Biology, Unit 1

Matter and Energy

Overview

Unit abstract

In this unit of study, students will construct explanations for the role of energy in the cycling of matter in organisms and ecosystems. They will apply mathematical concepts to develop evidence to support explanations of the interactions of photosynthesis and cellular respiration, and they will develop models to communicate these explanations. Students will understand organisms' interactions with each other and their physical environment and how organisms obtain resources.

Students can utilize the crosscutting concepts of matter and energy, systems, and system models to make sense of ecosystem dynamics.

Essential questions

- How do organisms obtain and use the energy they need to live and grow?
- How do matter and energy move through ecosystems?

Written Curriculum

Next Generation Science Standards[*]

HS. Matter and Energy in Organisms and Ecosystems

Students who demonstrate understanding can:

HS-LS2-3. **Construct and revise an explanation based on evidence for the cycling of matter and flow of energy in aerobic and anaerobic conditions.** [Clarification Statement: Emphasis is on conceptual understanding of the role of aerobic and anaerobic respiration in different environments.] [Assessment Boundary: Assessment does not include the specific chemical processes of either aerobic or anaerobic respiration.]

The performance expectations 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
Constructing Explanations and Designing Solutions Constructing explanations and designing solutions in 9–12 builds on K–8 experiences and progresses to explanations and designs that are supported by multiple and independent student-generated sources of evidence consistent with scientific ideas, principles, and theories. ▪ 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. (HS-LS2-3) ------------------------------------- ***Connections to Nature of Science*** **Scientific Knowledge is Open to Revision in Light of New Evidence** ▪ Most scientific knowledge is quite durable, but is, in principle, subject to change based on new evidence and/or reinterpretation of existing evidence. (HS-LS2-3)	**LS2.B: Cycles of Matter and Energy Transfer in Ecosystems** ▪ Photosynthesis and cellular respiration (including anaerobic processes) provide most of the energy for life processes. (HS-LS2-3)	**Systems and System Models** **Energy and Matter** ▪ Energy drives the cycling of matter within and between systems. (HS-LS2-3)

Connections to other DCIs in this grade-band: **HS.PS1.B** (HS-LS2-3); **HS.PS3.B** (HS-LS2-3); **HS.PS3.D** (HS-LS2-3); **HS.ESS2.A** (HS-LS2-3)

Articulation across grade-bands: **MS.PS1.B** (HS-LS2-3); **MS.PS3.D** (HS-LS2-3); **MS.LS1.C** (HS-LS2-3); **MS.LS2.B** (HS-LS2-3)

Common Core State Standards Connections:

ELA/Literacy –

RST.11-12.1 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-LS2-3)

WHST.9-12.2 Write informative/explanatory texts, including the narration of historical events, scientific procedures/experiments, or technical processes. (HS-LS2-3)

WHST.9-12.5 Develop and strengthen writing as needed by planning, revising, editing, rewriting, or trying a new approach, focusing on addressing what is most significant for a specific purpose and audience. (HS-LS2-3)

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HS. Matter and Energy in Organisms and Ecosystems

Students who demonstrate understanding can:

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

The performance expectations 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
Using Mathematics and Computational Thinking Mathematical and computational thinking in 9-12 builds on K-8 experiences and progresses to using algebraic thinking and analysis, a range of linear and nonlinear functions including trigonometric functions, exponentials and logarithms, and computational tools for statistical analysis to analyze, represent, and model data. Simple computational simulations are created and used based on mathematical models of basic assumptions. ▪ Use mathematical representations of phenomena or design solutions to support claims. (HS-LS2-4)	**LS2.B: Cycles of Matter and Energy Transfer in Ecosystems** ▪ Plants or algae form the lowest level of the food web. At each link upward in a food web, only a small fraction of the matter consumed at the lower level is transferred upward, to produce growth and release energy in cellular respiration at the higher level. Given this inefficiency, there are generally fewer organisms at higher levels of a food web. Some matter reacts to release energy for life functions, some matter is stored in newly made structures, and much is discarded. The chemical elements that make up the molecules of organisms pass through food webs and into and out of the atmosphere and soil, and they are combined and recombined in different ways. At each link in an ecosystem, matter and energy are conserved. (HS-LS2-4)	**Energy and Matter** ▪ Energy cannot be created or destroyed—it only moves between one place and another place, between objects and/or fields, or between systems.(HS-LS2-4)

Connections to other DCIs in this grade-band: **HS.PS3.B** (HS-LS2-4); **HS.PS3.D** (HS-LS2-4);

Articulation across grade-bands: **MS.PS3.D** (HS-LS2-4); **MS.LS1.C** (HS-LS2-4); **MS.LS2.B** (HS-LS2-4)

Common Core State Standards Connections:

Mathematics –

MP.2	Reason abstractly and quantitatively. (HS-LS2-4)
MP.4	Model with mathematics. *(HS-LS2-4)*
HSN-Q.A.1	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-LS2-4)
HSN-Q.A.2	Define appropriate quantities for the purpose of descriptive modeling. *(HS-LS2-4)*
HSN-Q.A.3	Choose a level of accuracy appropriate to limitations on measurement when reporting quantities. (HS-LS2-4)

HS. Matter and Energy in Organisms and Ecosystems		
Students who demonstrate understanding can: **HS-LS2-5. Develop a model to illustrate the role of photosynthesis and cellular respiration in the cycling of carbon among the biosphere, atmosphere, hydrosphere, and geosphere.** [Clarification Statement: Examples of models could include simulations and mathematical models.] [Assessment Boundary: Assessment does not include the specific chemical steps of photosynthesis and respiration.]		
The performance expectations 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**
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 worlds. ▪ Develop a model based on evidence to illustrate the relationships between systems or components of a system. (HS-LS2-5)	**LS2.B: Cycles of Matter and Energy Transfer in Ecosystems** ▪ 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. (HS-LS2-5) **PS3.D: Energy in Chemical Processes** ▪ The main way that solar energy is captured and stored on Earth is through the complex chemical process known as photosynthesis. *(secondary to HS-LS2-5)*	**Systems and System Models** ▪ Models (e.g., physical, mathematical, computer models) can be used to simulate systems and interactions—including energy, matter, and information flows—within and between systems at different scales. (HS-LS2-5)
Connections to other DCIs in this grade-band: **HS.PS1.B** (HS-LS2-5); **HS.ESS2.D** (HS-LS2-5)		
Articulation across grade-bands: **MS.PS3.D** (HS-LS2-5); **MS.LS1.C** (HS-LS2-5); **MS.LS2.B** (HS-LS2-5); **MS.ESS2.A** (HS-LS2-5)		
Common Core State Standards Connections: N/A		

Clarifying the standards

Prior learning

The following disciplinary core ideas are prior learning for the concepts in this unit of study. By the end of Grade 8, students know that:

Physical science

- Substances react chemically in characteristic ways.
- In a chemical process, atoms that make up the original substances are regrouped into different molecules, and the new substances have different properties from those of the reactants.
- In a chemical process, the total number of each type of atom is conserved, and thus the mass does not change.
- Some chemical reactions release energy; others store energy.
- The chemical reaction by which plants produce complex food molecules requires energy input from sunlight. In this reaction, carbon dioxide and water combine to form carbon-based organic molecules and to release oxygen.

Life science

- Cellular respiration in plants and animals involves chemical reactions with oxygen that released stored energy. Carbon-based molecules react with oxygen to produce carbon dioxide and other materials.
- Plants, algae, and many microorganisms use the energy from light, carbon dioxide from the atmosphere, and water to make sugars (food) through the process of photosynthesis, which also releases oxygen. These sugars can be used immediately or stored for growth or later use.
- Within individual organisms, food moves through a series of chemical reactions in which it is broken down and rearranged to form new molecules, support growth, or release energy.
- Food webs are models that demonstrate how matter and energy are transferred among 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 living and nonliving parts of the ecosystem.

Earth and space science

- All Earth processes are the result of energy flowing and matter cycling within and among the planet's systems.
- The energy that flows and the 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.

Progression of current learning

Driving question 1
How does matter cycle and energy flow in aerobic and anaerobic conditions?

Concepts

- Energy drives the cycling of matter within and between systems.
- Energy drives the cycling of matter within and between systems in aerobic and anaerobic conditions.
- Photosynthesis and cellular respiration (including anaerobic processes) provide most of the energy for life processes.

Practices

- Construct and revise an explanation for the cycling of matter and flow of energy in aerobic and anaerobic conditions, 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.
- Construct and revise an explanation for the cycling of matter and flow of energy in

aerobic and anaerobic conditions, considering that most scientific knowledge is quite durable but is, in principle, subject to change based on new evidence and/or reinterpretation of existing evidence.

Driving question 2
How does matter cycle and energy flow among organisms in an ecosystem?

Concepts

- Energy cannot be created or destroyed—it only moves between one place and another place, between objects and/or fields, or between systems.
- At each link in an ecosystem, matter and energy are conserved.
- 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.

Practices

- Support claims for the cycling of matter and flow of energy among organisms in an ecosystem using conceptual thinking and mathematical representations of phenomena.
- Use a mathematical model of stored energy in biomass to describe the transfer of energy from one trophic level to another and to show how matter and energy are conserved as matter cycles and energy flows through ecosystems.
- Use a mathematical model to describe the conservation of atoms and molecules as they move through an ecosystem.
- Use proportional reasoning to describe the cycling of matter and flow of energy through an ecosystem.

Driving question 3
What are the roles of photosynthesis and cellular respiration among the biosphere, atmosphere, hydrosphere, and geosphere?

Concepts

- Models (e.g., physical, mathematical, computer) can be used to simulate systems and interactions—including energy, matter, and information flows—within and between systems at different scales.
- Photosynthesis and cellular respiration are important components of the carbon cycle,

Practices

- Develop a model, based on evidence, to illustrate the roles of photosynthesis and cellular respiration in the cycling of carbon among the biosphere, atmosphere, hydrosphere, and geosphere, showing the relationships among variables in systems and their components in the natural and designed world.

in which carbon is exchanged among the biosphere, atmosphere, oceans, and geosphere through chemical, physical, geological, and biological processes.

- The main way that solar energy is captured and stored on Earth is through the complex chemical process known as photosynthesis.

- Develop a model, based on evidence, to illustrate the roles of photosynthesis and cellular respiration in the cycling of carbon among the biosphere, atmosphere, hydrosphere, and geosphere at different scales.

Integration of content, practices, and crosscutting concepts

Students will reinforce their understanding of the concept that energy drives the cycling of matter within and between systems by applying this concept directly to ecosystem processes and biogeochemical cycles. A variety of models, including computer simulations, diagrams, and drawings, could be used to enhance visual, verbal, and/or written understanding of the various ecological cycles (e.g., carbon, nitrogen, water, phosphorus). Modeling of photosynthesis and cellular respiration using chemical equations that summarize the interactions between these processes is covered in the chemistry course.

Energy flows within an ecosystem; therefore, a pattern of transfer is predictable and observable based on historical ecological data, since energy moves through trophic levels. Student-generated pyramids of biomass and food webs could illustrate this. Plants, algae, and chemosynthetic organisms form the lowest level of a food web. Students will learn that energy transfer from producer to multiple consumer levels is inefficient. Emphasize that 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.

Because energy cannot be created or destroyed and can move only between objects, fields, or systems, students must understand that an ecological system is a self-regulating accumulation of biotic and abiotic factors influenced by size, time, and available energy driving the cycling of matter. Models of an ecological system, such as energy pyramids or biogeochemical cycles, could be used to illustrate this concept.

The reactants and products of photosynthesis and cellular respiration (aerobic and anaerobic) will be used to explain energy transfer and cycling of matter. The carbon cycle can be used as a reference for this. Students must understand that photosynthesis and cellular respiration (including aerobic and anaerobic conditions) provide most of the energy for life processes.

Students must construct and revise an explanation of matter cycling and energy flowing in aerobic and anaerobic conditions based on valid and reliable evidence obtained from a variety of sources. Students might engage in their own investigations, simulations, and peer reviews, and/or generate models to validate theories. The assumption is 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 demonstrate that most scientific knowledge is quite durable but is, in principle, subject to change based on new evidence and/or reinterpretation of existing evidence, students should conduct an investigation of previous experiments that contributed to our understanding of photosynthesis and/or cellular respiration.

Using mathematical representations (e.g., pyramids of biomass, numbers, and energy amounts) and/or population size, students can manipulate proportions and calculations based on input and output of systems. Some matter reacts to release energy for life functions, some matter is stored in newly made structures, and much matter is discarded. Atoms and molecules—such as carbon, oxygen, hydrogen and nitrogen, which make up biotic and abiotic parts of the biosphere (atmosphere and soil)—are combined and recombined, demonstrating the conservation of matter and flow of energy.

To understand energy conservation, students will use proportional reasoning to demonstrate that on average, regardless of scale, 10% of energy is transferred up from one trophic level to another. Students might use various pyramids (e.g., energy, biomass) and calculate the amount of available energy at each trophic level.

Students could also analyze diagrams of chemical cycles (carbon, nitrogen, water, etc.) to identify the movement of matter within ecosystems.

Early in this unit, students examine biogeochemical cycles and how chemical elements are cycled. Building on this knowledge, students will investigate how carbon compounds are exchanged among biosphere, atmosphere, oceans, and geosphere through chemical, physical, geological, and biological processes such as photosynthesis and cellular respiration. Students will learn how photosynthesis (the main way that solar energy is captured and stored on Earth) and cellular respiration are important components of the carbon cycle, in which carbon is exchanged between living and nonliving systems. Assessment does not include the specific chemical steps of photosynthesis and respiration.

Through the use of diagrams, concept maps, or computer models, students will examine how energy is cycled within systems. Students will examine how energy drives the cycling of matter, using diagrams of ecosystems to map the flow of energy and the simultaneous changes in matter. Students could construct two systems, including autotrophs and heterotrophs, to model the transfer of energy. Emphasis is on the construction of student-based theories and explanations based on the interaction of the system. Students will then revise their primary explanation based on new evidence. Student explanations should demonstrate an understanding of the relationship between photosynthesis and cellular respiration.

Integration of mathematics and English language arts/literacy

Mathematics

- Represent the cycling of matter and flow of energy among organisms in an ecosystem symbolically and manipulate the representing symbols. Make sense of quantities of and relationships between matter and energy as they cycle and flow through an ecosystem.
- Use a mathematical model to describe the cycling of matter and flow of energy among organisms in an ecosystem. Identify important quantities in the cycling of matter and flow of energy among organisms in an ecosystem 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 matter and flow of energy among organisms in an ecosystem. Choose and interpret units consistently in formulas to determine the cycling of matter and flow of energy among organisms in an ecosystem. Choose and interpret the scale and the origin in graphs and data displays representing the cycling of matter and flow of energy among organisms in an ecosystem.
- Define appropriate quantities to represent matter and energy for the purpose of descriptive modeling of their cycling and flow among organisms in ecosystems.
- Choose a level of accuracy appropriate to limitations on measurement when reporting quantities representing matter cycles and energy flows among organisms in ecosystems.

English language arts/literacy

- Cite specific textual evidence to support an explanation for the cycling of matter and flow of energy in aerobic and anaerobic conditions, attending to important distinctions the author makes and to any gaps or inconsistencies in the account.
- Develop and write an explanation, based on evidence, for the cycling of matter and flow of energy in aerobic and anaerobic conditions by selecting the most significant and relevant facts, extended definitions, concrete details, quotations, or other information and examples.

- Develop and strengthen an explanation based on evidence for the cycling of matter and flow of energy in aerobic and anaerobic conditions by planning, revising, editing, rewriting, or trying a new approach, focusing on addressing what is most significant for a specific purpose and audience.

Connected learning

Connections to disciplinary core ideas in other high school courses are as follows:

Physical science

- 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.
- 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.

Earth and space science

- Earth's systems, being dynamic and interacting, cause feedback effects that can increase or decrease the original changes.
- 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, and 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.
- The geological record shows that changes to global and regional climate can be caused by interactions among changes in the sun's energy output or Earth's orbit, tectonic events, ocean circulation, volcanic activity, glaciers, vegetation, and human activities. These changes can occur on a variety of time scales from sudden (e.g., volcanic ash clouds) to intermediate (ice ages) to very long tectonic cycles.

- The foundation for Earth's global climate systems is the electromagnetic radiation from the sun, as well as its reflection, absorption, storage, and distribution among the atmosphere, ocean, and land systems, and this energy's re-radiation into space.
- Gradual atmospheric changes are due to plants and other organisms that capture carbon dioxide and release oxygen.
- Changes in the atmosphere due to human activity have increased carbon dioxide concentrations and thus affect climate.

Number of Instructional Days

Recommended number of instructional days: 10 (1 day = approximately 50 minutes)

Note—The recommended number of days is an estimate based on the information available at this time. Teachers are strongly encouraged to review the entire unit of study carefully and collaboratively to determine whether adjustments to this estimate need to be made.

Additional NGSS Resources

The following resources were consulted during the writing of this unit:

- Next Generation Science Standards Appendices L and M
- *A Framework for K–12 Science Education*
- *Common Core State Standards for Mathematics* and *Common Core State Standards for English Language Arts and Literacy in History/Social Studies, Science, & Technical Subjects*

Biology, Unit 2

Interdependent Relationships in Ecosystems

Overview

Unit abstract

In this unit of study, students formulate answers to the question "how and why do organisms interact with each other (biotic factors) and their environment (abiotic factors), and what affects these interactions?" Secondary ideas include the interdependent relationships in ecosystems; dynamics of ecosystems; and functioning, resilience, and social interactions, including group behavior. Students can use mathematical reasoning and models to demonstrate fundamental concepts such as carrying capacity, factors affecting biodiversity and populations, and the previously learned cycling of matter and flow of energy. Studying the role of animal behavior in interactions among individuals and species increases student understanding of interactions among organisms and how these interactions influence the dynamics of ecosystems.

Essential questions

- How and why do living organisms interact with each other and their environment?
- What are the effects of organisms' interactions with each other and their environment?

Written Curriculum

Next Generation Science Standards

HS. Interdependent Relationships in Ecosystems

Students who demonstrate understanding can:

HS-LS2-1. Use mathematical and/or computational representations to support explanations of factors that affect carrying capacity of ecosystems at different scales. [Clarification Statement: Emphasis is on quantitative analysis and comparison of the relationships among interdependent factors including boundaries, resources, climate and competition. Examples of mathematical comparisons could include graphs, charts, histograms, and population changes gathered from simulations or historical data sets.] [Assessment Boundary: Assessment does not include deriving mathematical equations to make comparisons.]

The performance expectations 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
Using Mathematics and Computational Thinking Mathematical and computational thinking in 9-12 builds on K-8 experiences and progresses to using algebraic thinking and analysis, a range of linear and nonlinear functions including trigonometric functions, exponentials and logarithms, and computational tools for statistical analysis to analyze, represent, and model data. Simple computational simulations are created and used based on mathematical models of basic assumptions. ▪ Use mathematical and/or computational representations of phenomena or design solutions to support explanations. (HS-LS2-1)	**LS2.A: Interdependent Relationships in Ecosystems** ▪ 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. (HS-LS2-1)	**Scale, Proportion, and Quantity** ▪ The significance of a phenomenon is dependent on the scale, proportion, and quantity at which it occurs. (HS-LS2-1)

Connections to other DCIs in this grade-band: N/A

Articulation across grade-bands: **MS.LS2.A** (HS-LS2-1); **MS.LS2.C** (HS-LS2-1); **MS.ESS3.A** (HS-LS2-1); **MS.ESS3.C** (HS-LS2-1)

HS. Interdependent Relationships in Ecosystems

Students who demonstrate understanding can:

HS-LS2-2. Use mathematical representations to support and revise explanations based on evidence about factors affecting biodiversity and populations in ecosystems of different scales. [Clarification Statement: Examples of mathematical representations include finding the average, determining trends, and using graphical comparisons of multiple sets of data.] [Assessment Boundary: Assessment is limited to provided data.]

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

Science and Engineering Practices

Using Mathematics and Computational Thinking

Mathematical and computational thinking in 9-12 builds on K-8 experiences and progresses to using algebraic thinking and analysis, a range of linear and nonlinear functions including trigonometric functions, exponentials and logarithms, and computational tools for statistical analysis to analyze, represent, and model data. Simple computational simulations are created and used based on mathematical models of basic assumptions.

- Use mathematical representations of phenomena or design solutions to support and revise explanations. (HS-LS2-2)

Connections to Nature of Science

Scientific Knowledge is Open to Revision in Light of New Evidence

- Most scientific knowledge is quite durable, but is, in principle, subject to change based on new evidence and/or reinterpretation of existing evidence. (HS-LS2-2)

Disciplinary Core Ideas

LS2.A: Interdependent Relationships in Ecosystems

- 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. (HS-LS2-2)

LS2.C: Ecosystem Dynamics, Functioning, and Resilience

- 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. (HS-LS2-2)

Crosscutting Concepts

Scale, Proportion, and Quantity

- Using the concept of orders of magnitude allows one to understand how a model at one scale relates to a model at another scale. (HS-LS2-2)

Connections to other DCIs in this grade-band: **HS.ESS2.E** (HS-LS2-2); **HS.ESS3.A** (HS-LS2-2); **HS.ESS3.C** (HS-LS2-2); **HS.ESS3.D** (HS-LS2-2)

Articulation across grade-bands: **MS.LS2.A** (HS-LS2-2); **MS.LS2.C** (HS-LS2-2); **MS.ESS3.C** (HS-LS2-2)

Common Core State Standards Connections:

ELA/Literacy –

RST.11-12.1	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-LS2-2)*
WHST.9-12.2	Write informative/explanatory texts, including the narration of historical events, scientific procedures/ experiments, or technical processes. *(HS-LS2-2)*

Mathematics –

MP.2	Reason abstractly and quantitatively. (HS-LS2-2)
MP.4	Model with mathematics. *(HS-LS2-2)*
HSN-Q.A.1	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-LS2-2)
HSN-Q.A.2	Define appropriate quantities for the purpose of descriptive modeling. *(HS-LS2-2)*
HSN-Q.A.3	Choose a level of accuracy appropriate to limitations on measurement when reporting quantities. (HS-LS2-2)

HS. Interdependent Relationships in Ecosystems

Students who demonstrate understanding can:

HS-LS2-6. Evaluate the claims, evidence, and reasoning that the complex interactions in ecosystems maintain relatively consistent numbers and types of organisms in stable conditions, but changing conditions may result in a new ecosystem. [Clarification Statement: Examples of changes in ecosystem conditions could include modest biological or physical changes, such as moderate hunting or a seasonal flood; and extreme changes, such as volcanic eruption or sea level rise.]

