrounds and cultures (e.g. multiple representation and multimodal experiences).
- Engage students with a variety of Science and Engineering practices to provide students with multiple entry points and multiple ways to demonstrate their understandings.
- Use project-based science learning to connect science with observable phenomena.
- Structure the learning around explaining or solving a social or community-based issue.
- Provide ELL students with multiple literacy strategies.
- Collaborate with after-school programs or clubs to extend learning opportunities.
- Restructure lesson using UDL principals ([http://www.cast.org/our-work/about-udl.html#.VXmoXcfD\\_UA](http://www.cast.org/our-work/about-udl.html#.VXmoXcfD_UA)).

#### Research on Student Learning

Students of all ages may hold the view that the world was always as it is now, or that any changes that have occurred must have been sudden and comprehensive. The students in these studies did not, however, have any formal instruction on the topics investigated. Moreover, middle-school students taught by traditional means are not able to construct coherent explanations about the causes of volcanoes and earthquakes. ([NSDL, 2015](#)).

#### Prior Learning

*Physical science*

- Substances are made from different types of atoms, which combine with one another in various ways. Atoms form molecules that range in size from two to thousands of atoms.
- Each pure substance has characteristic physical and chemical properties (for any bulk quantity under given conditions) that can be used to identify it.
- Gases and liquids are made of molecules or inert atoms that are moving about relative to each other.
- In a liquid, the molecules are constantly in contact with others; in a gas, they are widely spaced except when they happen to collide. In a solid, atoms are closely spaced and may vibrate in position but do not change relative locations.
- Solids may be formed from molecules, or they may be extended structures with repeating subunits (e.g., crystals).
- The changes of state that occur with variations in temperature or pressure can be described and predicted using these models of matter.
- When the motion energy of an object changes, there is inevitably some other change in energy at the same time.
- The amount of energy transfer needed to change the temperature of a matter sample by a given amount depends on the nature of the matter, the size of the sample, and the environment.
- Energy is spontaneously transferred out of hotter regions or objects and into colder ones.
- When light shines on an object, it is reflected, absorbed, or transmitted through the object, depending on the object's material and the frequency (color) of the light.
- The path that light travels can be traced as straight lines, except at surfaces between different transparent materials (e.g., air and water, air and glass) where the light path bends.
- A wave model of light is useful for explaining brightness, color, and the frequency-dependent bending of light at a surface between media.
- However, because light can travel through space, it cannot be a matter wave, like sound or water waves.

*Life science*

- Organisms, and populations of organisms, are dependent on their environmental interactions both with other living things and with nonliving factors.
- In any ecosystem, organisms and populations with similar requirements for food, water, oxygen, or other resources may compete with each other for limited resources, access to which consequently constrains their growth and reproduction. Growth of organisms and population increases are limited by access to resources.
- Similarly, predatory interactions may reduce the number of organisms or eliminate whole populations of organisms. Mutually beneficial interactions, in contrast, may become so interdependent that each organism requires the other for survival. Although the species involved in these competitive, predatory, and mutually beneficial interactions vary across ecosystems, the patterns of interactions of organisms with their environments, both living and nonliving, are shared.
- Food webs are models that demonstrate how matter and energy is transferred between producers, consumers, and decomposers as the three groups interact within an ecosystem. Transfers of matter into and out of the physical environment occur at every level. Decomposers recycle nutrients from dead plant or animal matter back to the soil in terrestrial environments or to the water in aquatic environments. The atoms that make up the organisms in an ecosystem are cycled repeatedly between the living and nonliving parts of the ecosystem.
- Ecosystems are dynamic in nature; their characteristics can vary over time. Disruptions to any physical or biological component of an ecosystem can lead to shifts in all its populations.
- Biodiversity describes the variety of species found in Earth's terrestrial and oceanic ecosystems. The completeness or integrity of an ecosystem's biodiversity is often used as a measure of its health.
- 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.
- 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.
- Comparison of the embryological development of different species also reveals similarities that show relationships not evident in the fully-formed anatomy.
- Natural selection leads to the predominance of certain traits in a population, and the suppression of others.
- In artificial selection, humans have the capacity to influence certain characteristics of organisms by selective breeding. One can choose desired parental traits determined by genes, which are then passed on to offspring.
- Adaptation by natural selection acting over generations is one important process by which species change over time in response to changes in environmental conditions. Traits that support successful survival and reproduction in the new environment become more common; those that do not become less common. Thus, the distribution of traits in a population changes.

*Earth and space science*

- Tectonic processes continually generate new ocean sea floor at ridges and destroy old sea floor at trenches.
- All Earth processes are the result of energy flowing and matter cycling within and among the planet's systems. This energy is derived from the sun and Earth's

hot interior. The energy that flows and matter that cycles produce chemical and physical changes in Earth's materials and living organisms.

- The planet's systems interact over scales that range from microscopic to global in size, and they operate over fractions of a second to billions of years. These interactions have shaped Earth's history and will determine its future.
- Maps of ancient land and water patterns, based on investigations of rocks and fossils, make clear how Earth's plates have moved great distances, collided, and spread apart.
- Water continually cycles among land, ocean, and atmosphere via transpiration, evaporation, condensation and crystallization, and precipitation, as well as downhill flows on land.
- The complex patterns of the changes and the movement of water in the atmosphere, determined by winds, landforms, and ocean temperatures and currents, are major determinants of local weather patterns.
- Global movements of water and its changes in form are propelled by sunlight and gravity.
- Variations in density due to variations in temperature and salinity drive a global pattern of interconnected ocean currents.
- Water's movements—both on the land and underground—cause weathering and erosion, which change the land's surface features and create underground formations.
- Weather and climate are influenced by interactions involving sunlight, the ocean, the atmosphere, ice, landforms, and living things. These interactions vary with latitude, altitude, and local and regional geography, all of which can affect oceanic and atmospheric flow patterns.
- Because these patterns are so complex, weather can only be predicted probabilistically.
- The ocean exerts a major influence on weather and climate by absorbing energy from the sun, releasing it over time, and globally redistributing it through ocean currents.
- Human activities have significantly altered the biosphere, sometimes damaging or destroying natural habitats and causing the extinction of other species. But changes to Earth's environments can have different impacts (negative and positive) for different living things.
- 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.
- Human activities, such as the release of greenhouse gases from burning fossil fuels, are major factors in the current rise in Earth's mean surface temperature (global warming). Reducing the level of climate change and reducing human vulnerability to whatever climate changes do occur depend on the understanding of climate science, engineering capabilities, and other kinds of knowledge, such as understanding of human behavior and on applying that knowledge wisely in decisions and activities.

## Connections to Other Courses

*Physical science*

- Each atom has a charged substructure consisting of a nucleus, which is made of protons and neutrons, surrounded by electrons.
- The periodic table orders elements horizontally by the number of protons in the atom's nucleus and places those with similar chemical properties in columns. The repeating patterns of this table reflect patterns of outer electron states.
- The structure and interactions of matter at the bulk scale are determined by electrical forces within and between atoms.
- A stable molecule has less energy than the same set of atoms separated; one must provide at least this energy in order to take the molecule apart.
- Chemical processes, their rates, and whether or not energy is stored or released can be understood in terms of the collisions of molecules and the rearrangements of atoms into new molecules, with consequent changes in the sum of all bond energies in the set of molecules that are matched by changes in kinetic energy.
- In many situations, a dynamic and condition-dependent balance between a reaction and the reverse reaction determines the numbers of all types of molecules present.
- The fact that atoms are conserved, together with knowledge of the chemical properties of the elements involved, can be used to describe and predict chemical reactions.
- Energy is a quantitative property of a system that depends on the motion and interactions of matter and radiation within that system. That there is a single quantity called energy is due to the fact that a system's total energy is conserved, even as, within the system, energy is continually transferred from one object to another and between its various possible forms.
- At the macroscopic scale, energy manifests itself in multiple ways, such as in motion, sound, light, and thermal energy.
- These relationships are better understood at the microscopic scale, at which all of the different manifestations of energy can be modeled as a combination of energy associated with the motion of particles and energy associated with the configuration (relative position of the particles). In some cases the relative position energy can be thought of as stored in fields (which mediate interactions between particles). This last concept includes radiation, a phenomenon in which energy stored in fields moves across space.
- Conservation of energy means that the total change of energy in any system is always equal to the total energy transferred into or out of the system.
- Energy cannot be created or destroyed, but it can be transported from one place to another and transferred between systems.
- Mathematical expressions, which quantify how the stored energy in a system depends on its configuration (e.g. relative positions of charged particles, compression of a spring) and how kinetic energy depends on mass and speed, allow the concept of conservation of energy to be used to predict and describe system behavior.
- The availability of energy limits what can occur in any system.
- Uncontrolled systems always evolve toward more stable states—that is, toward more uniform energy distribution (e.g., water flows downhill, objects hotter than their surrounding environment cool down).
- Although energy cannot be destroyed, it can be converted to less useful forms—for example, to thermal energy in the surrounding environment.