The performance expectations 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
Engaging in Argument from Evidence Engaging in argument from evidence in 9–12 builds from 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. ▪ Evaluate the claims, evidence, and reasoning behind currently accepted explanations or solutions to determine the merits of arguments. (HS-LS2-6) ------------------------------------- ***Connections to Nature of Science*** **Scientific Knowledge is Open to Revision in Light of New Evidence** ▪ Scientific argumentation is a mode of logical discourse used to clarify the strength of relationships between ideas and evidence that may result in revision of an explanation. (HS-LS2-6)	**LS2.C: Ecosystem Dynamics, Functioning, and Resilience** ▪ 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. (HS-LS2-6)	**Stability and Change** ▪ Much of science deals with constructing explanations of how things change and how they remain stable. (HS-LS2-6)

Connections to other DCIs in this grade-band: **HS.ESS2.E** (HS-LS2-6)

Articulation across grade-bands: **MS.LS2.A** (HS-LS2-6); **MS.LS2.C** (HS-LS2-6); **MS.ESS2.E** (HS-LS2-6); **MS.ESS3.C** (HS-LS2-6)

Common Core State Standards Connections:

ELA/Literacy –

RST.9-10.8 Assess the extent to which the reasoning and evidence in a text support the author's claim or a recommendation for solving a scientific or technical problem. (HS-LS2-6)

RST.11-12.1 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-LS2-6)

RST.11-12.7 Integrate and evaluate multiple sources of information presented in diverse formats and media (e.g., quantitative data, video, multimedia) in order to address a question or solve a problem. *(HS-LS2-6)*

RST.11-12.8 Evaluate the hypotheses, data, analysis, and conclusions in a science or technical text, verifying the data when possible and corroborating or challenging conclusions with other sources of information. (HS-LS2-6)

Mathematics –

MP.2 Reason abstractly and quantitatively. (HS-LS2-6)

HSS-ID.A.1 Represent data with plots on the real number line. *(HS-LS2-6)*

HSS-IC.A.1 Understand statistics as a process for making inferences about population parameters based on a random sample from that population. *(HS-LS2-6)*

HSS-IC.B.6 Evaluate reports based on data. *(HS-LS2-6)*

Clarifying the standards

Prior learning

The following disciplinary core ideas are prior learning for the concepts in this unit of study. By the end of Grade 8, students know that:

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.
- 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.

Earth and space science

- Humans depend on Earth’s land, ocean, atmosphere, and biosphere for many different resources. Minerals, fresh water, and biosphere resources are limited, and many are not renewable or replaceable over human lifetimes. These resources are distributed unevenly around the planet as a result of past geologic processes.
- 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.

Progression of current learning

Driving question 1

What are the factors that affect the carrying capacity of ecosystems at different scales?

Concepts

- Ecosystems have carrying capacities, which are limits to the number 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, completion, 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 (the number of individuals) of species in any given ecosystem.
- The significance of carrying capacity in ecosystems is dependent on the scale proportion and quantity at which it occurs.
- Quantitative analysis can be used to compare and determine relationships among interdependent factors that affect the carrying capacity of ecosystems at different scales.

Practices

- Use mathematical and/or computational representations to support explanations of factors that affect carrying capacity of ecosystems at different scales.
- Use quantitative analysis to compare relationships among interdependent factors and represent their effects on the carrying capacity of ecosystems at different scales.

Driving question 2

What are the factors affecting biodiversity and populations in ecosystems of different scales?

Concepts

- Most scientific knowledge is quite durable, but is, in principle, subject to change based on new evidence and/or reinterpretation of existing evidence.
- Ecosystems have carrying capacities, which are limits to the number of organisms and populations they can support.

Practices

- Use mathematical representations to support and revise explanations based on evidence about factors affecting biodiversity and populations in ecosystems of different scales.
- Use the concept of orders of magnitude to represent how factors affecting biodiversity and populations in ecosystems at one scale relate to those factors at another scale.

- These limits result from such factors as the availability of living and nonliving resources and from such challenges such as predation, completion, 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.
- 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.
- Using the concept of orders of magnitude allows one to understand how a model of factors affecting biodiversity and populations in ecosystems at one scale relates to a model at another scale.

Driving question 3

What are the complex interactions in ecosystems that maintain relatively consistent numbers and types of organisms or that may result in a new ecosystem?

Concepts

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

Practices

- Evaluate the claims, evidence, and reasoning that support the contention that complex interactions in ecosystems maintain relatively consistent numbers and types of organisms in stable conditions, but changing conditions may result in a new ecosystem.
- Construct explanations of how modest biological or physical changes versus

return to its more or less original status (i.e., the ecosystem) 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.
- Scientific argumentation is a mode of logical discourse used to clarify the strength of relationships between ideas and evidence that may result in revision of an explanation.

extreme changes affect stability and change in ecosystems.

Integration of content, practices, and crosscutting concepts

In this unit, students will be applying their knowledge of matter cycling and energy flowing in ecosystems as they examine the effects of these processes on populations, carrying capacity, community structure, and biodiversity.

The unit begins with the idea that ecosystems have carrying capacities that limit the number of organisms and populations they can support, based on factors such as the availability of living and nonliving resources and challenges such as predation, competition, and disease. In order to build an understanding of the factors that limit carrying capacities of organisms and populations, students could view and analyze quantitative data from graphs, charts, simulations, and historical data sets of population changes to determine cause-and-effect relationships that lead to change over time. Emphasis should be on having students make quantitative analysis and comparisons of the relationships among interdependent factors, including boundaries, resources, climate, and competition. When choosing materials for analysis, data should be presented at different scales, and students should use units as a way to understand the factors that affect carrying capacity of ecosystems at different scales. Students might also generate charts, graphs, and histograms from data sets. When reporting quantities representing the factors that affect carrying capacity of ecosystems, students should consider any limitations on measurement.

Mathematical and computational representations can be used to show that 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. Students can use quantitative analysis (e.g., graphs and other data displays with appropriate units and scale) to compare and determine how relationships among interdependent factors such as famine, disease, competition, predation, and shelter affect the carrying capacity of ecosystems at different scales. Examples of different scales could be data sets showing the population dynamics of an ecosystem in a jar, predator–prey oscillation studies, introduction of invasive species into an ecosystem, or changes as a result of the natural process of succession.

Through relevant reading experiences, students might also develop and write explanations, citing textual evidence, for factors that affect carrying capacity of ecosystems. In their explanations, students should select the most significant and relevant facts, extended definitions, concrete details, and quotations to support their explanations.

The availability of current technology allows for more sophisticated observations and more accurate data collection and analysis. These data represent the most recent explanations for phenomena. Students might study existing data on factors that affect biodiversity and write explanatory texts, citing evidence and noting gaps or inconsistencies. In their own investigations, students might model how bacterial populations respond to exposure to antibacterial gel over time, illustrating community biodiversity. Community diversity at a microscopic scale, illustrating logistic, exponential growth, and carrying capacity, can be used to better model similar patterns on a larger scale (e.g., habitat, ecosystem, biome, biosphere) using data sets. Students should identify important factors affecting biodiversity and populations in ecosystems, quantify those factors using appropriate units, and draw conclusions based on any noted relationships.

Students should have an overall understanding of the significance of carrying capacity and its dependence upon the relationships among interdependent factors including boundaries, resources, climate, and competition.

Quantitative data from simulations of modest biological or physical disturbances can demonstrate how ecosystems can return to original status, more or less. Examples of data showing modest disturbances might include changes in weather patterns (e.g., drought), clearing of land for development, or forest fires. In order to understand this phenomenon, students might also analyze data from old-field succession, abandoned urban parking lots, or transect studies in order to make claims, using evidence, about effects on biodiversity and populations. Students should also examine evidence of extreme fluctuations, such as from natural disasters, and how the functioning of ecosystems can be challenged in terms of resources and habitat availability. Mathematical representations to support explanations should include finding averages, determining trends, and using graphical comparisons of multiple sets of data.

Using food webs and ecological models/states, students can observe that the numbers and types of organisms are relatively constant over long periods of time under stable conditions. In order to make mathematical representations to support claims, students need to examine data showing the complex set of interactions that occur in ecosystems. Students should examine data illustrating the quantitative fluctuations in populations that occur because of factors such as predator–prey relationships, availability of resources, and habitat availability. To support claims about complex interactions in ecosystems and changes in numbers of organisms in stable and changing conditions, students should be able to cite specific textual evidence and integrate and evaluate multiple sources of information presented in diverse formats.

Students could develop an understanding of orders of magnitude that exist within the ecosystem concept through experiences such as microscopic examination of pond water producers and consumers (phytoplankton and zooplankton), construction of jar ecosystems, or visits to local terrestrial and/or aquatic ecosystems (forest, pond). Their study of ecosystem scale could then extend to models of regional ecosystems and global ecosystem types (biomes). Through activities such as these, students learn that ecological processes and interactions present at the microscopic level are the same as those found in the biosphere.

Integration of DCI from prior units within this grade level

In Unit 1, students learned that energy drives the cycling of matter through an ecosystem. They will use this information to understand the effect that biological disturbances have on ecosystems. Students investigate organisms' interactions with each other and their physical environment and how organisms obtain resources.

Integration of mathematics and English language arts/literacy

Mathematics

- Represent the factors that affect carrying capacity of ecosystems at different scales symbolically and manipulate the representing symbols. Make sense of quantities and relationships between different factors that affect carrying capacity of ecosystems at different scales.
- Use a mathematical model to describe factors that affect carrying capacity of ecosystems at different scales. Identify important quantities in factors that affect carrying capacity of ecosystems at different

scales 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 how factors affect the carrying capacity of ecosystems at different scales. Choose and interpret units consistently in formulas to determine carrying capacity. Choose and interpret the scale and origin in graphs and data displays showing factors that affect carrying capacity of ecosystems at different scales.
- Define appropriate quantities for the purpose of descriptive modeling of factors that affect carrying capacity of ecosystems at different scales.
- Choose a level of accuracy appropriate to limitations on measurement when reporting quantities representing factors that affect carrying capacity of ecosystems at different scales.
- Represent the factors that affect biodiversity and populations in ecosystems symbolically and manipulate the representing symbols. Make sense of quantities and relationships between different factors and their effects on biodiversity and populations in ecosystems.
- Use a mathematical model to describe the factors that affect biodiversity and populations in ecosystems. Identify important quantities in factors that affect biodiversity and populations in ecosystems 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 factors that affect biodiversity and populations in ecosystems. Choose and interpret units consistently in formulas to determine effects on biodiversity and populations in ecosystems. Choose and interpret the scale and the origin in graphs and data displays representing the factors that affect biodiversity and populations in ecosystems.
- Define appropriate quantities for the purpose of descriptive modeling of the factors that affect biodiversity and populations in ecosystems.
- Choose a level of accuracy appropriate to limitations on measurement when reporting quantities of the factors that affect biodiversity and populations in ecosystems.
- Represent claims that complex interactions in ecosystems maintain relatively consistent numbers and types of organisms in stable conditions, but changing conditions may result in a new ecosystem symbolically and manipulate the representing symbols. Make sense of quantities and relationships between complex interactions in ecosystems and ways in which ecosystems remain stable and ways in which they change.
- Represent data relating to complex interactions in ecosystems and their effects on stability and change in ecosystems with plots on the real number line (graph).
- Understand statistics as a process for making inferences about complex interactions in ecosystems and organism population parameters based on a random sample from that population.
- Evaluate reports of complex interactions and their effects on stability and change in ecosystems based on data showing numbers and types of organisms in stable conditions and in changing conditions.

English language arts/literacy

- Cite specific textual evidence to support analysis of science and technical texts supporting explanations of factors that affect carrying capacity of ecosystems at different scales, attending to important distinctions the author makes and to any gaps or inconsistencies in the account.
- Develop and write explanations of factors that affect carrying capacity of ecosystems at different scales by selecting the most significant and relevant facts, extended definitions, concrete details, quotations, or other information and examples appropriate to the audience's knowledge of the topic.
- Cite specific textual evidence to support how factors affect biodiversity and populations in ecosystems of different scale, attending to important distinctions the author makes and to any gaps or inconsistencies in the account.
- Write explanatory texts based on scientific procedures/experiments to explain how different factors affect biodiversity and populations in ecosystems at different scales.
- Assess the extent to which the claim that complex interactions in ecosystems maintain relatively consistent numbers and types of organisms in stable conditions, but changing conditions may result in a new ecosystem, is supported by reasoning and evidence.
- Cite specific textual evidence to support claims that complex interactions in ecosystems maintain relatively consistent numbers and types of organisms in stable conditions, but changing conditions may result in a new ecosystem, attending to important distinctions the author makes and to any gaps or inconsistencies in the account.
- Integrate and evaluate multiple sources of information presented in diverse formats and media in order to address claims that complex interactions in ecosystems maintain relatively consistent numbers and types of organisms in stable conditions, but changing conditions may result in a new ecosystem.
- Evaluate the validity of evidence and reasoning that support claims that complex interactions in ecosystems maintain relatively consistent numbers and types of organisms in stable conditions, but changing conditions may result in a new ecosystem, verifying the data when possible and corroborating or challenging conclusions with other sources of information.

Connected learning

Connections to disciplinary core ideas in other high school courses are as follows:

Earth and space science

- The many dynamic and delicate feedbacks among the biosphere and other Earth systems cause a continual co-evolution of Earth's surface and the life that exists on it.
- Resource availability has guided the development of human society.
- All forms of energy production and other resource extraction have associated economic, social, environmental, and geopolitical costs and risks as well as benefits. New technologies and social regulations can change the balance of these factors.
- 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.

- Although the magnitude of human impacts is greater than it has 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.

Number of Instructional Days

Recommended number of instructional days: 10 (1 day = approximately 50 minutes)

Note—The recommended number of days is an estimate based on the information available at this time. Teachers are strongly encouraged to review the entire unit of study carefully and collaboratively to determine whether adjustments to this estimate need to be made.

Additional NGSS Resources

The following resources were consulted during the writing of this unit:

- Next Generation Science Standards appendices L and M
- *A Framework for K–12 Science Education*
- *Common Core State Standards for Mathematics* and *Common Core State Standards for English Language Arts and Literacy in History/Social Studies, Science, & Technical Subjects*

Biology Unit 3
Human Activity and Climate

Overview

Unit abstract

In this unit of study, students will examine factors that have influenced the distribution and development of human society; these factors include climate, natural resource availability, and natural disasters. Students will use computational representations to analyze how earth systems and their relationships are being modified by human activity.

Students will develop an understanding of how human activities affect natural resources and of the interdependence between humans and Earth's systems, which affect the availability of natural resources. Students will apply their engineering capabilities to reduce human impacts on earth systems and improve social and environmental cost–benefit ratios. The crosscutting concepts of cause and effect, systems and systems models, stability and change, and the influence of engineering, technology, and science on society and the natural world are called out as organizing concepts for this unit.

Essential questions

- How do humans depend on Earth's resources?
- How and why do humans interact with their environment and what are the effects of these interactions?

Written Curriculum

Next Generation Science Standards

HS. Human Sustainability

Students who demonstrate understanding can:

HS-ESS3-1. Construct an explanation based on evidence for how the availability of natural resources, occurrence of natural hazards, and changes in climate have influenced human activity. [Clarification Statement: Examples of key natural resources include access to fresh water (such as rivers, lakes, and groundwater), regions of fertile soils such as river deltas, and high concentrations of minerals and fossil fuels. Examples of natural hazards can be from interior processes (such as volcanic eruptions and earthquakes), surface processes (such as tsunamis, mass wasting and soil erosion), and severe weather (such as hurricanes, floods, and droughts). Examples of the results of changes in climate that can affect populations or drive mass migrations include changes to sea level, regional patterns of temperature and precipitation, and the types of crops and livestock that can be raised.]

The performance expectations above were 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 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 knowledge, principles, and theories.

- Construct 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. (HS-ESS3-1)

Disciplinary Core Ideas

ESS3.A: Natural Resources

- Resource availability has guided the development of human society. (HS-ESS3-1)

ESS3.B: Natural Hazards

- Natural hazards and other geologic events have shaped the course of human history; [they] have significantly altered the sizes of human populations and have driven human migrations. (HS-ESS3-1)

Crosscutting Concepts

Cause and Effect

- Empirical evidence is required to differentiate between cause and correlation and make claims about specific causes and effects. (HS-ESS3-1)

Connections to Engineering, Technology, and Applications of Science

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

- Modern civilization depends on major technological systems. (HS-ESS3-1)

Connections to other DCIs in this grade-band: N/A

Articulation of DCIs across grade-bands: **MS.LS2.A** (HS-ESS3-1); **MS.LS4.D** (HS-ESS3-1); **MS.ESS2.A** (HS-ESS3-1); **MS.ESS3.A** (HS-ESS3-1); **MS.ESS3.B** (HS-ESS3-1)

Common Core State Standards Connections:

ELA/Literacy –

RST.11-12.1 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-ESS3-1)*

WHST.9-12.2 Write informative/explanatory texts, including the narration of historical events, scientific procedures/ experiments, or technical processes. (HS-ESS3-1)

Mathematics –

MP.2 Reason abstractly and quantitatively. *(HS-ESS3-1)*

HSN-Q.A.1 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-ESS3-1)*

HSN-Q.A.2 Define appropriate quantities for the purpose of descriptive modeling. *(HS-ESS3-1)*

HSN-Q.A.3 Choose a level of accuracy appropriate to limitations on measurement when reporting quantities. *(HS-ESS3-1)*

HS. Human Sustainability

Students who demonstrate understanding can:

HS-ESS3-6. Use a computational representation to illustrate the relationships among Earth systems and how those relationships are being modified due to human activity. [Clarification Statement: Examples of Earth systems to be considered are the hydrosphere, atmosphere, cryosphere, geosphere, and/or biosphere. An example of the far-reaching impacts from a human activity is how an increase in atmospheric carbon dioxide results in an increase in photosynthetic biomass on land and an increase in ocean acidification, with resulting impacts on sea organism health and marine populations.] [Assessment Boundary: Assessment does not include running computational representations but is limited to using the published results of scientific computational models.]

The performance expectations 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
Using Mathematics and Computational Thinking Mathematical and computational thinking in 9-12 builds on K-8 experiences and progresses to using algebraic thinking and analysis, a range of linear and nonlinear functions including trigonometric functions, exponentials and logarithms, and computational tools for statistical analysis to analyze, represent, and model data. Simple computational simulations are created and used based on mathematical models of basic assumptions. ▪ Use a computational representation of phenomena or design solutions to describe and/or support claims and/or explanations. (HS-ESS3-6)	**ESS2.D: Weather and Climate** ▪ Current models predict that, although future regional climate changes will be complex and varied, average global temperatures will continue to rise. The outcomes predicted by global climate models strongly depend on the amounts of human-generated greenhouse gases added to the atmosphere each year and by the ways in which these gases are absorbed by the ocean and biosphere. *(secondary to HS-ESS3-6)* **ESS3.D: Global Climate Change** ▪ 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. (HS-ESS3-6)	**Systems and System Models** ▪ When investigating or describing a system, the boundaries and initial conditions of the system need to be defined and their inputs and outputs analyzed and described using models. (HS-ESS3-6)

Connections to other DCIs in this grade-band: **HS.LS2.B** (HS-ESS3-6); **HS.LS2.C** (HS-ESS3-6); **HS.LS4.D** (HS-ESS3-6); **HS.ESS2.A** (HS-ESS3-6)

Articulation of DCIs across grade-bands: **MS.LS2.C** (HS-ESS3-6); **MS.ESS2.A** (HS-ESS3-6); **MS.ESS2.C** (HS-ESS3-6); **MS.ESS3.C** (HS-ESS3-6); **MS.ESS3.D** (HS-ESS3-6)

Common Core State Standards Connections:

Mathematics –

MP.2 Reason abstractly and quantitatively. (HS-ESS3-6)

MP.4 Model with mathematics. (HS-ESS3-6)

HSN-Q.A.1 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-ESS3-6)

HSN-Q.A.2 Define appropriate quantities for the purpose of descriptive modeling. (HS-ESS3-6)

HSN-Q.A.3 Choose a level of accuracy appropriate to limitations on measurement when reporting quantities. (HS-ESS3-6)

HS. Weather and Climate

Students who demonstrate understanding can:

HS-ESS3-5. **Analyze geoscience data and the results from global climate models to make an evidence-based forecast of the current rate of global or regional climate change and associated future impacts to Earth systems.** [Clarification Statement: Examples of evidence, for both data and climate model outputs, are for climate changes (such as precipitation and temperature) and their associated impacts (such as on sea level, glacial ice volumes, or atmosphere and ocean composition).] [Assessment Boundary: Assessment is limited to one example of a climate change and its associated impacts.]

The performance expectations 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
Analyzing and Interpreting Data Analyzing data in 9–12 builds on K–8 experiences and progresses to introducing more detailed statistical analysis, the comparison of data sets for consistency, and the use of models to generate and analyze data. ▪ Analyze data using computational models in order to make valid and reliable scientific claims. (HS-ESS3-5) --- ***Connections to Nature of Science*** **Scientific Investigations Use a Variety of Methods** ▪ Science investigations use diverse methods and do not always use the same set of procedures to obtain data. (HS-ESS3-5) ▪ New technologies advance scientific knowledge. (HS-ESS3-5) **Scientific Knowledge is Based on Empirical Evidence** ▪ Science knowledge is based on empirical evidence. (HS-ESS3-5) ▪ Science arguments are strengthened by multiple lines of evidence supporting a single explanation. (HS-ESS3-5)	**ESS3.D: Global Climate Change** ▪ 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. (HS-ESS3-5)	**Stability and Change** ▪ Change and rates of change can be quantified and modeled over very short or very long periods of time. Some system changes are irreversible. (HS-ESS3-5)

Connections to other DCIs in this grade-band: **HS.PS3.B** (HS-ESS3-5); **HS.PS3.D** (HS-ESS3-5); **HS.LS1.C** (HS-ESS3-5); **HS.ESS2.D** (HS-ESS3-5)

Articulation of DCIs across grade-bands: **MS.PS3.B** (HS-ESS3-5); **MS.PS3.D** (HS-ESS3-5); **MS.ESS2.A** (HS-ESS3-5); **MS.ESS2.D** (HS-ESS3-5); **MS.ESS3.B** (HS-ESS3-5); **MS.ESS3.C** (HS-ESS3-5); **MS.ESS3.D** (HS-ESS3-5)

Common Core State Standards Connections:

ELA/Literacy –

RST.11-12.1 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-ESS3-5)

RST.11-12.2 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-ESS3-5)*

RST.11-12.7 Integrate and evaluate multiple sources of information presented in diverse formats and media (e.g., quantitative data, video, multimedia) in order to address a question or solve a problem. (HS-ESS3-5)

Mathematics –

MP.2 Reason abstractly and quantitatively. (HS-ESS3-5)

HSN-Q.A.1 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-ESS3-5)

HSN-Q.A.2 Define appropriate quantities for the purpose of descriptive modeling. *(HS-ESS3-5)*

HSN-Q.A.3 Choose a level of accuracy appropriate to limitations on measurement when reporting quantities. (HS-ESS3-5)

HS. Human Sustainability

Students who demonstrate understanding can:

HS-ESS3-4. Evaluate or refine a technological solution that reduces impacts of human activities on natural systems.* [Clarification Statement: Examples of data on the impacts of human activities could include the quantities and types of pollutants released, changes to biomass and species diversity, or areal changes in land surface use (such as for urban development, agriculture and livestock, or surface mining). Examples for limiting future impacts could range from local efforts (such as reducing, reusing, and recycling resources) to large-scale geoengineering design solutions (such as altering global temperatures by making large changes to the atmosphere or ocean).]

The performance expectations 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
Constructing Explanations and Designing Solutions Constructing explanations and designing solutions in 9–12 builds on K–8 experiences and progresses to explanations and designs that are supported by multiple and independent student-generated sources of evidence consistent with scientific knowledge, principles, and theories. • Design or refine a solution to a complex real-world problem, based on scientific knowledge, student-generated sources of evidence, prioritized criteria, and tradeoff considerations. (HS-ESS3-4)	**ESS3.C: Human Impacts on Earth Systems** ▪ Scientists and engineers can make major contributions by developing technologies that produce less pollution and waste and that preclude ecosystem degradation. (HS-ESS3-4) **ETS1.B. Designing Solutions to Engineering Problems** ▪ When evaluating solutions, it is important to take into account a range of constraints, including cost, safety, reliability, and aesthetics, and to consider social, cultural, and environmental impacts. *(secondary to HS-ESS3-4)*	**Stability and Change** ▪ Feedback (negative or positive) can stabilize or destabilize a system. (HS-ESS3-4) --------------------------------------- ***Connections to Engineering, Technology, and Applications of Science*** **Influence of Engineering, Technology, and Science on Society and the Natural World** ▪ Engineers continuously modify these systems to increase benefits while decreasing costs and risks. (HS-ESS3-4)

Connections to other DCIs in this grade-band: **HS.LS2.C** (HS-ESS3-4); **HS.LS4.D** (HS-ESS3-4)

Articulation of DCIs across grade-bands: **MS.LS2.C** (HS-ESS3-4); **MS.ESS2.A** (HS-ESS3-4); **MS.ESS3.B** (HS-ESS3-4); **MS.ESS3.C** (HS-ESS3-4); **MS.ESS3.D** (HS-ESS3-4)

Common Core State Standards Connections:

ELA/Literacy –

RST.11-12.1 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-ESS3-4)

RST.11-12.8 Evaluate the hypotheses, data, analysis, and conclusions in a science or technical text, verifying the data when possible and corroborating or challenging conclusions with other sources of information. (HS-ESS3-4)

Mathematics –

MP.2 Reason abstractly and quantitatively. *(HS-ESS3-4)*

HSN-Q.A.1 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-ESS3-4)

HSN-Q.A.2 Define appropriate quantities for the purpose of descriptive modeling. *(HS-ESS3-4)*

HSN-Q.A.3 Choose a level of accuracy appropriate to limitations on measurement when reporting quantities. *(HS-ESS3-4)*

HS. Engineering Design		
Students who demonstrate understanding can: **HS-ETS1-3. Evaluate a solution to a complex real-world problem based on prioritized criteria and trade-offs that account for a range of constraints, including cost, safety, reliability, and aesthetics, as well as possible social, cultural, and environmental impacts.**		
The performance expectations 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**
Constructing Explanations and Designing Solutions Constructing explanations and designing solutions in 9–12 builds on K–8 experiences and progresses to explanations and designs that are supported by multiple and independent student-generated sources of evidence consistent with scientific ideas, principles and theories. ▪ Evaluate a solution to a complex real-world problem, based on scientific knowledge, student-generated sources of evidence, prioritized criteria, and tradeoff considerations. (HS-ETS1-3)	**ETS1.B: Developing Possible Solutions** ▪ When evaluating solutions, it is important to take into account a range of constraints, including cost, safety, reliability, and aesthetics, and to consider social, cultural, and environmental impacts. (HS-ETS1-3)	***Connections to Engineering, Technology, and Applications of Science*** **Influence of Science, Engineering, and Technology on Society and the Natural World** ▪ New technologies can have deep impacts on society and the environment, including some that were not anticipated. Analysis of costs and benefits is a critical aspect of decisions about technology. (HS-ETS1-3)
Connections to HS-ETS1.A: Defining and Delimiting Engineering Problems include: **Physical Science:** HS-PS2-3, HS-PS3-3 *Connections to HS-ETS1.B: Designing Solutions to Engineering Problems include:* **Earth and Space Science:** HS-ESS3-2, HS-ESS3-4, **Life Science:** HS-LS2-7, HS-LS4-6 *Connections to HS-ETS1.C: Optimizing the Design Solution include:* **Physical Science:** HS-PS1-6, HS-PS2-3		
Articulation of DCIs across grade-bands: **MS.ETS1.A** (HS-ETS1-3); **MS.ETS1.B** (HS-ETS1-3)		
Common Core State Standards Connections: *ELA/Literacy –* **RST.11-12.7** Integrate and evaluate multiple sources of information presented in diverse formats and media (e.g., quantitative data, video, multimedia) in order to address a question or solve a problem. *(HS-ETS1-3)* **RST.11-12.8** Evaluate the hypotheses, data, analysis, and conclusions in a science or technical text, verifying the data when possible and corroborating or challenging conclusions with other sources of information. (HS-ETS1-3) **RST.11-12.9** Synthesize information from a range of sources (e.g., texts, experiments, simulations) into a coherent understanding of a process, phenomenon, or concept, resolving conflicting information when possible. *(HS-ETS1-3)* *Mathematics –* **MP.2** Reason abstractly and quantitatively. *(HS-ETS1-3)* **MP.4** Model with mathematics.(HS-ETS1-3)		

Clarifying the standards

Prior learning

The following disciplinary core ideas are prior learning for the concepts in this unit of study. By the end of Grade 8, students know that:

Physical science

- 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.

Life science

- Organisms, and populations of organisms, are dependent on their environmental interactions 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.
- Changes in biodiversity can influence humans' resources, such as food, energy, and medicines, as well as ecosystem services that humans rely on, such as water purification and recycling.
- 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 chemical reaction by which plants produce complex food molecules (sugars) requires an energy input (i.e., from sunlight) to occur. In this reaction, carbon dioxide and water combine to form carbon-based organic molecules and release oxygen.
- Cellular respiration in plants and animals involve chemical reactions with oxygen that release stored energy. In these processes, complex molecules containing carbon react with oxygen to produce carbon dioxide and other materials.

Earth and space science

- 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 the 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.
- Humans depend on Earth's land, ocean, atmosphere, and biosphere for many different resources. Minerals, fresh water, and biosphere resources are limited, and many are not renewable or replaceable over human lifetimes. These resources are distributed unevenly around the planet as a result of past geologic processes.
- Mapping the history of natural hazards in a region, combined with an understanding of related geologic forces, can help forecast the locations and likelihoods of future events.
- 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.
- 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.
- 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.

Progression of current learning

Driving question 1
How are human activities influenced by the availability of natural resources, occurrence of natural hazards, and changes in climate?

Concepts

- Resource vitality has guided the development of human society.
- Natural hazards and other geologic events have shaped the course of human history.
- Natural hazards and other geologic events have significantly altered the sizes of human populations and have driven human migration.
- Empirical evidence is required to differentiate between cause and correlation and make claims about how the availability of natural resources, occurrence of natural hazards, and changes in climate have influenced human activities.
- Modern civilization depends on major technological systems.
- Changes in climate can affect population or drive mass migration.

Practices

- Construct an explanation based on valid and reliable evidence for how the availability of natural resources, occurrence of natural hazards, and changes in climate have influenced human activity.
- Use empirical evidence to differentiate between how the availability of natural resources, occurrence of natural hazards, and changes in climate have influenced human activity.

Driving question 2
What are the relationships among earth's systems and how are those relationships being modified due to human activity?

Concepts

- Current models predict that, although future regional climate changes will be complex and will vary, average global temperatures will continue to rise.
- The outcomes predicted by global climate models strongly depend on the amounts of human-generated greenhouse gases are added to the atmosphere each year and by the ways in which these gases are absorbed by the ocean and biosphere.
- Through computer simulations and other studies, important discoveries are still being made about how the ocean, the

Practices

- Use a computational representation to illustrate the relationships among Earth systems and how these relationships are being modified due to human activity.
- Describe the boundaries of Earth systems.
- Analyze and describe the inputs and outputs of Earth systems.

atmosphere, and the biosphere interact and are modified in response to human activities.

- When investigating or describing a system, the boundaries and initial conditions of the system need to be defined and their inputs and outputs analyzed and described using models.
- Criteria may need to be broken down into similar ones that can be approached systematically, and decisions about the priority of certain criteria over others (trade-offs) may be needed.
- Human activities can modify the relationships among Earth systems.

Driving question 3
What is the current rate of global or regional climate change and what are the associated future impacts to Earth's systems?

Concepts

- Although the magnitude of human impacts are greater than they have ever been, so too are human abilities to model, predict, and manage current and future impacts.
- Change in rates of change can be quantified and modeled over very short or very long periods of time. Some system changes are irreversible.
- Science investigations use diverse methods and do not always use the same set of procedures to obtain data.
- Science knowledge is based on empirical evidence.

Practices

- Analyze geosciences data and the results from global climate models to make an evidence-based forecast of the current rate of global or regional climate change and associated future impacts to Earth systems.
- Quantify and model change and rates of change in geosciences data and rates of global or regional climate change and associated impacts to Earth systems.

Driving question 4
How can the impacts of human activities on natural systems be reduced?

Concepts

- Scientist and engineers can make major contributions by developing technologies that produce less pollution and waste and that preclude ecosystem degradation.

Practices

- Evaluate or refine a technological solution that reduces impacts of human activities on natural systems based on scientific knowledge and student-generated sources of evidence; prioritize criteria and tradeoff considerations.

- Engineers continuously modify these systems to increase benefits while decreasing costs and risks.
- Feedback (negative or positive) can stabilize or destabilize natural systems.
- When evaluating solutions, it is important to take into account a range of constraints, including costs, safety, reliability, and aesthetics, and to consider social, cultural, and environmental impacts.
- New technologies can have deep impacts on society and the environment, including some that are not anticipated.
- Analysis of costs and benefits is a critical aspect of decisions about technology.

Integration of content, practices, and crosscutting concepts

Environmental factors have affected human populations over the course of history. Resource availability, natural disasters, and other geologic events have driven global development of societies, sizes of human populations, and human migrations. Student understanding of these relationships could be enhanced by examining and citing evidence from text or other investigations that show correlations between human population distribution and regional availability of resources such as fresh water, fertile soils, and fossils fuels. Students should look for cause-and-effect relationships between human population distribution and resource availability and distinguish between causality and correlation. In developing an explanation for how the availability of natural resources has influenced human activity, students might consider, for example, the dependence of large urban populations on the technology required to deliver potable water. An example of the role that technology plays could include the impounding of the Colorado River by the Hoover Dam and the formation of Lake Mead, which provides the water required to support large human populations in an otherwise arid and desert habitat.

Historical accounts of natural disasters (e.g., Krakatoa eruption, American Dust Bowl, Galveston Hurricane, and Hurricane Katrina) resulting human suffering and loss of life could provide empirical evidence of past impacts on human population size and distribution. Previous climate change events (sea level fall and rise, desertification of the Sahara) could be studied as examples of natural events that can drive human migrations. Students should use evidence from data analysis to make inferences and predictions about the impacts of future climate change and global warming on displacement or migration of humans.

When examining and reporting data, students should represent resource availability, natural disasters, and human activity symbolically and determine what quantitative relationships exist. Students might map these relationships in graphs, charts, or other descriptive models, while considering any limitations on measurement when reporting quantities.

Through computer simulations and other studies, important discoveries are still being made about how the ocean, atmosphere, and biosphere interact and are modified in response to human activities. Students should describe the boundaries of Earth’s systems by looking at models, data sets, or graphics showing temperatures and currents of the ocean and atmosphere. They should identify evidence to support the claim that human activity can modify Earth's systems. When students are investigating or describing a system, the boundaries and initial conditions of the system need to be defined and their inputs and outputs analyzed and described using models. Students might also analyze and describe the inputs and outputs of Earth's systems by researching and investigating the amount of carbon dioxide produced by human activities. In their research, students should integrate and evaluate multiple sources of information and verify data when possible. Students could then design a solution to decrease the amount of carbon dioxide added by human activity. The design process may need to be broken down into logical steps that can be approached systematically, and decisions about the priority of certain criteria over others should be considered throughout the process.

Current global models predict that, although future regional climate changes will be complex and varied, average global temperatures will continue to rise. The outcomes predicted by global climate models depend on the amount of human-generated greenhouse gases added to the atmosphere each year and on the ways in which these gases are absorbed by the ocean and biosphere. Students can use computational representations of geoscience data to illustrate these relationships and make forecasts about Earth's systems. Students might illustrate how relationships are being modified due to human activity by graphing temperature changes over a period of time. Rates of change should be quantified and modeled at different time scales. In symbolic representations of relationships between Earth's systems and human activity, students should consider appropriate quantities and limitations on measurement when reporting data.

When evaluating or refining a technological solution that reduces impacts of human activities on natural systems, such as use of alternative energy sources, students should read and integrate multiple sources of information to create a coherent understanding of the problem. In their evaluation, they should consider costs, benefits, and risks of systems created by engineers. When evaluating solutions, students should take into account a range of constraints, including costs, safety, and reliability, as well as any social, cultural, and environmental impacts. Models created by students should be used to illustrate and analyze positive and negative feedback within natural systems that may lead to stabilization or destabilization.

Examples of technologies that might limit future impacts of human activity could be small-scale local efforts or large-scale geoengineering solutions for more global issues. Students might research and analyze data regarding the use of fossil fuels to power machines and the quantities and types of pollutants produced. The analysis of data could be used to investigate how alternative energy machines, such as electric- or hydrogen-powered cars, could be used to reduce carbon emissions. Students should consider the availability of infrastructure, trained technicians, economic constraints, reliability, and other trade-offs, like personal aesthetic preference, in their evaluations or design decisions.

Integration of engineering

Performance expectation HS-ESS3-4 specifically identifies a connection to HS-ETS1-3. This requires students to evaluate a solution to a complex real-world problem based on prioritized criteria and trade-offs that account for a range of constraints, including cost, safety, reliability, and aesthetics, as well as possible social, cultural, and environmental impacts. To meet this requirement, students will evaluate technological solutions that limit human impacts on natural systems. In their evaluations, students should consider how 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.

Integration of DCI from prior units within this grade level

Students will use their understanding of photosynthesis, cellular respiration, and the carbon cycle from prior units and examine their relationship to climate change and human impact on climate. They will develop an understanding of how human activity can influence the complex set of interactions within an ecosystem, causing changes in the number of different types of species.

Students will also build on the idea that 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. All of these concepts support students' understanding of human dependence on Earth's resources, human interactions with the environment, and human impacts on Earth's systems.

Integration of mathematics and/or English language arts/literacy

Mathematics

- Represent how the availability of natural resources, occurrence of natural hazards, and changes in climate have influenced human activity symbolically and manipulate the representing symbols. Make sense of quantities and relationships between availability of natural resources, occurrence of natural hazards, and changes in climate and their influence on human activity.
- Use units as a way to understand the relationships between availability of natural resources, occurrence of natural hazards, and changes in climate and their influence on human activity. Choose and interpret units consistently in formulas to determine relationships between availability of natural resources, occurrence of natural hazards, and changes in climate and their influence on human activity. Choose and interpret the scale and the origin in graphs and data displays representing relationships between availability of natural resources, occurrence of natural hazards, and changes in climate and their influence on human activity.
- Define appropriate quantities for the purpose of descriptive modeling of relationships between availability of natural resources, occurrence of natural hazards, and changes in climate and their influence on human activity.
- Choose a level of accuracy appropriate to limitations on measurement when reporting quantities showing relationships between availability of natural resources, occurrence of natural hazards, and changes in climate and their influence on human activity.
- Represent symbolically the relationships among Earth systems and how these relationships are being modified due to human activity, and manipulate the representing symbols. Make sense of quantities and relationships between Earth systems and human activity.
- Use a mathematical model to describe the relationships among Earth systems and how those relationships are being modified due to human activity. Identify important quantities in human activities and their effects on Earth systems and map their relationships using tools. Analyze thrse 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 how relationships among Earth systems are being modified by human activity. Choose and interpret units consistently in formulas to determine relationships among Earth systems and how they are being modified by human activity. Choose and interpret the scale and origin in graphs and data displays representing how human activity modifies relationships among Earth systems.
- Define appropriate quantities for the purpose of descriptive modeling of how the relationships among Earth systems are being modified due to human activity.
- Choose a level of accuracy appropriate to limitations on measurement when reporting quantities representing relationships among Earth systems and how they are being modified due to human activity.
- Represent forecasts of the current rate of global or regional climate change and associated future impacts to Earth systems symbolically, and manipulate the representing symbols. Make sense of quantities and relationships between geoscience data and results from global climate models to

forecast of the current rate of global or regional climate change and associated future impacts to Earth systems.

- Define appropriate quantities for the purpose of descriptive modeling of forecasts of the current rate of global or regional climate change and associated future impacts to Earth systems.
- Choose a level of accuracy appropriate to limitations on measurement when reporting quantities representing forecasts of the current rate of global or regional climate change and associated future impacts to Earth systems.
- Represent impacts of human activities on natural systems symbolically and manipulate the representing symbols. Make sense of quantities and relationships between human activities and natural systems.
- Use units as a way to understand the impacts of human activities on natural systems. Choose and interpret units consistently in formulas to determine the impacts of human activities on natural systems. Choose and interpret the scale and origin in graphs and data displays representing the impacts of human activities on natural systems.
- Define appropriate quantities for the purpose of descriptive modeling of the impacts of human activities on natural systems.
- Choose a level of accuracy appropriate to limitations on measurement when reporting quantities of human activities and their impacts on natural systems.
- Use a mathematical model to describe human activities and their effects on natural systems. Identify important quantities in human activities and their effects on natural systems 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.

English language arts/literacy

- Cite specific textual evidence of the availability of natural resources, occurrence of natural hazards, and changes in climate and their influence on human activity.
- Use empirical evidence to write an explanation for how the availability of natural resources, occurrence of natural hazards, and changes in climate have influenced human activity.
- Cite specific textual evidence supporting forecasts of the current rate of global or regional climate change and associated future impacts to Earth systems, attending to important distinctions the author makes and to any gaps or inconsistencies in the account.
- Determine and clearly state results from data on global climate models and associated impacts to Earth systems by paraphrasing them in simpler but still accurate terms.
- Integrate and evaluate global climate change data from multiple sources to reveal patterns and relationships and forecast current rate of global or regional climate change and associated future impacts.
- Cite specific textual evidence to support a technological solution that reduces the impacts of human activities on natural systems, attending to important distinctions the author makes and to any gaps or inconsistencies in the account.
- Evaluate the validity of hypotheses, data, analysis, and conclusions in a science or technical text about the impact of human activities on natural systems, verifying the data when possible and corroborating or challenging conclusions with other sources of information.

- Integrate and evaluate multiple sources of information presented in diverse formats and media in order to evaluate or refine a technological solution that reduces impacts of human activities on natural systems.
- Read multiple sources in order to refine design solutions to reduce impacts of human activities on natural systems and create a coherent understanding of the problem.

Connected learning

Connections to disciplinary core ideas in other high school courses are as follows:

Physical science

- 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.

Life science

- 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, the ecosystem 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.
- 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.

Earth and space science

- Humans depend on the living world for resources and other benefits provided by biodiversity. But human activity is also having adverse impacts on biodiversity through overpopulation, overexploitation, habitat destruction, pollution, introduction of invasive species, and climate change. Thus sustaining biodiversity so that ecosystem functioning and productivity are maintained is essential to supporting and enhancing life on Earth. Sustaining biodiversity also aids humanity by preserving landscapes of recreational or inspirational value.
- Earth's systems, being dynamic and interacting, cause feedback effects that can increase or decrease the original changes.
- 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.
- Gradual atmospheric changes were due to plants and other organisms that captured carbon dioxide and released oxygen.
- Changes in the atmosphere due to human activity have increased carbon dioxide concentrations and thus affect climate.

Number of Instructional Days

Recommended number of instructional days: 16 (1 day = approximately 50 minutes)

Note—The recommended number of days is an estimate based on the information available at this time. Teachers are strongly encouraged to review the entire unit of study carefully and collaboratively to determine whether adjustments to this estimate need to be made.

Additional NGSS Resources

The following resources were consulted during the writing of this unit:

- NGSS Appendices L and M
- *A Framework for K-12 Science Education*
- *Common Core State Standards for Mathematics* and *Common Core State Standards for Literacy in History/Social Studies, Science, & Technical Subjects*

Biology Unit 4
Human Activity and Biodiversity

Overview

Unit abstract

In this unit of study, mathematical models provide support for students' conceptual understanding of systems and students' ability to design, evaluate, and refine solutions for reducing the impact of human activities on the environment and maintaining biodiversity. Students will create or revise a simulation to test solutions for mitigating adverse impacts of human activity on biodiversity. Crosscutting concepts of systems and system models play a central role in students' understanding of science and engineering practices and core ideas of ecosystems.