- Electromagnetic radiation (e.g., radio, microwaves, light) can be modeled as a wave of changing electric and magnetic fields or as particles called photons. The wave model is useful for explaining many features of electromagnetic radiation, and the particle model explains other features.
- When light or longer wavelength electromagnetic radiation is absorbed in matter, it is generally converted into thermal energy (heat). Shorter wavelength electromagnetic radiation (ultraviolet, X-rays, gamma rays) can ionize atoms and cause damage to living cells.

#### *Life science*

- The process of photosynthesis converts light energy to stored chemical energy by converting carbon dioxide plus water into sugars plus released oxygen.
- The sugar molecules thus formed contain carbon, hydrogen, and oxygen: their hydrocarbon backbones are used to make amino acids and other carbon-based molecules that can be assembled into larger molecules (such as proteins or DNA), used for example to form new cells.
- As matter and energy flow through different organizational levels of living systems, chemical elements are recombined in different ways to form different products.
- As a result of these chemical reactions, energy is transferred from one system of interacting molecules to another. Cellular respiration is a chemical process in which the bonds of food molecules and oxygen molecules are broken and new compounds are formed that can transport energy to muscles. Cellular respiration also releases the energy needed to maintain body temperature despite ongoing energy transfer to the surrounding environment.
- Ecosystems have carrying capacities, which are limits to the numbers of organisms and populations they can support. These limits result from such factors as the availability of living and nonliving resources and from such challenges such as predation, competition, and disease. Organisms would have the capacity to produce populations of great size were it not for the fact that environments and resources are finite. This fundamental tension affects the abundance (number of individuals) of species in any given ecosystem.
- Photosynthesis and cellular respiration (including anaerobic processes) provide most of the energy for life processes.
- Plants or algae form the lowest level of the food web. At each link upward in a food web, only a small fraction of the matter consumed at the lower level is transferred upward, to produce growth and release energy in cellular respiration at the higher level. Given this inefficiency, there are generally fewer organisms at higher levels of a food web. Some matter reacts to release energy for life functions, some matter is stored in newly made structures, and much is discarded. The chemical elements that make up the molecules of organisms pass through food webs and into and out of the atmosphere and soil, and they are combined and recombined in different ways. At each link in an ecosystem, matter and energy are conserved.
- Photosynthesis and cellular respiration are important components of the carbon cycle, in which carbon is exchanged among the biosphere, atmosphere, oceans, and geosphere through chemical, physical, geological, and biological processes.
- A complex set of interactions within an ecosystem can keep its numbers and types of organisms relatively constant over long periods of time under stable conditions. If a modest biological or physical disturbance to an ecosystem occurs, it may return to its more or less original status (i.e., the ecosystem is resilient), as opposed to becoming a very different ecosystem. Extreme fluctuations in conditions or the size of any population, however, can challenge the functioning of ecosystems in terms of resources and habitat availability.
- Moreover, anthropogenic changes (induced by human activity) in the environment—including habitat destruction, pollution, introduction of invasive species, overexploitation, and climate change—can disrupt an ecosystem and threaten the survival of some species.
- Genetic information provides evidence of evolution. DNA sequences vary among species, but there are many overlaps; in fact, the ongoing branching that produces multiple lines of descent can be inferred by comparing the DNA sequences of different organisms. Such information is also derivable from the

similarities and differences in amino acid sequences and from anatomical and embryological evidence.