Mathematical models provide support for students' conceptual understanding of systems and their ability to develop design solutions for reducing the impact of human activities on the environment and maintaining biodiversity.

Essential questions

- How do humans depend on Earth's resources?
- How and why do humans interact with their environment, and what are the effects of these interactions?

Written Curriculum

Next Generation Science Standards

HS. Human Sustainability

Students who demonstrate understanding can:

HS-ESS3-3. Create a computational simulation to illustrate the relationships among management of natural resources, the sustainability of human populations, and biodiversity. [Clarification Statement: Examples of factors that affect the management of natural resources include costs of resource extraction and waste management, per-capita consumption, and the development of new technologies. Examples of factors that affect human sustainability include agricultural efficiency, levels of conservation, and urban planning.] [Assessment Boundary: Assessment for computational simulations is limited to using provided multi-parameter programs or constructing simplified spreadsheet calculations.]

The performance expectations 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
Using Mathematics and Computational Thinking Mathematical and computational thinking in 9-12 builds on K-8 experiences and progresses to using algebraic thinking and analysis, a range of linear and nonlinear functions including trigonometric functions, exponentials and logarithms, and computational tools for statistical analysis to analyze, represent, and model data. Simple computational simulations are created and used based on mathematical models of basic assumptions. ▪ Create a computational model or simulation of a phenomenon, designed device, process, or system. (HS-ESS3-3)	**ESS3.C: Human Impacts on Earth Systems** ▪ The sustainability of human societies and the biodiversity that supports them requires responsible management of natural resources. (HS-ESS3-3)	**Stability and Change** ▪ Change and rates of change can be quantified and modeled over very short or very long periods of time. Some system changes are irreversible. (HS-ESS3-3) --------------------------------------- ***Connections to Engineering, Technology, and Applications of Science*** **Influence of Engineering, Technology, and Science on Society and the Natural World** ▪ Modern civilization depends on major technological systems. (HS-ESS3-3) ▪ New technologies can have deep impacts on society and the environment, including some that were not anticipated. (HS-ESS3-3) ------------------------------------- ***Connections to Nature of Science*** **Science is a Human Endeavor** ▪ Scientific knowledge is a result of human endeavors, imagination, and creativity. (HS-ESS3-3)

Connections to other DCIs in this grade-band: **HS.PS1.B** (HS-ESS3-3); **HS.LS2.A** (HS-ESS3-3); **HS.LS2.B** (HS-ESS3-3); **HS.LS2.C** (HS-ESS3-3); **HS.LS4.D** (HS-ESS3-3); **HS.ESS2.A** (HS-ESS3-3); **HS.ESS2.E** (HS-ESS3-3)

Articulation of DCIs across grade-bands: **MS.PS1.B** (HS-ESS3-3); **MS.LS2.A** (HS-ESS3-3); **MS.LS2.B** (HS-ESS3-3); **MS.LS2.C** (HS-ESS3-3); **MS.LS4.C** (HS-ESS3-3); **MS.LS4.D** (HS-ESS3-3); **MS.ESS2.A** (HS-ESS3-3); **MS.ESS3.A** (HS-ESS3-3); **MS.ESS3.C** (HS-ESS3-3)

Common Core State Standards Connections:

Mathematics –

MP.2 Reason abstractly and quantitatively. (HS-ESS3-3)

MP.4 Model with mathematics. (HS-ESS3-3)

HS. Interdependent Relationships in Ecosystems		
Students who demonstrate understanding can: **HS-LS2-7. Design, evaluate, and refine a solution for reducing the impacts of human activities on the environment and biodiversity. *** [Clarification Statement: Examples of human activities can include urbanization, building dams, and dissemination of invasive species.]		
The performance expectations above were 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 9–12 builds on K–8 experiences and progresses to explanations and designs that are supported by multiple and independent student-generated sources of evidence consistent with scientific ideas, principles, and theories. ▪ Design, evaluate, and refine a solution to a complex real-world problem, based on scientific knowledge, student-generated sources of evidence, prioritized criteria, and tradeoff considerations. (HS-LS2-7)	**Disciplinary Core Ideas** **LS2.C: Ecosystem Dynamics, Functioning, and Resilience** ▪ 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. (HS-LS2-7) **LS4.D: Biodiversity and Humans** ▪ Biodiversity is increased by the formation of new species (speciation) and decreased by the loss of species (extinction). *(secondary to HS-LS2-7)* ▪ Humans depend on the living world for the resources and other benefits provided by biodiversity. But human activity is also having adverse impacts on biodiversity through overpopulation, overexploitation, habitat destruction, pollution, introduction of invasive species, and climate change. Thus sustaining biodiversity so that ecosystem functioning and productivity are maintained is essential to supporting and enhancing life on Earth. Sustaining biodiversity also aids humanity by preserving landscapes of recreational or inspirational value. *(secondary to HS-LS2-7)* **ETS1.B: Developing Possible Solutions** ▪ When evaluating solutions, it is important to take into account a range of constraints, including cost, safety, reliability, and aesthetics, and to consider social, cultural, and environmental impacts. *(secondary to HS-LS2-7)*	**Crosscutting Concepts** **Stability and Change** ▪ Much of science deals with constructing explanations of how things change and how they remain stable. (HS-LS2-7)
Connections to other DCIs in this grade-band: **HS.ESS2.D** (HS-LS2-7); **HS.ESS2.E** (HS-LS2-7); **HS.ESS3.A** (HS-LS2-7); **HS.ESS3.C** (HS-LS2-7)		
Articulation across grade-bands: **MS.LS2.C** (HS-LS2-7); **MS.ESS3.C** (HS-LS2-7); **MS.ESS3.D** (HS-LS2-7)		

Common Core State Standards Connections:
ELA/Literacy –

RST.9-10.8	Assess the extent to which the reasoning and evidence in a text support the author's claim or a recommendation for solving a scientific or technical problem. *(HS-LS2-7)*
RST.11-12.7	Integrate and evaluate multiple sources of information presented in diverse formats and media (e.g., quantitative data, video, multimedia) in order to address a question or solve a problem. *(HS-LS2-7)*
RST.11-12.8	Evaluate the hypotheses, data, analysis, and conclusions in a science or technical text, verifying the data when possible and corroborating or challenging conclusions with other sources of information. (HS-LS2-7)
WHST.9-12.7	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-LS2-7)

Mathematics –

MP.2	Reason abstractly and quantitatively. *(HS-LS2-7)*
HSN-Q.A.1	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

HS. Interdependent Relationships in Ecosystems

Students who demonstrate understanding can:

HS-LS4-6. Create or revise a simulation to test a solution to mitigate adverse impacts of human activity on biodiversity. * [Clarification Statement: Emphasis is on designing solutions for a proposed problem related to threatened or endangered species, or to genetic variation of organisms for multiple species.]

The performance expectations 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
Using Mathematics and Computational Thinking Mathematical and computational thinking in 9-12 builds on K-8 experiences and progresses to using algebraic thinking and analysis, a range of linear and nonlinear functions including trigonometric functions, exponentials and logarithms, and computational tools for statistical analysis to analyze, represent, and model data. Simple computational simulations are created and used based on mathematical models of basic assumptions. ▪ Create or revise a simulation of a phenomenon, designed device, process, or system. (HS-LS4-6)	**LS4.C: Adaptation** ▪ 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. (HS-LS4-6) **LS4.D: Biodiversity and Humans** ▪ Humans depend on the living world for the resources and other benefits provided by biodiversity. But human activity is also having adverse impacts on biodiversity through overpopulation, overexploitation, habitat destruction, pollution, introduction of invasive species, and climate change. Thus sustaining biodiversity so that ecosystem functioning and productivity are maintained is essential to supporting and enhancing life on Earth. Sustaining biodiversity also aids humanity by preserving landscapes of recreational or inspirational value. (HS-LS4-6) **ETS1.B: Developing Possible Solutions** ▪ When evaluating solutions, it is important to take into account a range of constraints, including cost, safety, reliability, and aesthetics, and to consider social, cultural, and environmental impacts. *(secondary to HS-LS4-6)* ▪ Both physical models and computers can be used in various ways to aid in the engineering design process. Computers are useful for a variety of purposes, such as running simulations to test different ways of solving a problem or to see which one is most efficient or economical; and in making a persuasive presentation to a client about how a given design will meet his or her needs. *(secondary to HS-LS4-6)*	**Cause and Effect** ▪ Empirical evidence is required to differentiate between cause and correlation and make claims about specific causes and effects. (HS-LS4-6)

Connections to other DCIs in this grade-band: **HS.ESS2.D** (HS-LS4-6); **HS.ESS2.E** (HS-LS4-6); **HS.ESS3.A** (HS-LS4-6); **HS.ESS3.C** (HS-LS4-6); **HS.ESS3.D** (HS-LS4-6)

Articulation across grade-bands: **MS.LS2.C** (HS-LS4-6), **MS.ESS3.C** (HS-LS4-6)

Common Core State Standards Connections:
ELA/Literacy –

WHST.9-12.5 Develop and strengthen writing as needed by planning, revising, editing, rewriting, or trying a new approach, focusing on addressing what is most significant for a specific purpose and audience. *(HS-LS4-6)*

WHST.9-12.7 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

HS. Engineering Design

Students who demonstrate understanding can:

HS-ETS1-1. Analyze a major global challenge to specify qualitative and quantitative criteria and constraints for solutions that account for societal needs and wants.

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

Science and Engineering Practices

Asking Questions and Defining Problems

Asking questions and defining problems in 9–12 builds on K–8 experiences and progresses to formulating, refining, and evaluating empirically testable questions and design problems using models and simulations.

- Analyze complex real-world problems by specifying criteria and constraints for successful solutions. (HS-ETS1-1)

Disciplinary Core Ideas

ETS1.A: Defining and Delimiting Engineering Problems

- Criteria and constraints also include satisfying any requirements set by society, such as taking issues of risk mitigation into account, and they should be quantified to the extent possible and stated in such a way that one can tell if a given design meets them. (HS-ETS1-1)
- Humanity faces major global challenges today, such as the need for supplies of clean water and food or for energy sources that minimize pollution, which can be addressed through engineering. These global challenges also may have manifestations in local communities. (HS-ETS1-1)

Crosscutting Concepts

Connections to Engineering, Technology, and Applications of Science

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

- New technologies can have deep impacts on society and the environment, including some that were not anticipated. Analysis of costs and benefits is a critical aspect of decisions about technology. (HS-ETS1-1)

Connections to HS-ETS1.A: Defining and Delimiting Engineering Problems include:
Physical Science: HS-PS2-3, HS-PS3-3
Connections to HS-ETS1.B: Designing Solutions to Engineering Problems include:
Earth and Space Science: HS-ESS3-2, HS-ESS3-4, **Life Science:** HS-LS2-7, HS-LS4-6
Connections to HS-ETS1.C: Optimizing the Design Solution include:
Physical Science: HS-PS1-6, HS-PS2-3

Articulation of DCIs across grade-bands: **MS.ETS1.A** (HS-ETS1-1)

Common Core State Standards Connections:
ELA/Literacy –

RST.11-12.7 Integrate and evaluate multiple sources of information presented in diverse formats and media (e.g., quantitative data, video, multimedia) in order to address a question or solve a problem. (HS-ETS1-1)

RST.11-12.8 Evaluate the hypotheses, data, analysis, and conclusions in a science or technical text, verifying the data when possible and corroborating or challenging conclusions with other sources of information. *(HS-ETS1-1)*

RST.11-12.9 Synthesize information from a range of sources (e.g., texts, experiments, simulations) into a coherent understanding of a process, phenomenon, or concept, resolving conflicting information when possible. (HS-ETS1-1)

Mathematics –

MP.2 Reason abstractly and quantitatively. (HS-ETS1-1)

MP.4 Model with mathematics. (HS-ETS1-1)

HS. Engineering Design		
Students who demonstrate understanding can: **HS-ETS1-2. Design a solution to a complex real-world problem by breaking it down into smaller, more manageable problems that can be solved through engineering.**		
The performance expectations 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**
Constructing Explanations and Designing Solutions Constructing explanations and designing solutions in 9–12 builds on K–8 experiences and progresses to explanations and designs that are supported by multiple and independent student-generated sources of evidence consistent with scientific ideas, principles and theories. ▪ Design a solution to a complex real-world problem, based on scientific knowledge, student-generated sources of evidence, prioritized criteria, and tradeoff considerations. (HS-ETS1-2)	**ETS1.C: Optimizing the Design Solution** ▪ Criteria may need to be broken down into simpler ones that can be approached systematically, and decisions about the priority of certain criteria over others (trade-offs) may be needed. (HS-ETS1-2)	N/A
Connections to HS-ETS1.A: Defining and Delimiting Engineering Problems include: **Physical Science:** HS-PS2-3, HS-PS3-3 *Connections to HS-ETS1.B: Designing Solutions to Engineering Problems include:* **Earth and Space Science:** HS-ESS3-2, HS-ESS3-4, **Life Science:** HS-LS2-7, HS-LS4-6 *Connections to HS-ETS1.C: Optimizing the Design Solution include:* **Physical Science:** HS-PS1-6, HS-PS2-3		
Articulation of DCIs across grade-bands: **MS.ETS1.A** (HS-ETS1-2); **MS.ETS1.B** (HS-ETS1-2); **MS.ETS1.C** (HS-ETS1-2)		
Common Core State Standards Connections: *Mathematics –* **MP.4** Model with mathematics. (HS-ETS1-2)		

HS. Engineering Design

Students who demonstrate understanding can:

HS-ETS1-3. Evaluate a solution to a complex real-world problem based on prioritized criteria and trade-offs that account for a range of constraints, including cost, safety, reliability, and aesthetics, as well as possible social, cultural, and environmental impacts.

The performance expectations 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
Constructing Explanations and Designing Solutions Constructing explanations and designing solutions in 9–12 builds on K–8 experiences and progresses to explanations and designs that are supported by multiple and independent student-generated sources of evidence consistent with scientific ideas, principles and theories. ▪ Evaluate a solution to a complex real-world problem, based on scientific knowledge, student-generated sources of evidence, prioritized criteria, and tradeoff considerations. (HS-ETS1-3)	**ETS1.B: Developing Possible Solutions** ▪ When evaluating solutions, it is important to take into account a range of constraints, including cost, safety, reliability, and aesthetics, and to consider social, cultural, and environmental impacts. (HS-ETS1-3)	***Connections to Engineering, Technology, and Applications of Science*** **Influence of Science, Engineering, and Technology on Society and the Natural World** ▪ New technologies can have deep impacts on society and the environment, including some that were not anticipated. Analysis of costs and benefits is a critical aspect of decisions about technology. (HS-ETS1-3)

Connections to HS-ETS1.A: Defining and Delimiting Engineering Problems include:
Physical Science: HS-PS2-3, HS-PS3-3
Connections to HS-ETS1.B: Designing Solutions to Engineering Problems include:
Earth and Space Science: HS-ESS3-2, HS-ESS3-4, **Life Science:** HS-LS2-7, HS-LS4-6
Connections to HS-ETS1.C: Optimizing the Design Solution include:
Physical Science: HS-PS1-6, HS-PS2-3

Articulation of DCIs across grade-bands: **MS.ETS1.A** (HS-ETS1-3); **MS.ETS1.B** (HS-ETS1-3)

Common Core State Standards Connections:
ELA/Literacy –

RST.11-12.7 Integrate and evaluate multiple sources of information presented in diverse formats and media (e.g., quantitative data, video, multimedia) in order to address a question or solve a problem. *(HS-ETS1-3)*

RST.11-12.8 Evaluate the hypotheses, data, analysis, and conclusions in a science or technical text, verifying the data when possible and corroborating or challenging conclusions with other sources of information. (HS-ETS1-3)

RST.11-12.9 Synthesize information from a range of sources (e.g., texts, experiments, simulations) into a coherent understanding of a process, phenomenon, or concept, resolving conflicting information when possible. *(HS-ETS1-3)*

Mathematics –

MP.2 Reason abstractly and quantitatively. *(HS-ETS1-3)*

MP.4 Model with mathematics.(HS-ETS1-3)

HS. Engineering Design		
Students who demonstrate understanding can: **HS-ETS1-4. Use a computer simulation to model the impact of proposed solutions to a complex real-world problem with numerous criteria and constraints on interactions within and between systems relevant to the problem.**		
The performance expectations 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**
Using Mathematics and Computational Thinking Mathematical and computational thinking in 9-12 builds on K-8 experiences and progresses to using algebraic thinking and analysis, a range of linear and nonlinear functions including trigonometric functions, exponentials and logarithms, and computational tools for statistical analysis to analyze, represent, and model data. Simple computational simulations are created and used based on mathematical models of basic assumptions. ▪ Use mathematical models and/or computer simulations to predict the effects of a design solution on systems and/or the interactions between systems. (HS-ETS1-4)	**ETS1.B: Developing Possible Solutions** ▪ Both physical models and computers can be used in various ways to aid in the engineering design process. Computers are useful for a variety of purposes, such as running simulations to test different ways of solving a problem or to see which one is most efficient or economical; and in making a persuasive presentation to a client about how a given design will meet his or her needs. (HS-ETS1-4)	**Systems and System Models** ▪ Models (e.g., physical, mathematical, computer models) can be used to simulate systems and interactions—including energy, matter, and information flows— within and between systems at different scales. (HS-ETS1-4)
Connections to HS-ETS1.A: Defining and Delimiting Engineering Problems include: **Physical Science:** HS-PS2-3, HS-PS3-3 *Connections to HS-ETS1.B: Designing Solutions to Engineering Problems include:* **Earth and Space Science:** HS-ESS3-2, HS-ESS3-4, **Life Science:** HS-LS2-7, HS-LS4-6 *Connections to HS-ETS1.C: Optimizing the Design Solution include:* **Physical Science:** HS-PS1-6, HS-PS2-3		
Articulation of DCIs across grade-bands: **MS.ETS1.A** (HS-ETS1-4); **MS.ETS1.B** (HS-ETS1-4); **MS.ETS1.C** (HS-ETS1-4)		
Common Core State Standards Connections: *Mathematics –* **MP.2** Reason abstractly and quantitatively. *(HS-ETS1-4)* **MP.4** Model with mathematics. (HS-ETS1-4)		

Clarifying the standards

Prior learning

The following disciplinary core ideas are prior learning for the concepts in this unit of study. By the end of Grade 8, students know that:

Physical science

- Substances react chemically in characteristic ways. In a chemical process, the atoms that make up the original substances are regrouped into different molecules, and these new substances have different properties from those of the reactants.
- The total number of each type of atom is conserved, and thus the mass does not change.
- Some chemical reactions release energy; others store energy.

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 or 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 very 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 are transferred among 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.
- 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

- 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.
- Humans depend on Earth's land, ocean, atmosphere, and biosphere for many different resources. Minerals, fresh water, and biosphere resources are limited, and many are not renewable or replaceable over human lifetimes. These resources are distributed unevenly around the planet as a result of past geologic processes.
- 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.

Progression of current learning

Driving question 1
What is the relationship among management of natural resources, the sustainability of human populations and biodiversity?

Concepts

- The sustainability of human societies and the biodiversity that supports them require responsible management of natural resources.
- Change and rates of change can be quantified and modeled over very short or very long periods.
- Some system changes are irreversible.
- Modern civilization depends on major technological systems.
- New technologies can have deep impacts on society and the environment including some that are not anticipated.
- Scientific knowledge is a result of human endeavors imagination and creativity.

Practices

- Create a computational simulation to illustrate the relationships among management of natural resources, the sustainability of human populations, and biodiversity.
- Quantify and model change and rates of change in the relationships among management of natural resources, the sustainability of human populations, and biodiversity.

Driving question 2
How can the impacts of human activities in the environment and on biodiversity be reduced?

Concepts

- 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.
- Biodiversity is increased by the formation of new species (speciation) and decreased by the loss of species (extinction).
- Humans depend on the living world for the resources and other benefits provided by biodiversity. But human activity is also having adverse impacts on biodiversity through overpopulation, overexploitation, habitat destruction, pollution, introduction of invasive species, and climate change. Thus sustaining biodiversity so that ecosystem functioning and productivity are maintained is essential to supporting and enhancing life on Earth.
- Sustaining biodiversity also aids humanity by preserving landscapes of recreational or inspirational value.
- Much of science deals with constructing explanations of how things change and how they remain stable.
- When evaluating solutions, it is important to take into account a range of constraints—including costs, safety, reliability, and aesthetics—and to consider social, cultural, and environmental impacts.
- Criteria may need to be broken down into simpler ones that can be approached systematically, and decisions about the priority of certain criteria over others (trade-offs) may be needed.
- New technologies can have deep impacts on society and the environment, including some that where not anticipated. Analysis of cost and benefits is a critical aspect of decisions about technology.

Practices

- Design, evaluate, and refine a solution for reducing the impacts of human activities on the environment and biodiversity based on scientific knowledge, student-generated sources of evidence, prioritized criteria, and tradeoff considerations.
- Construct explanations for how the environment and biodiversity change and stay the same when affected by human activity.
- Evaluate a solution for reducing the impacts of human activities on the environment and biodiversity based on scientific knowledge, student-generated sources of evidence, prioritized criteria, and tradeoff considerations.
- Analyze costs and benefits of a solution for reducing the impacts of human activities on the environment and biodiversity based on scientific knowledge, student-generated sources of evidence, prioritized criteria, and tradeoff considerations.

Driving question 3
How can the adverse impacts of human activity on biodiversity be mitigated?

Concepts

- Changes in the physical environment, whether naturally occurring or human induced, have 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.
- Humans depend on the living world for the resources and other benefits provided by biodiversity. But human activity is also having adverse impacts on biodiversity through overpopulation, overexploitation, habitat destruction, pollution, introduction of invasive species, and climate change. Thus sustaining biodiversity so that ecosystems' functioning and productivity are maintained is essential to supporting and enhancing life on Earth. Sustaining biodiversity also aids humanity by preserving landscapes of recreational or inspirational value.
- Empirical evidence is required to differentiate between cause and correlation and make claims about specific causes and effects.
- When evaluating solutions, it is important to take into account a range of constraints, including cost, safety, reliability, and aesthetics, and to consider social, cultural, and environmental impacts.
- Both physical models and computers can be used in various ways to aid the engineering design process. Computers are useful for a variety of purposes, such as running simulations to test ways of solving a problem or to see which one is most efficient or economical, and in making a persuasive presentation to a client about how a given design will meet his or her needs.

Practices

- Create or revise a simulation based on scientific knowledge, student-generated sources of evidence, prioritized criteria, and tradeoff considerations to test a solution to mitigate adverse impacts of human activity on biodiversity.
- Use empirical evidence to make claims about the impacts of human activity on biodiversity.
- Break down the criteria for the design of a simulation to test a solution for mitigating adverse impacts of human activity on biodiversity into simpler ones that can be approached systematically based on consideration of trade-offs.
- Design a solution for a proposed problem related to threatened or endangered species or to genetic variation of organisms for multiple species.
- Analyze costs and benefits of a solution to mitigate adverse impacts of human activity on biodiversity.

- Criteria may need to be broken down into simpler ones that can be approached systematically, and decisions about the priority of certain criteria over others (trade-offs) may be needed.
- 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.

Integration of content, practices, and crosscutting concepts

Humans depend on the living world for resources and other benefits provided by biodiversity. Students must know that the sustainability of human societies and the biodiversity that supports them require responsible management of natural resources. Change and rates of change in biodiversity and environmental conditions should be quantified and modeled by students over short and long periods of time. Students should keep in mind that some system changes are irreversible. Deforestation of tropical rain forests and desertification of grasslands are examples of changes students might research. In their research, students should synthesize information from multiple sources and evaluate claims about the impacts of human activity on biodiversity based on analysis of evidence.

Modern civilization depends on major technological systems. New technologies can have deep impacts on society and the environment, both anticipated and unanticipated. Examples of impacts include extinction of species and loss of habitat. These changes can lead to a decrease in biodiversity. To address these concepts, students should create a computational simulation or mathematical model illustrating the relationships among management of natural resources, the sustainability of human populations, and biodiversity. Simulations should model change and rates of change in those relationships. When possible, students should symbolically and quantitatively represent natural resource management, sustainability of human populations, and biodiversity. Students should also map relationships discovered, considering limitations on measurement when reporting quantities or data.

Students will learn that natural and anthropogenic changes in the physical environment contribute to changes in biodiversity. Changes may include species expansion, invasive species, and extinction. Because humans depend on the living world for resources and other benefits provided by biodiversity, adverse human activities such as overpopulation, exploitation of resources, habitat destruction, pollution, introduction of invasive species, and human impact on climate change must be addressed. Students should understand that sustaining biodiversity is critical to maintaining functional ecosystems. Students might collect data on growth patterns (exponential, logistic) and carrying capacity using bacterial populations in a petri dish, status of local fish and mollusk populations in Narragansett Bay, erosion of eel grass beds, or continued Quonset Point dredging. Data could also be collected on Asian Shore Crab infestation and competition with local crabs, or the negative effect of warming Narragansett Bay water temperature on flounder reproduction rates. Students could use data to make informed decisions about how environmental issues affect their communities politically, economically, and ecologically.

Students should connect scientific knowledge to human endeavors, imagination, and creativity using conceptual simulations that illustrate relationships such as those between the management of natural resources in local New England fisheries or the lobster-harvesting industry, the needs of the human population, and the effect on marine diversity. Students can use data collected to model changes in marine animal populations to better understand the relationship between management of natural resources, biodiversity, and the sustainability of human populations. Students can also investigate and research major contributions of scientists and engineers who have developed technologies to produce less pollution and waste in order to prevent ecosystem degradation. Students should synthesize information from multiple sources to construct explanations and verify claims about how the environment and biodiversity change and stay the same when affected by human activity.

In this unit, students are tasked with designing and evaluating a solution for a proposed problem related to threatened or endangered species or to genetic variation of organisms for multiple species. As they consider a design solution, they should know that technological advances by modern civilizations have solved, and sometimes caused, problems related to human interactions with the environment. This relationship could be studied by examining impacts of past technological advances such as electricity generation/distribution, antibiotic production, advanced farming practices, and damming of rivers. This may set the context for a discussion of limits of technological solutions. Criteria may need to be broken down into simpler ones that can be approached systematically, and decisions about the priority of certain criteria over others (trade-offs) may be needed. Students may need to determine long- and short-terms goals of a potential solution, while considering that new technologies can have deep impacts on society and the environment, including some that were not anticipated. For instance, students might consider solutions that address the unanticipated negative impact wind farms have on birds, bats, and offshore fishing grounds.

Students might use empirical evidence of decreasing bird populations to differentiate between specific causes and effects. Students could choose an adverse practice and research solutions to associated problems. They might consider wind turbines, deforestation, waste management, noise pollution, or automobile fuel (hydrogen, electricity, water). Solutions for minimizing adverse effects should account for a range of constraints such as cost, safety, reliability, and aesthetics, as wellas social, cultural, and environmental impacts, since practical solutions are more likely to be implemented by society. Students can use physical models and computer simulations to aid in the engineering process, test potential solutions, and refine designs. As they work, project criteria should be broken down and approached systematically.

By evaluating or refining a technological solution, such as alternative energy, that reduces impacts of humans on biodiversity, students should consider the cost, benefits, and risks of systems created by engineers. An example might be modeling a solution for addressing the melting of permafrost and the release of previously trapped methane. Students should analyze data for positive and negative feedback within natural systems to predict if there would be stabilization or destabilization of greenhouse gas concentrations. When evaluating solutions, students need to take into account a range of constraints, including costs, safety, and reliability, as well as social, cultural, and environmental impacts.

Integration of engineering

In this unit, there are two related performance expectations, HS-LS2-7 and HS-LS4-6, that each identify a connection to HS-ETS1-3. Students will be examining solutions for reducing or mitigating impacts of human activity on the environment and biodiversity. Because they are asked to design, evaluate, refine or revise, and finally test a solution, this unit has been identified as an opportunity for students to experience the complete engineering cycle. All HS-ETS1 performance expectations have been included here.

Integration of DCI from prior units within this grade level

In previous units, students learned that photosynthesis and cellular respiration (including anaerobic processes) provide most of the energy for life processes, and that 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.

Students also have an understanding of how 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. This included examining how modest biological or physical disturbances or extreme fluctuations in conditions affect ecosystems. Anthropogenic changes causing disruptions to biodiversity in ecosystems and stability and resilience were also considered.

These understandings will support students as they continue to explore human dependence on Earth's resources and the nature and effects of human interactions with their environment.

<u>Integration of mathematics and English Language Arts/literacy</u>

Mathematics

- Represent symbolically the relationships among management of natural resources, the sustainability of human populations, and biodiversity, and manipulate the representing symbols. Make sense of quantities and relationships among management of natural resources, the sustainability of human populations, and biodiversity.
- Use a mathematical model to describe the management of natural resources, the sustainability of human populations, and biodiversity. Identify important quantities in relationships among management of natural resources, the sustainability of human populations, and biodiversity, and map their relationships using tools. Analyze these relationships mathematically to draw conclusions, reflecting on the results and improving the model if it has not served its purpose.
- Represent symbolically the impacts of human activities on the environment and biodiversity, and manipulate the representing symbols. Make sense of quantities and relationships of the impacts of human activities on the environment and biodiversity
- Use units to understand the impacts of human activities on the environment and biodiversity and to guide the solution of multistep problems to reduce these impacts. Choose and interpret units consistently in formulas to determine the impacts of human activities on the environment and biodiversity. Choose and interpret the scale and origin in graphs and data displays showing impacts of human activities on the environment and biodiversity.
- Define appropriate quantities for the purpose of descriptive modeling of impacts of human activities on the environment and biodiversity.
- Choose a level of accuracy appropriate to limitations on measurement when reporting quantities showing impacts of human activities on the environment and biodiversity.
- Use a mathematical model to describe the impacts of human activities on the environment and biodiversity. Identify important quantities in the impacts of human activities on the environment and biodiversity 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 a mathematical model to describe a solution to mitigate adverse impacts of human activity on biodiversity. Identify important quantities in the impacts of human activities on the biodiversity 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.

English language arts/literacy

- Evaluate the validity of claims about the impacts of human activities on the environment and biodiversity based on an analysis of evidence.
- Evaluate multiple sources of information expressed visually or mathematically to reveal deeper explanations of the impacts of human activities on the environment and biodiversity.

- Evaluate data to verify claims about the impacts of human activities on the environment and biodiversity, verifying the data when possible and corroborating or challenging conclusions with other sources of information.
- Conduct short as well as more sustained research projects to determine the impacts of human activities on the environment and biodiversity, synthesizing information from multiple sources.
- Synthesize information from a range of sources about the impacts of human activities on the environment and biodiversity into a coherent understanding of a process, phenomenon, or concept, resolving conflicting information when possible.
- Develop and strengthen writing as needed by planning, revising, editing, rewriting, or trying a new approach, focusing on the impacts of human activity on biodiversity and how to mitigate these impacts.
- Conduct short as well as more sustained research projects to determine the impacts of human activity on biodiversity and how to mitigate these impacts.
- Evaluate data presented in diverse formats in order to determine the impacts of human activity on biodiversity and how to mitigate these impacts.
- Evaluate data to verify claims about the impacts of human activities on biodiversity and how to mitigate these impacts.
- Synthesize information from a range of sources into a coherent understanding of the impacts of human activities on biodiversity and how to mitigate these impacts.

Connected learning

Connections to disciplinary core ideas in other high school courses are as follows:

Physical science

- Attraction and repulsion between electrical charges at the atomic scale explain the structure, properties, and transformations of matter, as well as the contact forces between material objects.

Life science

- 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.
- Humans depend on the living world for resources and other benefits provided by biodiversity. But human activity is also having adverse impacts on biodiversity through overpopulation, overexploitation, habitat destruction, pollution, introduction of invasive species, and climate change. Thus sustaining biodiversity so that ecosystem functioning and productivity are maintained is essential to supporting and enhancing life on Earth. Sustaining biodiversity also aids humanity by preserving landscapes of recreational or inspirational value.

Earth and space science

- Earth's systems, being dynamic and interacting, cause feedback effects that can increase or decrease the original changes.
- 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, and 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.
- The geological record shows that changes to global and regional climate can be caused by interactions among changes in the sun's energy output or Earth's orbit, tectonic events, ocean circulation, volcanic activity, glaciers, vegetation, and human activities. These changes can occur on a variety of time scales from sudden (e.g., volcanic ash clouds) to intermediate (ice ages) to very long-term tectonic cycles.
- 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.
- The sustainability of human societies and the biodiversity that supports them require 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.

- 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.
- Gradual atmospheric changes were due to plants and other organisms that captured carbon dioxide and released oxygen.
- Changes in the atmosphere due to human activity have increased carbon dioxide concentrations and thus affect climate.
- Current models predict that, although future regional climate changes will be complex and varied, average global temperatures will continue to rise. The outcomes predicted by global climate models strongly depend on the amounts of human-generated greenhouse gases added to the atmosphere each year and by the ways in which these gases are absorbed by the ocean and biosphere.
- Resource availability has guided the development of human society.
- All forms of energy production and other resource extraction have associated economic, social, environmental, and geopolitical costs and risks as well as benefits. New technologies and social regulations can change the balance of these factors.

Number of Instructional Days

Recommended number of instructional days: 20 (1 day = approximately 50 minutes)

Note—The recommended number of days is an estimate based on the information available at this time. Teachers are strongly encouraged to review the entire unit of study carefully and collaboratively to determine whether adjustments to this estimate need to be made.

Additional NGSS Resources

The following resources were used when writing this unit:

- NGSS appendices L and M
- A Framework for K-12 Science Education
- *Common Core State Standards for Mathematics* and *Common Core State Standards for Literacy in History/Social Studies, Science, & Technical Subjects*

Biology Unit 5

Cell Specialization and Homeostasis

Overview

Unit abstract

In this unit of study, students formulate an answer to the question "How do the structures of organisms enable life's functions?" High school students are able to investigate explanations of the structure and functions of cells as the basic unit of life, of hierarchical organization of interacting organ systems, and of the role of specialized cells for maintenance and growth. Students demonstrate understanding through critical reading, using models, and conducting investigations. The crosscutting concepts of structure and function, matter and energy, and systems and system models in organisms are called out as organizing concepts.

Essential question

- How do the structures of organisms enable life's functions?

Written Curriculum

Next Generation Science Standards

HS. Structure and Function

Students who demonstrate understanding can:

HS-LS1-1. Construct an explanation based on evidence for how the structure of DNA determines the structure of proteins which carry out the essential functions of life through systems of specialized cells. [Assessment Boundary: Assessment does not include identification of specific cell or tissue types, whole body systems, specific protein structures and functions, or the biochemistry of protein synthesis.]

The performance expectations 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
Constructing Explanations and Designing Solutions Constructing explanations and designing solutions in 9–12 builds on K–8 experiences and progresses to explanations and designs that are supported by multiple and independent student-generated sources of evidence consistent with scientific ideas, principles, and theories. ▪ Construct 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. (HS-LS1-1)	**LS1.A: Structure and Function** ▪ Systems of specialized cells within organisms help them perform the essential functions of life. (HS-LS1-1) ▪ All cells contain genetic information in the form of DNA molecules. Genes are regions in the DNA that contain the instructions that code for the formation of proteins, which carry out most of the work of cells. (HS-LS1-1) *(Note: This Disciplinary Core Idea is also addressed by HS-LS3-1.)*	**Structure and Function** ▪ Investigating or designing new systems or structures requires a detailed examination of the properties of different materials, the structures of different components, and connections of components to reveal its function and/or solve a problem. (HS-LS1-1)

Connections to other DCIs in this grade-band: **HS.LS3.A** (HS-LS1-1)

Articulation across grade-bands: **MS.LS1.A** (HS-LS1-1); **MS.LS3.A** (HS-LS1-1); **MS.LS3.B** (HS-LS1-1)

Common Core State Standards Connections:

ELA/Literacy –

RST.11-12.1	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-LS1-1)
WHST.9-12.2	Write informative/explanatory texts, including the narration of historical events, scientific procedures/ experiments, or technical processes. (HS-LS1-1)
WHST.9-12.9	Draw evidence from informational texts to support analysis, reflection, and research. (HS-LS1-1)

HS. Structure and Function

Students who demonstrate understanding can:

HS-LS1-2. **Develop and use a model to illustrate the hierarchical organization of interacting systems that provide specific functions within multicellular organisms.** [Clarification Statement: Emphasis is on functions at the organism system level such as nutrient uptake, water delivery, and organism movement in response to neural stimuli. An example of an interacting system could be an artery depending on the proper function of elastic tissue and smooth muscle to regulate and deliver the proper amount of blood within the circulatory system.] [Assessment Boundary: Assessment does not include interactions and functions at the molecular or chemical reaction level.]

The performance expectations 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
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. ▪ Develop and use a model based on evidence to illustrate the relationships between systems or between components of a system. (HS-LS1-2)	**LS1.A: Structure and Function** ▪ Multicellular organisms have a hierarchical structural organization, in which any one system is made up of numerous parts and is itself a component of the next level. (HS-LS1-2)	**Systems and System Models** ▪ Models (e.g., physical, mathematical, computer models) can be used to simulate systems and interactions—including energy, matter, and information flows—within and between systems at different scales. (HS-LS1-2)

Connections to other DCIs in this grade-band: N/A

Articulation across grade-bands: **MS.LS1.A** (HS-LS1-2)

Common Core State Standards Connections:

ELA/Literacy –

SL.11-12.5 Make strategic use of digital media (e.g., textual, graphical, audio, visual, and interactive elements) in presentations to enhance understanding of findings, reasoning, and evidence and to add interest. *(HS-LS1-2)*

HS. Structure and Function

Students who demonstrate understanding can:

HS-LS1-3. **Plan and conduct an investigation to provide evidence that feedback mechanisms maintain homeostasis.** [Clarification Statement: Examples of investigations could include heart rate response to exercise, stomate response to moisture and temperature, and root development in response to water levels.] [Assessment Boundary: Assessment does not include the cellular processes involved in the feedback mechanism.]

The performance expectations 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
Planning and Carrying Out Investigations Planning and carrying out in 9-12 builds on K-8 experiences and progresses to include investigations that provide evidence for and test conceptual, mathematical, physical, and empirical models. ▪ Plan and conduct an investigation individually and collaboratively to produce data to serve as the basis for evidence, and in the design: decide on types, how much, and accuracy of data needed to produce reliable measurements and consider limitations on the precision of the data (e.g., number of trials, cost, risk, time), and refine the design accordingly. (HS-LS1-3) ------------------------------------- ***Connections to Nature of Science*** **Scientific Investigations Use a Variety of Methods** ▪ Scientific inquiry is characterized by a common set of values that include: logical thinking, precision, open-mindedness, objectivity, skepticism, replicability of results, and honest and ethical reporting of findings. (HS-LS1-3)	**LS1.A: Structure and Function** ▪ All cells contain genetic information in the form of DNA molecules. Genes are regions in the DNA that contain the instructions that code for the formation of proteins, which carry out most of the work of cells. (HS-LS1-1) *(Note: This Disciplinary Core Idea is also addressed by HS-LS3-1.)* ▪ Feedback mechanisms maintain a living system's internal conditions within certain limits and mediate behaviors, allowing it to remain alive and functional even as external conditions change within some range. Feedback mechanisms can encourage (through positive feedback) or discourage (negative feedback) what is going on inside the living system. (HS-LS1-3)	**Stability and Change** ▪ Feedback (negative or positive) can stabilize or destabilize a system. (HS-LS1-3)

Connections to other DCIs in this grade-band: N/A

Articulation across grade-bands: **MS.LS1.A** (HS-LS1-3)

Common Core State Standards Connections:

ELA/Literacy –

WHST.9-12.7 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-LS1-3)

WHST.11-12.8 Gather relevant information from multiple authoritative print and digital sources, using advanced searches effectively; assess the strengths and limitations of each source in terms of the specific task, purpose, and audience; integrate information into the text selectively to maintain the flow of ideas, avoiding plagiarism and overreliance on any one source and following a standard format for citation. *(HS-LS1-3)*

HS. Inheritance and Variation of Traits		
Students who demonstrate understanding can: **HS-LS1-4. Use a model to illustrate the role of cellular division (mitosis) and differentiation in producing and maintaining complex organisms.** [Assessment Boundary: Assessment does not include specific gene control mechanisms or rote memorization of the steps of mitosis.]		
The performance expectations above were 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 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 worlds. ▪ Use a model based on evidence to illustrate the relationships between systems or between components of a system. (HS-LS1-4)	**Disciplinary Core Ideas** **LS1.B: Growth and Development of Organisms** ▪ In multicellular organisms individual cells grow and then divide via a process called mitosis, thereby allowing the organism to grow. The organism begins as a single cell (fertilized egg) that divides successively to produce many cells, with each parent cell passing identical genetic material (two variants of each chromosome pair) to both daughter cells. Cellular division and differentiation produce and maintain a complex organism, composed of systems of tissues and organs that work together to meet the needs of the whole organism. (HS-LS1-4)	**Crosscutting Concepts** **Systems and System Models** ▪ Models (e.g., physical, mathematical, computer models) can be used to simulate systems and interactions—including energy, matter, and information flows—within and between systems at different scales. (HS-LS1-4)
Connections to other DCIs in this grade-band: N/A		
Articulation across grade-bands: **MS.LS1.A** (HS-LS1-4); **MS.LS1.B** (HS-LS1-4); **MS.LS3.A** (HS-LS1-4)		
Common Core State Standards Connections: *ELA/Literacy –* **SL.11-12.5** Make strategic use of digital media (e.g., textual, graphical, audio, visual, and interactive elements) in presentations to enhance understanding of findings, reasoning, and evidence and to add interest. *(HS-LS1-4)* *Mathematics –* **MP.4** Model with mathematics. *(HS-LS1-4)* **HSF-IF.C.7** Graph functions expressed symbolically and show key features of the graph, by hand in simple cases and using technology for more complicated cases. *(HS-LS1-4)* **HSF-BF.A.1** Write a function that describes a relationship between two quantities. *(HS-LS1-4)*		

Clarifying the standards

Prior learning

The following disciplinary core ideas are prior learning for the concepts in this unit of study. By the end of Grade 8, students know that:

Life science

- All living things are made up of cells, which is the smallest unit that can be said to be alive. An organism may consist of one single cell (unicellular) or many different numbers and types of cells (multicellular).
- Within cells, special structures are responsible for particular functions, and the cell membrane forms the boundary that controls what enters and leaves the cell.
- In multicellular organisms, the body is a system of multiple interacting subsystems. These subsystems are groups of cells that work together to form tissues and organs that are specialized for particular body functions.
- Genes are located in the chromosomes of cells, with each chromosome pair containing two variants of each of many distinct genes. Each distinct gene chiefly controls the production of specific proteins, which in turn affect the traits of the individual. Changes (mutations) to genes can result in changes to proteins, which can affect the structures and functions of the organism and thereby change traits.
- Variations of inherited traits between parent and offspring arise from genetic differences that result from the subset of chromosomes (and therefore genes) inherited.
- In sexually reproducing organisms, each parent contributes half of the genes acquired (at random) by the offspring. Individuals have two of each chromosome and hence two alleles of each gene, one acquired from each parent. These versions may be identical or may differ from each other.
- Animals engage in characteristic behaviors that increase the odds of reproduction.
- Plants reproduce in a variety of ways, sometimes depending on animal behavior and specialized features for reproduction.
- Genetic factors as well as local conditions affect the growth of the adult plant.
- 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.

Progression of current learning

Driving question 1
How does the structure of DNA determine the structure of proteins, and what is the function of proteins?

Concepts

- Systems of specialized cells within organisms help them perform the essential functions of life.
- All cells contain genetic information in the form of DNA molecules. Genes are regions in the DNA that contain the instructions that code for the formation of proteins, which carry out most of the work of cells.
- Investigating or designing new systems or structures requires a detailed examination of the properties of different materials, the structures of different components, and connections of components to reveal their functions and/or solve a problem.

Practices

- Construct an explanation based on valid and reliable evidence obtained from a variety of sources (including students' own investigations, models, theories, simulations, peer review) for how the structure of DNA determines the structure of proteins, which carry out the essential functions of life through systems of specialized cells.
- Construct an explanation, based on 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, for how the structure of DNA determines the structure of proteins, which carry out the essential functions of life through systems of specialized cells.
- Conduct a detailed examination of the structure and function of DNA.