- Natural selection occurs only if there is both (1) variation in the genetic information between organisms in a population and (2) variation in the expression of that genetic information—that is, trait variation—that leads to differences in performance among individuals.
- The traits that positively affect survival are more likely to be reproduced, and thus are more common in the population. Evolution is a consequence of the interaction of four factors: (1) the potential for a species to increase in number, (2) the genetic variation of individuals in a species due to mutation and sexual reproduction, (3) competition for an environment’s limited supply of the resources that individuals need in order to survive and reproduce, and (4) the ensuing proliferation of those organisms that are better able to survive and reproduce in that environment.
- Natural selection leads to adaptation that is, to a population dominated by organisms that are anatomically, behaviorally, and physiologically well suited to survive and reproduce in a specific environment. That is, the differential survival and reproduction of organisms in a population that have an advantageous heritable trait leads to an increase in the proportion of individuals in future generations that have the trait and to a decrease in the proportion of individuals that do not.
- Adaptation also means that the distribution of traits in a population can change when conditions change.
- Changes in the physical environment, whether naturally occurring or human induced, have thus contributed to the expansion of some species, the emergence of new distinct species as populations diverge under different conditions, and the decline—and sometimes the extinction—of some species.
- Species become extinct because they can no longer survive and reproduce in their altered environment. If members cannot adjust to change that is too fast or drastic, the opportunity for the species’ evolution is lost.

#### *Earth and space science*

- The sustainability of human societies and the biodiversity that supports them requires responsible management of natural resources.
- Scientists and engineers can make major contributions by developing technologies that produce less pollution and waste and that preclude ecosystem degradation.
- Though the magnitudes of human impacts are greater than they have ever been, so too are human abilities to model, predict, and manage current and future impacts.
- Through computer simulations and other studies, important discoveries are still being made about how the ocean, the atmosphere, and the biosphere interact and are modified in response to human activities.

**Sample of Open Education Resources**

[MY NASA DATA](#): Students select satellite datasets to answer questions related to system interactions and feedbacks.

[Finding the Crater](#): Students “visit” different K-T boundary sites, evaluate the evidence found in the cores at each site, find these sites on a map, and predict where the impact crater is located.

[Images of Change](#): Students explore these images of the impacts of climate change over time to develop explanations from evidence of how an impact in one component of the Earth system has effects in other components of the Earth system.

[Climate Reanalyzer](#): Students use the Environmental Change Model of the Climate Reanalyzer to study the feedbacks in the climate system.

[USGS Realtime Water data](#) and [Climate data](#): Students create and run an investigation to determine the relationship between streamflow and precipitation data, or another parameter.

[Greenhouse Effect](#): Students explore the atmosphere during the ice age and today. What happens when you add clouds? Change the greenhouse gas concentration and see how the temperature changes. Then compare to the effect of glass panes. Zoom in and see how light interacts with molecules. Do all atmospheric gases contribute to the greenhouse effect?

[Earth Systems Activity](#): Students model the carbon cycle and it’s connection with Earth’s climate.

[Carbon and Climate](#): Students run a model of carbon sources and sinks and interpret results to develop their own model of the relationship of the carbon cycle to the Earth’s climate. Students can also work through the content of the entire module called [Carbon Connections](#) which includes numerous models and interactives to gain a deeper understanding of the role of carbon in the climate system.

[EarthViewer \(IPAd or Android\)](#) or for [Chrome](#) browsers: Students explore the co-evolution of the geology and biology found on Earth to develop arguments from evidence for the co-evolution of geology and biology found on Earth. If iPads, Androids or Chrome browsers are not available, similar interactives may be found at this [link](#), and this [link](#).

**Appendix A: NGSS and Foundations for the Unit**

**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.]* ([HS-ESS2-2](#))

**Plan and conduct an investigation of the properties of water and its effects on Earth materials and surface processes.** *[Clarification Statement: Emphasis is on mechanical and chemical investigations with water and a variety of solid materials to provide the evidence for connections between the hydrologic cycle and system interactions commonly known as the rock cycle. Examples of mechanical investigations include stream transportation and deposition using a stream table, erosion using variations in soil moisture content, or frost wedging by the expansion of water as it freezes. Examples of chemical investigations include chemical weathering and recrystallization (by testing the solubility of different materials) or melt generation (by examining how water lowers the melting temperature of most solids).]* ([HS-ESS2-5](#))

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

**Construct an argument based on evidence about the simultaneous co-evolution 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.]* ([HS-ESS2-7](#))