Driving question 2
What is the hierarchical organization of the specific functions of interacting systems within multicellular organisms?

Concepts

- Multicellular organisms have a hierarchical structural organization, in which any one system is made up of numerous parts and is itself a component of the next level.
- Models (e.g., physical, mathematical, computer models) can be used to simulate systems and interactions—including energy, matter, and information flows—within and between systems at different scales.

Practices

- Develop and use a model based on evidence to illustrate hierarchical organization of interacting systems that provide specific functions within multicellular organism.
- Develop and use a model based on evidence to illustrate the interaction of functions at the organism system level.
- Develop and use a model based on evidence to illustrate the flow of matter and energy within and between systems of an organism at different scales.

Driving question 3
How do feedback mechanisms maintain homeostasis?

Concepts

- All cells contain genetic information in the form of DNA molecules. Genes are regions in the DNA that contain the instructions that code for the formation of proteins, which carry out most of the work of cells.
- Feedback mechanisms maintain a living system's internal conditions within certain limits, and they mediate behaviors, allowing the system to remain alive and functional even as external conditions change within some range. Feedback mechanisms can encourage (through positive feedback) or discourage (negative feedback) what is going on inside the living system.
- Feedback (negative or positive) can stabilize or destabilize a system.

Practices

- Plan and conduct an investigation individually and collaboratively to produce evidence that feedback mechanisms (negative and positive) maintain homeostasis.
- In the planning of the investigation, decide on the types, amount, and accuracy of the data needed to produce reliable measurements, consider limitations on the precision of the data, and refine the design accordingly.

Driving question 4
What is the role of cellular division (mitosis) and differentiation?

Concepts

- In multicellular organisms, individual cells grow and then divide via a process called mitosis, thereby allowing the organism to grow.
- The organism begins as a single cell (fertilized egg) that divides successively to produce many cells, with each parent cell passing identical genetic material (two variants of each chromosome pair) to both daughter cells.
- Cellular division and differentiation produce and maintain a complex organism, composed of systems of tissues and organs that work together to meet the needs of the whole organism.
- Models (e.g., physical, mathematical, and computer models) can be used to simulate systems and interactions, including energy, matter, and information flows, within and between systems at different scales.

Practices

- Use a model based on evidence to illustrate the role of cellular division (mitosis) and differentiation in producing and maintaining complex organisms.
- Use a model to illustrate the role of cellular division and differentiation in terms of energy, matter, and information flows within and between systems of cells/organisms.

Integration of content, practices, and crosscutting concepts

Students must learn that systems of specialized cells within organisms help the organisms perform the essential functions of life. All cells contain genetic information in the form of DNA molecules. Genes are regions of DNA that contain the instructions that code (transcription and translation) for the formation of proteins, which carry out most of the work of cells. Students should conduct a detailed examination of the structure and function of DNA by building a model of DNA to demonstrate their knowledge of Chargaff's Rule. Models can also be used to illustrate the processes of transcription and translation to clarify the function of DNA in terms of protein synthesis. Students should also draw and cite evidence from informational texts to support an explanation for how the structure of DNA determines the structure of proteins.

Multicellular organisms have a hierarchical structural organization in which one system is made of numerous parts and is itself a component of the next level. Models (e.g. physical, mathematical, and computer models) could be used by students to simulate systems and interactions—including energy, matter, and information flows—within and between systems at different scales. Students should also examine matter and energy transfers within and between systems of an organism at different scales. Students might create presentations, using digital media, to enhance their understanding of the hierarchical organization of interacting systems that provide specific functions within multicellular organisms.

Students should develop an understanding of how systems of cells, tissues, and organs work together to meet the needs of the whole organism. Students should use models and oral presentations to simulate maintenance and development within complex organisms by mitosis and cell differentiation. For example, students might develop models of kidney function using dialysis tubing to illustrate the filtration of particular solutes. The same materials can be used to connect the specialized cells of the kidney to the rest of the organ, organ system, and organism in relation to excretion. Other system models that represent the hierarchical levels of organization that perform necessary life functions maintaining homeostasis could be used. Some examples include gas exchange, secretion, absorption, transport, and communication.

Students need an understanding of how external conditions affect the internal conditions of an organism. Feedback mechanisms maintain the internal conditions of living systems within a limited range, in part due to mediated behaviors such as basking, use of shade, mud baths, and burrowing. These feedback mechanisms can encourage or discourage physiological responses in living systems. Students can investigate sugar, oxygen, and temperature regulations, individually and collaboratively, to produce evidence that feedback mechanisms maintain homeostasis. Because feedback can stabilize or destabilize a system, the planning of investigations should address decisions about the type, quantity, accuracy, reliability, and limitations of the data. Design of investigations should be adjusted accordingly. In planning their investigations, students should conduct research and and synthesize information from multiple reliable sources to support claims about how feedback mechanisms maintain homeostasis.

Students should investigate and model the role of cellular division (mitosis) and differentiation in producing and maintaining complex organisms. In multicellular organisms, individual cells grow and then divide in the process called mitosis. At the earliest stage of life, a single cell, or zygote, divides successively to produce many cells (stem cells). These cells pass identical genetic material (two variants of each chromosome pair) in the form of homologous chromosome pairs to both daughter cells. Complex multicellular organisms maintain themselves by growing and developing through cellular divisions (mitosis) and differentiation of cells. Students should identify important quantities in the role of cellular division and differentiation and use mathematical models to illustrate how these processes produce and maintain complex organisms. Models might include data showing numbers of cells at different stages of development. Data could be collected from observing the different stages of mitosis using a microscope or virtual/computer simulation. Graphs and functions could be used to show growth rate in terms of cell division.

Integration of mathematics and/or English language arts/literacy

Mathematics

- Use a mathematical model to illustrate the role of cellular division and differentiation in producing and maintaining complex organisms. Identify important quantities in the role of cellular division and differentiation in producing and maintaining complex organisms 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.
- Graph functions expressed symbolically showing the role of cellular division and differentiation in producing and maintaining complex organisms and show key features of the graph, by hand in simple cases and using technology for more complicated cases.
- Write a function that describes a relationship between the role of cellular division and differentiation and the production and maintenance of complex organisms.

English language arts/literacy

- Cite specific textual evidence that supports how the structure of DNA determines the structure of proteins, which carry out the essential functions of life through systems of specialized cells.
- Write an explanation that supports how the structure of DNA determines the structure of proteins, which carry out the essential functions of life through systems of specialized cells.
- Draw evidence from informational texts to support how the structure of DNA determines the structure of proteins, which carry out the essential functions of life through systems of specialized cells.
- Make strategic use of digital media in presentations to enhance understanding of the hierarchical organization of interacting systems that provide specific functions within multicellular organisms.
- Conduct short as well as more sustained research to determine how feedback mechanisms maintain homeostasis. Synthesize multiple sources on the subject, demonstrating understanding of the subject under investigation.
- Gather applicable information from multiple reliable sources to support claims that feedback mechanisms maintain homeostasis. Use advanced searches effectively; assess the strengths and limitations of each source in terms of the specific task, purpose, and audience; integrate information into the text selectively to maintain the flow of ideas, avoiding plagiarism and overreliance on any one source and following a standard format for citation.
- Make strategic use of digital media in presentations to enhance understanding of the role of cellular division (mitosis) and differentiation in producing and maintaining complex organisms.

Connected learning

Connections to disciplinary core ideas in other high school courses are as follows:

Life science

- Each chromosome consists of a single, very long DNA molecule, and each gene on a chromosome is a particular segment of that DNA. The instructions for forming species' characteristics are carried in DNA. All cells in an organism have the same genetic content, but the genes used (expressed) by the cell may be regulated in different ways. Not all DNA codes for a protein; some segments of DNA are involved in regulatory or structural functions, and some have no known function.

Number of Instructional Days

Recommended number of instructional days: 18 (1 day = approximately 50 minutes)

Note—The recommended number of days is an estimate based on the information available at this time. Teachers are strongly encouraged to review the entire unit of study carefully and collaboratively to determine whether adjustments to this estimate need to be made.

Additional NGSS Resources

The following resources were used when writing this unit:

- NGSS Appendices L and M
- *A Framework for K-12 Science Education*
- *Common Core State Standards for Mathematics* and *Common Core State Standards for Literacy in History/Social Studies, Science, & Technical Subjects*

Biology Unit 6
DNA and Inheritance

Overview

Unit abstract

In this unit of study, students will demonstrate an understanding of the relationship between DNA and chromosomes in the process of cellular division, which passes traits from one generation to the next. Students can determine why individuals of the same species vary in how they look, function, and behave. Students develop conceptual models of the role of DNA in the unity of life on Earth and use statistical models to explain the importance of variation within populations for the survival and evolution of species. Ethical issues related to genetic modification of organisms and the nature of science are described. Students explain the mechanisms of genetic inheritance and describe the environmental and genetic causes of gene mutation and the alteration of gene expressions.

The crosscutting concepts of structure and function, patterns, and cause and effect developed in this unit help students generalize understanding of inheritance of traits to other applications in science.

Essential question

- How are characteristics from one generation related to the previous generation?

Written Curriculum

Next Generation Science Standards

HS. Inheritance and Variation of Traits		
Students who demonstrate understanding can: **HS-LS3-1. Ask questions to clarify relationships about the role of DNA and chromosomes in coding the instructions for characteristic traits passed from parents to offspring.** [Assessment Boundary: Assessment does not include the phases of meiosis or the biochemical mechanism of specific steps in the process.]		
The performance expectations 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**
Asking Questions and Defining Problems Asking questions and defining problems in 9-12 builds on K-8 experiences and progresses to formulating, refining, and evaluating empirically testable questions and design problems using models and simulations. ▪ Ask questions that arise from examining models or a theory to clarify relationships. (HS-LS3-1)	**LS1.A: Structure and Function** ▪ All cells contain genetic information in the form of DNA molecules. Genes are regions in the DNA that contain the instructions that code for the formation of proteins. *(secondary to HS-LS3-1) (Note: This Disciplinary Core Idea is also addressed by HS-LS1-1.)* **LS3.A: Inheritance of Traits** ▪ Each chromosome consists of a single very long DNA molecule, and each gene on the chromosome is a particular segment of that DNA. The instructions for forming species' characteristics are carried in DNA. All cells in an organism have the same genetic content, but the genes used (expressed) by the cell may be regulated in different ways. Not all DNA codes for a protein; some segments of DNA are involved in regulatory or structural functions, and some have no as-yet known function. (HS-LS3-1)	**Cause and Effect** ▪ Empirical evidence is required to differentiate between cause and correlation and make claims about specific causes and effects. (HS-LS3-1)
Connections to other DCIs in this grade-band: N/A		
Articulation across grade-bands: **MS.LS3.A** (HS-LS3-1); **MS.LS3.B** (HS-LS3-1)		
Common Core State Standards Connections: *ELA/Literacy –* **RST.11-12.1** 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-LS3-1)* **RST.11-12.9** Synthesize information from a range of sources (e.g., texts, experiments, simulations) into a coherent understanding of a process, phenomenon, or concept, resolving conflicting information when possible. *(HS-LS3-1)*		

HS. Inheritance and Variation of Traits

Students who demonstrate understanding can:

HS-LS3-2. Make and defend a claim based on evidence that inheritable genetic variations may result from: (1) new genetic combinations through meiosis, (2) viable errors occurring during replication, and/or (3) mutations caused by environmental factors. [Clarification Statement: Emphasis is on using data to support arguments for the way variation occurs.] [Assessment Boundary: Assessment does not include the phases of meiosis or the biochemical mechanism of specific steps in the process.]

The performance expectations 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
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. ▪ Make and defend a claim based on evidence about the natural world that reflects scientific knowledge, and student-generated evidence. (HS-LS3-2)	**LS3.B: Variation of Traits** ▪ In sexual reproduction, chromosomes can sometimes swap sections during the process of meiosis (cell division), thereby creating new genetic combinations and thus more genetic variation. Although DNA replication is tightly regulated and remarkably accurate, errors do occur and result in mutations, which are also a source of genetic variation. Environmental factors can also cause mutations in genes, and viable mutations are inherited. (HS-LS3-2) ▪ Environmental factors also affect expression of traits, and hence affect the probability of occurrences of traits in a population. Thus the variation and distribution of traits observed depends on both genetic and environmental factors. (HS-LS3-2)	**Cause and Effect** ▪ Empirical evidence is required to differentiate between cause and correlation and make claims about specific causes and effects. (HS-LS3-2)

Connections to other DCIs in this grade-band: N/A

Articulation across grade-bands: **MS.LS3.A** (HS-LS3-2); **MS.LS3.B** (HS-LS3-2)

Common Core State Standards Connections:

ELA/Literacy –

RST.11-12.1 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-LS3-2)*

WHST.9-12.1 Write arguments focused on *discipline-specific content.* (HS-LS3-2)

Mathematics –

MP.2 Reason abstractly and quantitatively. (HS-LS3-2)

<table>
<tr><th colspan="3">HS. Inheritance and Variation of Traits</th></tr>
<tr><td colspan="3">Students who demonstrate understanding can:
HS-LS3-3. Apply concepts of statistics and probability to explain the variation and distribution of expressed traits in a population. [Clarification Statement: Emphasis is on the use of mathematics to describe the probability of traits as it relates to genetic and environmental factors in the expression of traits.] [Assessment Boundary: Assessment does not include Hardy-Weinberg calculations.]</td></tr>
<tr><td colspan="3">The performance expectations above were developed using the following elements from the NRC document A Framework for K-12 Science Education:</td></tr>
<tr><td>Science and Engineering Practices
Analyzing and Interpreting Data
Analyzing data in 9-12 builds on K-8 experiences and progresses to introducing more detailed statistical analysis, the comparison of data sets for consistency, and the use of models to generate and analyze data.
▪ Apply concepts of statistics and probability (including determining function fits to data, slope, intercept, and correlation coefficient for linear fits) to scientific and engineering questions and problems, using digital tools when feasible. (HS-LS3-3)</td><td>Disciplinary Core Ideas
LS3.B: Variation of Traits
▪ Environmental factors also affect expression of traits, and hence affect the probability of occurrences of traits in a population. Thus the variation and distribution of traits observed depends on both genetic and environmental factors. (HS-LS3-3)</td><td>Crosscutting Concepts
Scale, Proportion, and Quantity
▪ Algebraic thinking is used to examine scientific data and predict the effect of a change in one variable on another (e.g., linear growth vs. exponential growth). (HS-LS3-3)

Connections to Nature of Science
Science is a Human Endeavor
▪ Technological advances have influenced the progress of science and science has influenced advances in technology. (HS-LS3-3)
▪ Science and engineering are influenced by society and society is influenced by science and engineering. (HS-LS3-3)</td></tr>
<tr><td colspan="3">Connections to other DCIs in this grade-band: HS.LS2.A (HS-LS3-3); HS.LS2.C (HS-LS3-3); HS.LS4.B (HS-LS3-3); HS.LS4.C (HS-LS3-3)</td></tr>
<tr><td colspan="3">Articulation across grade-bands: MS.LS2.A (HS-LS3-3);; MS.LS3.B (HS-LS3-3); MS.LS4.C (HS-LS3-3)</td></tr>
<tr><td colspan="3">Common Core State Standards Connections:
Mathematics –
MP.2 Reason abstractly and quantitatively. (HS-LS3-3)</td></tr>
</table>

Clarifying the standards

Prior learning

The following disciplinary core ideas are prior learning for the concepts in this unit of study. By the end of Grade 8, students know that:

Life science

- Genes are located in the chromosomes of cells, with each chromosome pair containing two variants of each of many distinct genes. Each distinct gene chiefly controls the production of specific proteins, which in turn affect the traits of the individual. Changes (mutations) to genes can result in changes to proteins, which can affect the structures and functions of the organism and thereby change traits.
- Variations of inherited traits between parent and offspring arise from genetic differences that result from the subset of chromosomes (and therefore genes) inherited.
- In sexually reproducing organisms, each parent contributes half of the genes acquired (at random) by the offspring. Individuals have two of each chromosome and hence two alleles of each gene, one acquired from each parent. These versions may be identical or may differ from each other.
- In addition to variations that arise from sexual reproduction, genetic information can be altered because of mutations. Though rare, mutations may result in changes to the structure and function of proteins. Some changes are beneficial, others harmful, and some neutral to the organism.
- 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.
- 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.
- In sexually reproducing organisms, each parent contributes half of the genes acquired (at random) by the offspring. Individuals have two of each chromosome and hence two alleles of each gene, one acquired from each parent. These versions may be identical or may differ from each other.

Progression of current learning

Driving question 1
What is the relationship between the role of DNA, chromosomes, and characteristic traits passed from parents to offspring?

Concepts

- All cells contain genetic information in the form of DNA molecules.
- Genes are regions in the DNA that contain the instructions that code for the formation of proteins.
- Each chromosome consists of a single, very long DNA molecule, and each gene on the chromosome is a particular segment of that DNA.
- The instructions for forming species' characteristics are carried in the DNA.
- All cells in an organism have the same genetic content, but the genes used (expressed) by the cell may be regulated in different ways.
- Not all DNA codes for a protein; some segments of DNA are involved in regulatory or structural functions, and some have, as yet, no known function.
- Empirical evidence is required to differentiate between cause and correlation and to make claims about the role of DNA and chromosomes in coding the instructions for the characteristic traits passed from parents to offspring.

Practices

- Ask questions that arise from examining models or a theory to clarify relationships about the role of DNA and chromosomes in coding the instructions for characteristic traits passed from parent to offspring.
- Use empirical evidence to differentiate between cause and correlation and make claims about the role of DNA and chromosomes in coding the instructions for characteristics passed from parents to offspring.

Driving question 2
How does inheritable genetic variation occur?

Concepts

- In sexual reproduction, chromosomes can sometimes swap sections during the process of meiosis (cell division), thereby creating new genetic combinations and thus more genetic variation.
- Although DNA replication is tightly regulated and remarkably accurate, errors do occur and result in mutations, which are also a source of genetic variation. Environmental factors can also cause mutations in genes, and viable mutations are inherited.
- Environmental factors also affect expression of traits, and hence affect the probability of occurrence of traits in a population. Thus the variation and distribution of traits observed depends on both genetic and environmental factors.
- Empirical evidence is required to differentiate between cause and correlation and to make claims about inheritable genetic variations resulting from new genetic combinations through meiosis, viable errors occurring during replication, and/or mutations caused by environmental factors.

Practices

- Make and defend a claim based on evidence that inheritable genetic variations may result from new genetic combinations through meiosis, viable errors occurring during replication, and/or mutations caused by environmental factors.
- Use data to support arguments for the ways inheritable genetic variation occurs.
- Use empirical evidence to differentiate between cause and correlation and make claims about the ways inheritable genetic variation occurs.

Driving question 3
What is the relationship between the variation and the distribution of expressed traits in a population?

Concepts

- Environmental factors affect expression of traits, and hence affect the probability of occurrences of traits in a population. Thus the variations and distributions of traits observed depend on both genetic and environmental factors.
- Algebraic thinking is used to examine scientific data and predict the distribution of traits in a population as they relate to the genetic and environmental factors (e.g., linear growth vs. exponential growth).
- Technological advances have influenced the progress of science, and science has influenced advances in technology.
- Science and engineering are influenced by society, and society is influenced by science and engineering.

Practices

- Apply concepts of statistics and probability (including determining function fits to data, slope, intercepts, and correlation coefficient for linear fits) to explain the variation and distribution of expressed traits in a population.
- Use mathematics to describe the probability of traits as it relates to genetic and environmental factors in the expression of traits.
- Use algebraic thinking to examine scientific data on the variation and distribution of traits in a population and predict the effect of a change in probability of traits as it relates to genetic and environmental factors.

Integration of content, practices, and crosscutting concepts

From the previous unit, students have an understanding that all cells contain genetic information in the form of DNA molecules, and that these DNA molecules contain the instructions for forming species' characteristics. In the current unit, students should identify the terms *genes*, *chromosomes*, and *histones* to develop an understanding that genes are regions in the DNA that contain the instructions that code for the formation of proteins. In addition, students should know that each chromosome consists of a single, very long DNA molecule, and that each gene on the chromosome is a particular segment of that DNA.

Students might demonstrate that all cells in an organism have the same genetic content by using paper models, manipulatives, or computer simulations to simulate DNA replication. Students could examine the concept that genes used (expressed) by the cell may be regulated in different ways through a study of changes that occur during puberty, such as development of secondary sexual characteristics and the influence that hormones have on this gene expression process. Focus should be on student questions that arise from examination of models. Students should synthesize information and cite specific evidence from texts, experiments, or simulations to gain a coherent understanding of and support explanations about the relationship between the role of DNA and chromosomes in coding instructions for characteristic traits passed from parents to offspring.

Students should also research and investigate types of DNA, including DNA that codes for proteins (hemoglobin, actin, myosin), DNA that is involved in regulatory or structural functions (cell membrane proteins, cyclins) and DNA that has no known function (introns).

To understand environmental influence on gene expression, a study and evaluation of empirical evidence detailing frequencies of different forms of cancer could be correlated with specific environmental factors (climate, diet, pollution, lifestyle). Students should then determine whether cause-and-effect relationships exist. Students should also make claims about the relationship between the role of DNA and chromosomes in coding for characteristic traits passed from parent to offspring. Students might also conduct research on examples of genetic engineering, such as post-HIV infection treatment using the genetically engineered CCR5delta32 gene, to expand their claims about the role of DNA and chromosomes.

New genetic combinations are the result of sexual reproduction, crossing over during meiosis, mutations due to errors in DNA replication, or environmental influences. Students should make and defend claims, citing evidence from text, about how inheritable genetic variations may result from new genetic combinations. Conducting experiments with fruit flies, radiated plant seeds, and computer models will provide students with the necessary data to evaluate and defend findings. Using data from these or other experiments, students can support arguments for the ways inheritable genetic variation occurs. Ideally, student-conducted experiments will yield empirical evidence correlating the inheritable variation to the cause. Students should make and defend claims about the ways variation occurs using this empirical evidence. Students must understand that although DNA replication is tightly regulated, mutation can occur and can result in genetic variations.

Environmental factors affect the expression of the inherited traits. To illustrate this, students might collect empirical data (possibly by visiting local zoos) on populations of Arctic Fox. They might then focus on the role that temperature plays in influencing coat color and density in response to cold and warm air. Other studies on the role of temperature in gene expression might address the development of sexual organs among reptiles. Additional organisms, including earthworms, grouper fish, damselfish and some frog species, may illustrate how environmental triggers, such as gender density, can influence gene expression.

Students should be provided with the opportunity to determine the probability of occurrence of traits in a population using mathematical models. Through these activities, students will observe and predict the variation and distributions of traits and connect their expression to both genetic and environmental factors. In developing mathematical models to represent the variation and distribution of expressed traits, students should make sense of quantities and relationships in order to make predictions about the expression of traits.

The variation and distribution of traits depend on both genetic and environmental factors. Students should understand how environmental factors affect the expression of traits and the probability of trait occurrences in populations. Data showing the relationship between environmental factors and the expression of traits can be used to examine trait variation within a population. Students should be able make predictions as they relate to gene frequencies in populations affected by both genetic and environmental factors.

Punnett Squares, graphing, Chi square analysis, and Hardy Weinberg calculations could be used to apply concepts of statistics and probability to gene expression and frequency. Algebraic thinking should be used to examine scientific data and to predict the distribution of traits in a population. Through the use of graphs, linear growth can be compared to exponential growth as these types of growth relate to traits within the population.

Students should be aware that technology and science are related and that technological advances have influenced the progress of science. Science in turn influences advances in technology, such as in the development of gene therapies. Students should have an understanding of how science and engineering are influenced by society (e.g., need for cures for genetic diseases), and how society is influenced by science and technology (e.g., the bio-ethics and economics of genetically modified foods).

Integration of DCI from prior units within this grade level

Previously, students learned how environmental factors influence changes in population. They also learned how changes in the physical environment (whether naturally occurring or human induced) contribute to the expansion of some species. These concepts are important to understanding in the current unit, because environmental factors and mutagens can cause mutations resulting in new genetic combinations.

Integration of mathematics and/or English language arts/literacy

Mathematics

- Represent symbolically evidence that inheritable genetic variations may result from new genetic combinations through meiosis, viable errors occurring during replication, and/or mutations caused by environmental factors, and manipulate the representing symbols. Make sense of quantities and relationships to describe and predict the ways in which inheritable genetic variation occurs.
- Represent the variation and distribution of expressed traits in a population symbolically and manipulate the representing symbols. Make sense of quantities and relationships to describe and predict the variation and distribution of expressed traits in a population.

English language arts/literacy

- Cite specific textual evidence to support analysis of science and technical texts describing the role of DNA and chromosomes in coding the instructions for characteristic traits passed from parents to offspring, attending to important distinctions the author makes and to any gaps or inconsistencies in the account.
- Synthesize information from a range of sources (e.g., texts, experiments, simulations) into a coherent understanding of the role of DNA and chromosomes in coding the instructions for characteristic traits passed from parents to offspring, resolving conflicting information when possible.
- Cite specific textual evidence to support analysis of science and technical texts describing the ways that inheritable genetic variation occurs, attending to important distinctions the author makes and to any gaps or inconsistencies in the account.
- Write arguments, based on evidence, that inheritable genetic variations may result from new genetic combinations through meiosis, viable errors occurring during replication, and/or mutations caused by environmental factors.

Connected learning

Connections to disciplinary core ideas in other high school courses are as follows:

Life science

- 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.
- 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.

- 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.

Number of Instructional Days

Recommended number of instructional days: 18 (1 day = approximately 50 minutes)

Note—The recommended number of days is an estimate based on the information available at this time. Teachers are strongly encouraged to review the entire unit of study carefully and collaboratively to determine whether adjustments to this estimate need to be made.

Additional NGSS Resources

The following resources were used when writing this unit:

- NGSS appendices L and M
- *A Framework for K-12 Science Education*
- *Common Core State Standards for Mathematics* and *Common Core State Standards for Literacy in History/Social Studies, Science, & Technical Subjects*

Biology Unit 7
Natural Selection

Overview

Unit abstract

In this unit of study, high school students can investigate patterns to find the relationship between the environment and natural selection. Students demonstrate understanding of the factors causing natural selection of species over time. They demonstrate understanding of how multiple lines of evidence contribute to the strength of scientific theories of natural selection. Students demonstrate an understanding of these concepts by constructing explanations and designing solutions, analyzing and interpreting data, and engaging in argument from evidence. The crosscutting concepts of patterns and cause and effect support the development of a deeper understanding.

Essential question

- How can there be so many similarities among organisms yet so many different plants, animals, and microorganisms?

Written Curriculum

Next Generation Science Standards

HS. Natural Selection and Evolution

Students who demonstrate understanding can:

HS-LS4-4. Construct an explanation based on evidence for how natural selection leads to adaptation of populations. [Clarification Statement: Emphasis is on using data to provide evidence for how specific biotic and abiotic differences in ecosystems (such as ranges of seasonal temperature, long-term climate change, acidity, light, geographic barriers, or evolution of other organisms) contribute to a change in gene frequency over time, leading to adaptation of populations.]

The performance expectations 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
Constructing Explanations and Designing Solutions Constructing explanations and designing solutions in 9–12 builds on K–8 experiences and progresses to explanations and designs that are supported by multiple and independent student-generated sources of evidence consistent with scientific ideas, principles, and theories. ▪ Construct 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. (HS-LS4-4)	**LS4.C: Adaptation** ▪ 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. (HS-LS4-4)	**Cause and Effect** ▪ Empirical evidence is required to differentiate between cause and correlation and make claims about specific causes and effects. (HS-LS4-4) ------------------------------------- ***Connections to Nature of Science*** **Scientific Knowledge Assumes an Order and Consistency in Natural Systems** ▪ 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. (HS-LS4-4)

Connections to other DCIs in this grade-band: **HS.LS2.A** (HS-LS4-4); **HS.LS2.D** (HS-LS4-4)

Articulation across grade-bands: **MS.LS4.B** (HS-LS4-4); **MS.LS4.C** (HS-LS4-4)

Common Core State Standards Connections:

ELA/Literacy –

RST.11-12.1 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-LS4-4)

WHST.9-12.2 Write informative/explanatory texts, including the narration of historical events, scientific procedures/ experiments, or technical processes. (HS-LS4-4)

WHST.9-12.9 Draw evidence from informational texts to support analysis, reflection, and research. (HS-LS4-4)

Mathematics –

MP.2 Reason abstractly and quantitatively. *(HS-LS4-4)*

HS. Natural Selection and Evolution

Students who demonstrate understanding can:

HS-LS4-3. **Apply concepts of statistics and probability to support explanations that organisms with an advantageous heritable trait tend to increase in proportion to organisms lacking this trait.** [Clarification Statement: Emphasis is on analyzing shifts in numerical distribution of traits and using these shifts as evidence to support explanations.] [Assessment Boundary: Assessment is limited to basic statistical and graphical analysis. Assessment does not include allele frequency calculations.]

The performance expectations above were 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 9–12 builds on K–8 experiences and progresses to introducing more detailed statistical analysis, the comparison of data sets for consistency, and the use of models to generate and analyze data.

- Apply concepts of statistics and probability (including determining function fits to data, slope, intercept, and correlation coefficient for linear fits) to scientific and engineering questions and problems, using digital tools when feasible. (HS-LS4-3)

Disciplinary Core Ideas

LS4.B: Natural Selection

- 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. (HS-LS4-3)
- The traits that positively affect survival are more likely to be reproduced, and thus are more common in the population. (HS-LS4-3)

LS4.C: Adaptation

- 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. (HS-LS4-3)
- Adaptation also means that the distribution of traits in a population can change when conditions change. (HS-LS4-3)

Crosscutting Concepts

Patterns

- 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. (HS-LS4-3)

Connections to other DCIs in this grade-band: **HS.LS2.A** (HS-LS4-3); **HS.LS2.D** (HS-LS4-3); **HS.LS3.B** (HS-LS4-3)

Articulation across grade-bands: **MS.LS2.A** (HS-LS4-3); **MS.LS3.B** (HS-LS4-3); **MS.LS4.B** (HS-LS4-3); **MS.LS4.C** (HS-LS4-3)

Common Core State Standards Connections:

ELA/Literacy –

RST.11-12.1	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-LS4-3)*
WHST.9-12.2	Write informative/explanatory texts, including the narration of historical events, scientific procedures/ experiments, or technical processes. *(HS-LS4-3)*
WHST.9-12.9	Draw evidence from informational texts to support analysis, reflection, and research. *(HS-LS4-3)*

Mathematics –

MP.2	Reason abstractly and quantitatively. (HS-LS4-3)

HS. Natural Selection and Evolution

Students who demonstrate understanding can:

HS-LS4-5. **Evaluate the evidence supporting claims that changes in environmental conditions may result in: (1) increases in the number of individuals of some species, (2) the emergence of new species over time, and (3) the extinction of other species.** [Clarification Statement: Emphasis is on determining cause and effect relationships for how changes to the environment such as deforestation, fishing, application of fertilizers, drought, flood, and the rate of change of the environment affect distribution or disappearance of traits in species.]

The performance expectations 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
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 or historical episodes in science. ▪ Evaluate the evidence behind currently accepted explanations or solutions to determine the merits of arguments. (HS-LS4-5)	**LS4.C: Adaptation** ▪ 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. (HS-LS4-5) ▪ 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. (HS-LS4-5)	**Cause and Effect** ▪ Empirical evidence is required to differentiate between cause and correlation and make claims about specific causes and effects. (HS-LS4-5)

Connections to other DCIs in this grade-band: **HS.LS2.A** (HS-LS4-5); **HS.LS2.D** (HS-LS4-5); **HS.LS3.B** (HS-LS4-5); **HS.ESS2.E** (HS-LS4-5); **HS.ESS3.A** (HS-LS4-5)

Articulation across grade-bands: **MS.LS2.A** (HS-LS4-5); **MS.LS2.C** (HS-LS4-5); **MS.LS4.C** (HS-LS4-5); **MS.ESS3.C** (HS-LS4-5)

Common Core State Standards Connections:

ELA/Literacy –

RST.11-12.8 Evaluate the hypotheses, data, analysis, and conclusions in a science or technical text, verifying the data when possible and corroborating or challenging conclusions with other sources of information. (HS-LS4-5)

WHST.9-12.9 Draw evidence from informational texts to support analysis, reflection, and research. (HS-LS4-5)

Mathematics –

MP.2 Reason abstractly and quantitatively. *(HS-LS4-5)*

HS. Interdependent Relationships in Ecosystems

Students who demonstrate understanding can:

HS-LS2-8. Evaluate the evidence for the role of group behavior on individual and species' chances to survive and reproduce. [Clarification Statement: Emphasis is on: (1) distinguishing between group and individual behavior, (2) identifying evidence supporting the outcomes of group behavior, and (3) developing logical and reasonable arguments based on evidence. Examples of group behaviors could include flocking, schooling, herding, and cooperative behaviors such as hunting, migrating, and swarming.]

The performance expectations 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
Engaging in Argument from Evidence Engaging in argument from evidence in 9–12 builds from 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. ▪ Evaluate the evidence behind currently accepted explanations or solutions to determine the merits of arguments. (HS-LS2-8) -------------------------------------- ***Connections to Nature of Science*** **Scientific Knowledge is Open to Revision in Light of New Evidence** ▪ Scientific argumentation is a mode of logical discourse used to clarify the strength of relationships between ideas and evidence that may result in revision of an explanation. (HS-LS2-8)	**LS2.D: Social Interactions and Group Behavior** ▪ Group behavior has evolved because membership can increase the chances of survival for individuals and their genetic relatives. (HS-LS2-8)	**Cause and Effect** ▪ Empirical evidence is required to differentiate between cause and correlation and make claims about specific causes and effects. (HS-LS2-8)

Connections to other DCIs in this grade-band: N/A

Articulation across grade-bands: **MS.LS1.B** (HS-LS2-8)

Common Core State Standards Connections:

ELA/Literacy –

RST.9-10.8	Assess the extent to which the reasoning and evidence in a text support the author's claim or a recommendation for solving a scientific or technical problem. *(HS-LS2-8)*
RST.11-12.1	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-LS2-8)
RST.11-12.7	Integrate and evaluate multiple sources of information presented in diverse formats and media (e.g., quantitative data, video, multimedia) in order to address a question or solve a problem. *(HS-LS2-8)*
RST.11-12.8	Evaluate the hypotheses, data, analysis, and conclusions in a science or technical text, verifying the data when possible and corroborating or challenging conclusions with other sources of information. (HS-LS2-8)

Clarifying the standards

Prior learning

The following disciplinary core ideas are prior learning for the concepts in this unit of study. By the end of Grade 8, students know that:

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 cause the organisms involved to 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.
- In sexually reproducing organisms, each parent contributes half of the genes acquired (at random) by the offspring. Individuals have two of each chromosome and hence two alleles of each gene, one acquired from each parent. These versions may be identical or may differ from each other.
- In addition to variations that arise from sexual reproduction, genetic information can be altered because of mutations. Though rare, mutations may result in changes to the structure and function of proteins. Some changes are beneficial, others harmful, and some neutral to the organism.
- 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.
- 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.

Earth and space science

- 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.

Progression of current learning

Driving question 1
How does natural selection lead to adaptations of populations?

Concepts

- 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.
- Empirical evidence is required to differentiate between cause and correlation and make claims about how natural selection leads to adaptation of populations.
- Empirical evidence is required to differentiate between cause and correlation and make claims about how specific biotic and abiotic differences in ecosystems contribute to change in gene frequency over time, leading to adaptation of populations.
- Scientific knowledge is based on the assumption that natural laws operate today as they did in the past and will continue to do so in the future.

Practices

- Construct an explanation based on valid and reliable evidence obtained from a variety of sources (including students' own investigations, models, theories, simulations, peer review), and on 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, for how natural selection leads to adaptation of populations.
- Use data to differentiate between cause and correlation and to make claims about how specific biotic and abiotic differences in ecosystems contribute to change in gene frequency over time, leading to adaptation of populations.

Driving question 2
What is the relationship between the numbers of organisms with an advantageous heritable trait and the numbers of organisms lacking this trait?

Concepts

- 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.
- 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.
- Different patterns may be observed at each of the scales at which a system is studied and can provide evidence for causality in explanations that organisms with an advantageous heritable trait tend to increase in proportion to organisms lacking this trait.

Practices

- Apply concepts of statistics and probability (including determining function fits to data, slope, intercept, and correlation coefficient for linear fits) to support explanations that organisms with an advantageous heritable trait tend to increase in proportion to organisms lacking this trait.
- Analyze shifts in numerical distribution of traits and, using these shifts as evidence, support explanations that organisms with an advantageous heritable trait tend to increase in proportion to organisms lacking this trait.
- Observe patterns at each of the scales at which a system is studied to provide evidence for causality in explanations that organisms with an advantageous heritable trait tend to increase in proportion to organisms lacking this trait.

Driving question 3
How are species affected by changing environmental conditions?

Concepts

- Changes in the physical environment, whether naturally occurring or human induced, have 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.
- Empirical evidence is required to differentiate between cause and correlation and make claims that changes in environmental conditions may result in: (1) increases in the number of individuals of some species, (2) the emergence of new species over time, and (3) the extinction of other species.

Practices

- Evaluate the evidence supporting claims that changes in environmental conditions may result in: (1) increases in the number of individuals of some species, (2) the emergence of new species over time, and (3) the extinction of other species.
- Determine cause-and-effect relationships for how changes to the environment affect distribution or disappearance of traits in species.
- Use empirical evidence to differentiate between cause and correlation and to make claims that changes in environmental conditions may result in: (1) increases in the number of individuals of some species, (2) the emergence of new species over time, and (3) the extinction of other species.

Driving question 4
What is the role of group behavior in individual and species' chances to survive and reproduce?

Concepts

- Group behavior has evolved because membership can increase the chances of survival for individuals and their genetic relatives.
- Empirical evidence is required to differentiate between cause and correlation and to make claims about the role of group behavior in individual and species' chances to survive and reproduce.
- Scientific argumentation is a mode of logical discourse used to clarify the strength of relationships between ideas and evidence that may result in the revision of an explanation about the role of group behavior on individual and species' chances to survive and reproduce.

Practices

- Evaluate the evidence for the role of group behavior on individual and species' chances to survive and reproduce.
- Distinguish between group and individual behavior.
- Identify evidence supporting the outcome of group behavior.
- Develop logical and reasonable arguments based on evidence to evaluate the role of group behavior on individual and species' chances to survive and reproduce.
- Use empirical evidence to differentiate between cause and correlation and to make claims about the role of group behavior on individual and species' chances to survive and reproduce.

Integration of content, practices, and crosscutting concepts

In this unit, students begin by developing an understanding of the way natural selection leads to adaptation in a population dominated by organisms that are anatomically, behaviorally, and physiologically well suited to survive and reproduce in a specific environment. Empirical evidence (including students' own investigations, models, theories, simulations, peer review) should be used to differentiate between cause and correlation and to make claims about how natural selection leads to adaptation of populations. Students should make sense of quantities and relationships between specific biotic and abiotic differences in ecosystems and their contributions to a change in gene frequency over time that leads to adaptation of populations, paying attention to proportional increases in organisms with advantageous heritable traits.

Students should use data to provide evidence for how specific biotic and abiotic differences in ecosystems (such as ranges of seasonal temperature, long-term climate change, acidity, light, geographic barriers, or evolution of other organisms) contribute to a change in gene frequency over time, leading to adaptation of populations. To enhance understanding, students should examine scientific text and cite specific textual evidence to support analysis and explanations for how natural selection leads to change in populations over time. Students need to connect current learning to past events to enhance understanding that scientific knowledge is based on natural laws that operate today as they did in the past and will continue to do so in the future.

Students will build on their knowledge of the factors that contribute to the variations of different traits within a population. Students should examine how individuals possessing certain forms of inherited traits may have a survival advantage over others in the population. Increased survival and reproductive success in these individuals can cause advantageous traits to become more common in the population. In other words, the population adapts to its environment. This process of change over time, as the environment "selects" for advantageous forms of heritable traits, is called natural selection. This process could be experienced by students through a variety of hands-on experiments, such as simulations of Kettlewell or peppered moth studies and industrial melanism. Many computer simulations are available that allow students to manipulate changes in the environment and observe how the population changes as individuals with advantageous traits survive and reproduce, while those lacking these traits die in greater numbers before reproducing. From experiments such as these, students can collect numerical data and observe that while the total number of individuals in the population may remain relatively constant, the traits represented in that population can change in response to environmental change. As an extension, students may apply the HWE theorem to analyze shifts in allele frequencies over several generations. Students could make predictions as to what environmental factor exerted the selection pressure responsible for the shift. In further studies students could predict how future environmental change such as global warming could drive changes in dominant traits as conditions change. Emphasis is on statistical and graphical analysis of numerical distribution of traits and using shifts as evidence to support explanations.

Human influence can cause changes to the physical environment. Naturally occurring or human-induced behaviors can also contribute the expansion of some species such as zebra mussels, fire ants, or Africanized bees. Students might research migratory patterns of Africanized bees or West Nile virus using CDC data. They might also focus on how species decline and sometimes become extinct using data from research.

Species extinction can also result from faster or drastic changes limiting the possibilities of species evolution. Students can investigate claims in order to support how environmental conditions may result in an increase in the number of species, emergence of new species over time, or in the extinction of other species.

Students should determine the cause-and-effect relationships involved in how changes in the environment affect the distribution or disappearance of traits in a specific species. Addressing how changes to the environment affect the distribution or disappearance of traits in a species could be explained from a cause-and-effect perspective. Possible outcomes of human interactions include changes in the number of individuals of some species, emergence of new species over time, and the extinction of other species.

Students can research the influence of eutrophication of the Taunton River, Blackstone River, and Providence River on the upper Narragansett Bay. The recent increase in Narragansett Bay temperature has negatively influenced the distribution of species, contributing to the disappearance of some species. Because of increased Bay temperatures, lower reproductive rates among flounder have resulted, suggesting that water temperatures have negatively affected reproductive rates. In their research, students should evaluate hypotheses, data, analysis, and conclusions about how changes in environmental conditions may result in changes in the numbers of some species. They should support their findings with evidence.

Group behavior of organisms has evolved because membership can increase the chance of survival for individuals and their genetic relatives. Students should collect empirical data that differentiates between cause and correlation relating to the survival rate of species and group behaviors. Students should develop logical and reasonable arguments to clarify the strength of the relationship and interactions between ideas and evidence that may be used to explain the role of group behavior on survival rate. Students might use models of schooling and flocking behavior of organisms as a role that increases species survival. Students might also consider the role of behaviors such as herding, cooperative hunting, migrating, and swarming. Individual and group survival behaviors can be studied to determine their survival advantages, (mimicry, camouflage, flocking, swarming, etc.) Evidence supporting the benefits of group behavior such as predation and life expectancy could be used to illustrate concepts.

Integration of DCI from prior units within this grade level

Students learned that ecosystems have limits, which result from challenges such as predation, competition, and disease, that limit the number of organisms in the population. Also in earlier units, students learned how resource availability has guided the development of human population. Students learned how environmental factors affect expression of traits and the probability of occurrences of traits in a population. Thus, the variation and distribution of traits observed depend on both genetic and environmental factors. These ideas support students' current learning, in which they are developing an understanding that phenotypic variation can influence the chances of survival.

<u>*Integration of mathematics and/or English language arts/literacy*</u>

Mathematics

- Represent how natural selection leads to adaptation of populations symbolically, and manipulate the representing symbols. Make sense of quantities and relationships between specific biotic and abiotic differences in ecosystems and their contributions to a change in gene frequency over time that leads to adaptation of populations.
- Represent symbolically the proportional increase in organisms with an advantageous heritable trait as compared with organisms lacking this trait, and manipulate the representing symbols. Make sense of quantities and relationships between the proportional increase in organisms with an advantageous heritable trait as compared with the numbers of organisms lacking this trait.