The Student Learning Objectives above were 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
<p><b>Analyzing and Interpreting Data</b></p> <ul style="list-style-type: none"> <li>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. (HS-ESS2-2)</li> </ul> <p><b>Planning and Carrying Out Investigations</b></p> <ul style="list-style-type: none"> <li>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. (HS-ESS2-5)</li> </ul> <p><b>Developing and Using Models</b></p> <ul style="list-style-type: none"> <li>Develop a model based on evidence to illustrate the relationships between systems or between components of a system. (HS-ESS2-6)</li> </ul> <p><b>Engaging in Argument from Evidence</b></p> <ul style="list-style-type: none"> <li>Construct an oral and written argument or counter-arguments based on data and evidence. (HS-ESS2-7)</li> </ul>	<p><b>ESS2.A: Earth Materials and Systems</b></p> <ul style="list-style-type: none"> <li>Earth’s systems, being dynamic and interacting, cause feedback effects that can increase or decrease the original changes. (HS-ESS2-2.)</li> </ul> <p><b>ESS2.C: The Roles of Water in Earth's Surface Processes</b></p> <ul style="list-style-type: none"> <li>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. (HS-ESS2-5)</li> </ul> <p><b>ESS2.D: Weather and Climate</b></p> <ul style="list-style-type: none"> <li>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. (HS-ESS2-2)</li> </ul> <p><b>ESS2.D: Weather and Climate</b></p> <ul style="list-style-type: none"> <li>Gradual atmospheric changes were due to plants and other organisms that captured carbon dioxide and released oxygen. (HS-ESS2-6),(HS-ESS2-7)</li> <li>Changes in the atmosphere due to human activity have increased carbon dioxide concentrations and thus affect climate. (HS-ESS2-6)</li> </ul>	<p><b>Stability and Change</b></p> <ul style="list-style-type: none"> <li>Change and rates of change can be quantified and modeled over very short or very long periods of time. Some system changes are irreversible. (HS-ESS2-2)</li> <li>Much of science deals with constructing explanations of how things change and how they remain stable. (HS-ESS2-7)</li> </ul> <p><b>Structure and Function</b></p> <ul style="list-style-type: none"> <li>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. (HS-ESS2-5)</li> </ul> <p><b>Energy and Matter</b></p> <ul style="list-style-type: none"> <li>The total amount of energy and matter in closed systems is conserved. (HS-ESS2-6)</li> </ul> <p>-----</p> <p><b>Influence of Engineering, Technology, and Science on Society and the Natural World</b></p> <ul style="list-style-type: none"> <li>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. (HS-ESS2-2)</li> </ul>

	<p><b>ESS2.E Biogeology</b></p> <ul style="list-style-type: none"> <li>The many dynamic and delicate feedbacks between the biosphere and other Earth systems cause a continual co-evolution of Earth’s surface and the life that exists on it. (HS-ESS2-7)</li> </ul>	
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English Language Arts	Mathematics
<p>Cite specific textual evidence to support analysis of science and technical texts, attending to important distinctions the author makes and to any gaps or inconsistencies in the account. (HS-ESS2-2) <b>RST.11-12.1</b></p> <p>Determine the central ideas or conclusions of a text; summarize complex concepts, processes, or information presented in a text by paraphrasing them in simpler but still accurate terms. (HS-ESS2-2) <b>RST.11-12.2</b></p> <p>Conduct short as well as more sustained research projects to answer a question (including a self-generated question) or solve a problem; narrow or broaden the inquiry when appropriate; synthesize multiple sources on the subject, demonstrating understanding of the subject under investigation. (HS-ESS2-5) <b>WHST.11-12.7</b></p> <p>Write arguments focused on <i>discipline-specific content</i>. (HS-ESS2-7) <b>WHST.9-12.1</b></p>	<p>Reason abstractly and quantitatively. (HS-ESS2-2), (HS-ESS2-6) <b>MP.2</b></p> <p>Use units as a way to understand problems and to guide the solution of multi-step problems; choose and interpret units consistently in formulas; choose and interpret the scale and the origin in graphs and data displays. (HS-ESS2-2), (HS-ESS2-6) <b>HSN.Q.A.1</b></p> <p>Choose a level of accuracy appropriate to limitations on measurement when reporting quantities. (HS-ESS2-2), (HS-ESS2-5), (HS-ESS2-6) <b>HSN.Q.A.3</b></p> <p>Model with mathematics. (HS-ESS2-6) <b>MP.4</b></p> <p>Define appropriate quantities for the purpose of descriptive modeling. (HS-ESS2-6) <b>HSN.Q.A.2</b></p>