English language arts/literacy

- Cite specific textual evidence to support analysis of science and technical texts describing how natural selection leads to adaptation of populations, attending to important distinctions the author makes and to any gaps or inconsistencies in the account.
- Write informative/explanatory texts describing how natural selection leads to adaptation of populations, including the narration of historical events, scientific procedures/experiments, or technical processes.
- Draw evidence from informational texts to support analysis, reflection, and research about how natural selection leads to adaptation of populations.
- Cite specific textual evidence to support analysis of science and technical texts that provide explanations that organisms with an advantageous heritable trait tend to increase in proportion to organisms lacking this trait, attending to important distinctions the author makes and to any gaps or inconsistencies in the account.
- Write informative/explanatory texts about explanations that organisms with an advantageous heritable trait tend to increase in proportion to organisms lacking this trait, including the narration of historical events, scientific procedures/experiments, or technical processes.
- Draw evidence from information texts to support analysis, reflection, and research about organisms with an advantageous heritable trait and their proportional increase as compared to organisms lacking this trait.
- Evaluate the hypotheses, data, analysis, and conclusions in a science or technical text supporting claims that changes in environmental conditions may result in (1) increases in the number of individuals of some species, (2) the emergence of new species over time, and (3) the extinction of other species, verifying the data when possible and corroborating or challenging conclusions with other sources of information.
- Draw evidence from information texts making claims that changes in environmental conditions may result in: (1) increases in the number of individuals of some species, (2) the emergence of new species over time, and (3) the extinction of other species to support analysis, reflection, and research.
- Assess the extent to which the reasoning and evidence in a text support the author's claim about the role of group behavior on individual and species' chances to survive and reproduce.

- Cite specific textual evidence to support analysis of science and technical texts about the role of group behavior on individual and species' chances to survive and reproduce.
- Integrate and evaluate multiple sources of information presented in diverse formats and media (e.g., quantitative data, video, multimedia) in order to address the role of group behavior on individual and species' chances to survive and reproduce.
- Evaluate the hypotheses, data, analysis, and conclusions in a science or technical text about the role of group behavior on individual and species' chances to survive and reproduce, verifying the data when possible and corroborating or challenging conclusions with other sources of information.

Connected learning

Connections to disciplinary core ideas in other high school courses are as follows:

Life science

- 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 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.
- Group behavior has evolved because membership can increase the chances of survival for individuals and their genetic relatives.
- In sexual reproduction, chromosomes can sometimes swap sections during the process of meiosis (cell division), thereby creating new genetic combinations and thus more genetic variation. Although DNA replication is tightly regulated and remarkably accurate, errors do occur and result in mutations, which are also a source of genetic variation. Environmental factors can also cause mutations in genes, and viable mutations are inherited.
- Environmental factors also affect expression of traits, and hence affect the probability of occurrences of traits in a population. Thus the variation and distribution of traits observed depends on both genetic and environmental factors.

Earth and space science

- 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.
- Resource availability has guided the development of human society.
- All forms of energy production and other resource extraction have associated economic, social, environmental, and geopolitical costs and risks as well as benefits. New technologies and social regulations can change the balance of these.

Number of Instructional Days

Recommended number of instructional days: 20 (1 day = approximately 50 minutes)

Note—The recommended number of days is an estimate based on the information available at this time. Teachers are strongly encouraged to review the entire unit of study carefully and collaboratively to determine whether adjustments to this estimate need to be made.

Additional NGSS Resources

The following resources were used when writing this unit:

- NGSS appendices L and M
- *A Framework for K-12 Science Education*
- *Common Core State Standards for Mathematics* and *Common Core State Standards for Literacy in History/Social Studies, Science, & Technical Subjects*

Biology Unit 8
Evolution

Overview

Unit abstract

In this unit of study, students can construct explanations for the processes of natural selection and evolution and then communicate how multiple lines of evidence support these explanations. Students can evaluate evidence of the conditions that may result in new species and understand the role of genetic variation in natural selection. Additionally, students can apply concepts of probability to explain trends in population as those trends relate to advantageous heritable traits in a specific environment. Students demonstrate an understanding of these concepts by obtaining, evaluating, and communicating information and constructing explanations and designing solutions. The crosscutting concepts of patterns and cause and effect support the development of a deeper understanding.

Essential question

- What evidence shows that different species are related?

Written Curriculum

Next Generation Science Standards

HS. Natural Selection and Evolution

Students who demonstrate understanding can:

HS-LS4-1. Communicate scientific information that common ancestry and biological evolution are supported by multiple lines of empirical evidence. [Clarification Statement: Emphasis is on a conceptual understanding of the role each line of evidence has relating to common ancestry and biological evolution. Examples of evidence could include similarities in DNA sequences, anatomical structures, and order of appearance of structures in embryological development.]

The performance expectations 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
Obtaining, Evaluating, and Communicating Information Obtaining, evaluating, and communicating information in 9–12 builds on K–8 experiences and progresses to evaluating the validity and reliability of the claims, methods, and designs. ▪ Communicate scientific information (e.g., about phenomena and/or the process of development and the design and performance of a proposed process or system) in multiple formats (including orally, graphically, textually, and mathematically). (HS-LS4-1) -- ***Connections to Nature of Science*** **Science Models, Laws, Mechanisms, and Theories Explain Natural Phenomena** ▪ 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. (HS-LS4-1)	**LS4.A: Evidence of Common Ancestry and Diversity** ▪ 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. (HS-LS4-1)	**Patterns** ▪ 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. (HS-LS4-1) -- ***Connections to Nature of Science*** **Scientific Knowledge Assumes an Order and Consistency in Natural Systems** ▪ 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. (HS-LS4-1)

Connections to other DCIs in this grade-band: **HS.LS2.A** (HS-LS4-2),(HS-LS4-3),(HS-LS4-4),(HS-LS4-5); **HS.LS2.D** (HS-LS4-2),(HS-LS4-3),(HS-LS4-4),(HS-LS4-5); **HS.LS3.A** (HS-LS4-1); **HS.LS3.B** (HS-LS4-1),(HS-LS4-2) (HS-LS4-3),(HS-LS4-5); **HS.ESS1.C** (HS-LS4-1); **HS.ESS2.E** (HS-LS4-2),(HS-LS4-5); **HS.ESS3.A** (HS-LS4-2),(HS-LS4-5)

Articulation across grade-bands: **MS.LS3.A** (HS-LS4-1); **MS.LS3.B** (HS-LS4-1); **MS.LS4.A** (HS-LS4-1); **MS.ESS1.C** (HS-LS4-1)

Common Core State Standards Connections:

ELA/Literacy –

RST.11-12.1	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-LS4-1)*
WHST.9-12.2	Write informative/explanatory texts, including the narration of historical events, scientific procedures/ experiments, or technical processes. *(HS-LS4-1)*
WHST.9-12.9	Draw evidence from informational texts to support analysis, reflection, and research. *(HS-LS4-1)*
SL.11-12.4	Present claims and findings, emphasizing salient points in a focused, coherent manner with relevant evidence, sound valid reasoning, and well-chosen details; use appropriate eye contact, adequate volume, and clear pronunciation. *(HS-LS4-1)*

Mathematics –

MP.2	Reason abstractly and quantitatively. *(HS-LS4-1)*

HS. Natural Selection and Evolution		
Students who demonstrate understanding can: **HS-LS4-2. Construct an explanation based on evidence that the process of evolution primarily results from four factors: (1) the potential for a species to increase in number, (2) the heritable genetic variation of individuals in a species due to mutation and sexual reproduction, (3) competition for limited resources, and (4) the proliferation of those organisms that are better able to survive and reproduce in the environment.** [Clarification Statement: Emphasis is on using evidence to explain the influence each of the four factors has on number of organisms, behaviors, morphology, or physiology in terms of ability to compete for limited resources and subsequent survival of individuals and adaptation of species. Examples of evidence could include mathematical models such as simple distribution graphs and proportional reasoning.] [Assessment Boundary: Assessment does not include other mechanisms of evolution, such as genetic drift, gene flow through migration, and co-evolution.]		
The performance expectations above were 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 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. ▪ Construct 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. (HS-LS4-2)	**Disciplinary Core Ideas** **LS4.B: Natural Selection** ▪ 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. (HS-LS4-2) **LS4.C: Adaptation** ▪ 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. (HS-LS4-2)	**Crosscutting Concepts** **Cause and Effect** ▪ Empirical evidence is required to differentiate between cause and correlation and make claims about specific causes and effects. (HS-LS4-2)
Connections to other DCIs in this grade-band: **HS.LS2.A** (HS-LS4-2); **HS.LS2.D** (HS-LS4-2); **HS.LS3.B** (HS-LS4-2); **HS.ESS2.E** (HS-LS4-2); **HS.ESS3.A** (HS-LS4-2)		
Articulation across grade-bands: **MS.LS2.A** (HS-LS4-2); **MS.LS3.B** (HS-LS4-2); **MS.LS4.B** (HS-LS4-2); **MS.LS4.C** (HS-LS4-2)		
Common Core State Standards Connections: *ELA/Literacy –* **RST.11-12.1** 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-LS4-2) **WHST.9-12.2** Write informative/explanatory texts, including the narration of historical events, scientific procedures/ experiments, or technical processes. (HS-LS4-2) **WHST.9-12.9** Draw evidence from informational texts to support analysis, reflection, and research. (HS-LS4-2) **SL.11-12.4** Present claims and findings, emphasizing salient points in a focused, coherent manner with relevant evidence, sound valid reasoning, and well-chosen details; use appropriate eye contact, adequate volume, and clear pronunciation. *(HS-LS4-2)* *Mathematics –* **MP.2** Reason abstractly and quantitatively. (HS-LS4-2) **MP.4** Model with mathematics. *(HS-LS4-2)*		

Clarifying the standards

Prior learning

The following disciplinary core ideas are prior learning for the concepts in this unit of study. By the end of Grade 8, students know that:

Life science

- Genes are located in the chromosomes of cells, with each chromosome pair containing two variants of each of many distinct genes. Each distinct gene chiefly controls the production of specific proteins, which in turn affect the traits of the individual. Changes (mutations) to genes can result in changes to proteins, which can affect the structures and functions of the organism and thereby change traits.
- Variations of inherited traits between parent and offspring arise from genetic differences that result from the subset of chromosomes (and therefore genes) inherited.
- In sexually reproducing organisms, each parent contributes half of the genes acquired (at random) by the offspring. Individuals have two of each chromosome and hence two alleles of each gene, one acquired from each parent. These versions may be identical or may differ from each other.
- In addition to variations that arise from sexual reproduction, genetic information can be altered because of mutations. Though rare, mutations may result in changes to the structure and function of proteins. Some changes are beneficial, others harmful, and some neutral to the organism.
- 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 among 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.

Earth and space science

- 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.
- 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.

Progression of current learning

Driving question 1
What is the evidence for common ancestry and biological evolution?

Concepts

- 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.
- 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.
- Different patterns in multiple lines of empirical evidence may be observed at each of the scales at which a system is studied and can provide evidence for causality in explanations of common ancestry and biological evolution.

Practices

- Communicate scientific information in multiple forms that common ancestry and biological evolution are supported by multiple lines of empirical evidence.
- Understand the role each line of evidence has relating to common ancestry and biological evolution.
- Observe patterns in multiple lines of empirical evidence at different scales and provide evidence for causality in explanations of common ancestry and biological evolution.

Driving question 2
What are factors that influence the process of evolution?

Concepts

- 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.

Practices

- Construct 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, that the process of evolution primarily results from four

- 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.
- Empirical evidence is required to differentiate between cause and correlation and make claims about the process of evolution.

factors: (1) the potential for a species to increase in number, (2) the heritable genetic variation of individuals in a species due to mutation and sexual reproduction, (3) competition for limited resources, and (4) the proliferation of those organisms that are better able to survive and reproduce in the environment.

- Use empirical evidence to explain the influences of: (1) the potential for a species to increase in number, (2) the heritable genetic variation of individuals in a species due to mutation and sexual reproduction, (3) competition for limited resources, and (4) the proliferation of those organisms that are better able to survive and reproduce in the environment, on number of organisms, behaviors, morphology, or physiology in terms of ability to compete for limited resources and subsequent survival of individuals and adaptation of species.

Integration of content, practices, and crosscutting concepts

Evolution is a theory substantiated by explanations of the natural world that are based on facts, observations, experiments, and evidence. The theory can be modified upon the discovery of new evidence validated by the scientific community. In this unit of study, students should communicate scientific information related to the evidence for evolution and evolutionary relationships between organisms. Students should analyze DNA sequences, amino acid sequences in proteins, and homologous structures in organisms using various models. Models might include illustrations of embryonic development, amino acid sequences, and cladograms. Students should be able to identify patterns in multiple lines of empirical evidence in order to develop an understanding of the role each line of evidence has in supporting common ancestry and biological evolution.

Students will also need to construct and write explanations supported by evidence from text and build on previous experiences to promote a deeper understanding of natural selection. Natural selection posits there is variation among organisms within a population. The variation present in the genetic information generates the phenotypic differences potentially leading to varying performance among individuals as they compete for limited resources. Students should understand that 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.

Students can construct explanations using quantitative models, such as histograms, that are based on valid and reliable evidence obtained from a variety of sources such as investigations, graphs, tables, and simulations. Students might demonstrate comprehension by drawing evidence from informational text describing common ancestry and biological evolution. Explanations should be supported by analysis, reflection, and research. Students could also share this information with others by way of oral presentations, written reports, or technology-based presentations.

Students might research the range of human birth weights illustrating stabilizing selection, in which individuals too small or too large are selected against. The use of antibiotics and pesticides also can be used to further understand directional selection for an extreme phenotype. The result of these investigations reinforces the concept that the natural world operates today as it has in the past and the future.

Students will learn that within the process of evolution, there is a potential for species to increase in number. Mutation and sexual reproduction can generate genetic variation, and species compete for limited resources. These factors influence survivorship, reproduction, and the proliferation of species with adaptive phenotypes.

Students can research the relationship between phenotypic variation and survivorship by studying beak size among the Galapagos Island finches, Coral and King snake mimicry, and the lack of pigment deposited in polar bear fur, which fosters the absorption and retention of solar heat while also maintaining camouflage. Additional empirical evidence students may collect includes modeling industrial melanism among peppered moths. Behavioral adaptations may include chimpanzees' use of twigs to capture termites or sea otters' use of rocks to open shellfish.

Integration of DCI from prior units within this grade level

Previously, students learned that different factors (including mutations and sexual reproduction) contribute to variation in a population and that natural selection can influence frequencies of heritable traits by providing survival advantages to some individuals. This understanding will be applied in the current unit as students examine the four factors that primarily influence evolution: (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.

Integration of mathematics and/or English language arts/literacy

Mathematics

- Represent evidence that common ancestry and biological evolution are supported by multiple lines of empirical evidence symbolically, and manipulate the representing symbols. Make sense of quantities and relationships to describe and predict common ancestry and biological evolution.

English language arts/literacy

- Cite specific textual evidence to support analysis of science and technical texts describing common ancestry and biological evolution, attending to important distinctions the author makes and to any gaps or inconsistencies in the account.
- Write informative/explanatory texts describing common ancestry and biological evolution, including the narration of historical events, scientific procedures/experiments, or technical processes.
- Draw evidence from informational texts describing common ancestry and biological evolution to support analysis, reflection, and research.
- Present claims and findings about common ancestry and biological evolution, emphasizing salient points in a focused, coherent manner with relevant evidence, sound valid reasoning, and well-chosen details; use appropriate eye contact, adequate volume, and clear pronunciation.

Connected learning

Connections to disciplinary core ideas in other high school courses are as follows:

Life science

- 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.
- Group behavior has evolved because membership can increase the chances of survival for individuals and their genetic relatives.
- Each chromosome consists of a single, very long DNA molecule, and each gene on the chromosome is a particular segment of that DNA. The instructions for forming species' characteristics are carried in DNA. All cells in an organism have the same genetic content, but the genes used (expressed) by the cell may be regulated in different ways. Not all DNA codes for a protein; some segments of DNA are involved in regulatory or structural functions, and some have, as yet, no known function.
- In sexual reproduction, chromosomes can sometimes swap sections during the process of meiosis (cell division), thereby creating new genetic combinations and thus more genetic variation. Although DNA replication is tightly regulated and remarkably accurate, errors do occur and result in mutations, which are also a source of genetic variation. Environmental factors can also cause mutations in genes, and viable mutations are inherited.
- Environmental factors also affect expression of traits, and hence affect the probability of occurrences of traits in a population. Thus the variation and distribution of traits observed depends on both genetic and environmental factors.

Earth and space science

- 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.
- 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.
- 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.
- Resource availability has guided the development of human society.
- All forms of energy production and other resource extraction have associated economic, social, environmental, and geopolitical costs and risks as well as benefits. New technologies and social regulations can change the balance of these factors.

Number of Instructional Days

Recommended number of instructional days: 22 (1 day = approximately 50 minutes)

Note—The recommended number of days is an estimate based on the information available at this time. Teachers are strongly encouraged to review the entire unit of study carefully and collaboratively to determine whether adjustments to this estimate need to be made.

Additional NGSS Resources

The following resources were consulted during the writing of this unit:

- NGSS appendices L and M
- *A Framework for K–12 Science Education*
- *Common Core State Standards for Mathematics* and *Common Core State Standards for Literacy in History/Social Studies, Science, & Technical Subjects*

Biology Unit 9
Bioecology

Overview

Unit abstract

In this unit of study, students develop models and explanations for the ways that feedbacks between different Earth systems control the appearance of Earth's surface. Students will learn that Earth's history includes the coevolution of the biosphere with Earth's other systems. Students will demonstrate understanding by engaging in argument from evidence. The crosscutting concept of stability and change is called out as an organizing element.

Essential question

- How do the major systems of the Earth interact?

Written Curriculum

Next Generation Science Standards

HS. Earth's Systems

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 expectations 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
Engaging in Argument from Evidence Engaging in argument from evidence in 9–12 builds on K–8 experiences and progresses to using appropriate and sufficient evidence and scientific reasoning to defend and critique claims and explanations about the natural and designed world(s). Arguments may also come from current scientific or historical episodes in science. ▪ Construct an oral and written argument or counter-arguments based on data and evidence. (HS-ESS2-7)	**ESS2.D: Weather and Climate** ▪ Gradual atmospheric changes were due to plants and other organisms that captured carbon dioxide and released oxygen. (HS-ESS2-7) **ESS2.E: Biogeology** ▪ 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)	**Stability and Change** ▪ Much of science deals with constructing explanations of how things change and how they remain stable. (HS-ESS2-7)

Connections to other DCIs in this grade-band: **HS.LS2.A** (HS-ESS2-7); **HS.LS2.C** (HS-ESS2-7); **HS.LS4.A** (HS-ESS2-7); **HS.LS4.B** (HS-ESS2-7); **HS.LS4.C** (HS-ESS2-7); **HS.LS4.D** (HS-ESS2-7);

Articulation of DCIs across grade-bands: **MS.LS2.A** (HS-ESS2-7); **MS.LS2.C** (HS-ESS2-7); **MS.LS4.A** (HS-ESS2-7); **MS.LS4.B** (HS-ESS2-7); **MS.LS4.C** (HS-ESS2-7); **MS.ESS1.C** (HS-ESS2-7); **MS.ESS2.A** (HS-ESS2-7); **MS.ESS2.C** (HS-ESS2-7)

Common Core State Standards Connections:
ELA/Literacy –
WHST.9-12.1 Write arguments focused on *discipline-specific content.* (HS-ESS2-7)

Clarifying the standards

Prior learning

The following disciplinary core ideas are prior learning for the concepts in this unit of study. By the end of Grade 8, students know that:

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.
- 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

- 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.
- 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.
- 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.

Progression of current learning

Driving question 1
What evidence exists for the simultaneous coevolution of Earth's systems and life on Earth?

Concepts

- Gradual atmospheric changes were due to plants and other organisms that captured carbon dioxide and released oxygen.
- 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.
- Much of science deals with constructing explanations of how things change and how they remain stable.

Practices

- Construct an argument based on evidence about the simultaneous coevolution of Earth's systems and life on Earth.
- Construct an argument based on evidence about the dynamic causes, effects, and feedbacks among the biosphere and other Earth systems—whereby geoscience factors control the evolution of life which in turn continuously alters Earth's surface—and how these factors cause the simultaneous coevolution of Earth's surface and the life that exists on it.
- Construct an argument based on evidence about how Earth's systems and life on Earth have changed and how they remain stable.

Integration of content, practices, and crosscutting concepts

In the current unit, students should develop an understanding of the relationships between geoscience factors and the evolution of life. Students will learn that atmospheric changes that occurred during early Earth history were due to plants and other organisms that captured carbon dioxide and released oxygen. The gradual accumulation of atmospheric oxygen due to increased photosynthesis initiated a series of dynamic and delicate feedback systems. This caused the coevolution of the Earth's surface and the life forms on it. Students should develop an understanding for how the Earth and the life forms on it have changed over time and how they have remained stable. For example, during the Carboniferous Period, increasing concentrations of oxygen allowed for higher metabolic rates among terrestrial arthropods, which fostered an enlargement in their size and diversification. Additionally, the accumulation of atmospheric oxygen generated by marine autotrophs lead to the formation of a stratospheric ozone layer which blocked dangerous UV radiation, promoting the evolution of terrestrial life.

Students should construct and write arguments for the coevolution of Earth's systems and life on Earth, based on evidence of the dynamic causes, effects, and feedbacks between the biosphere and Earth's other systems. Students might conduct research and analyze data sets of how Earth's atmospheric conditions have changed and how life on Earth has changed throughout Earth's history. Students might also research changes in land features that might be related to changing amounts of atmospheric oxygen and look for relationships between these factors and changes in organisms.

Integration of DCI from prior units within this grade level

Students previously learned about factors affecting biodiversity and populations in ecosystems of different scales. Complex interactions in ecosystems maintain relatively consistent numbers and types of organisms in stable conditions, but changing conditions may result in new ecosystems. Photosynthesis plays a critical role in providing both organic matter and oxygen to the biosphere. Common ancestry and biological evolution are supported by multiple lines of empirical evidence.

This prior knowledge provides students with an informed perspective regarding the coevolution of biotic organisms and abiotic systems—for example, 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. Microbial life on land increased the formation of soil and cycling of nutrients, which in turn allowed for the evolution of land plants.

Integration of English language arts/literacy

- Write arguments focused on the simultaneous coevolution of Earth's systems and life on Earth.

Connected learning

Connections to disciplinary core ideas in other high school courses are as follows:

Life science

- 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.
- 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, like the fossil record, 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. The differential survival and reproduction of organisms in a population that have an advantageous heritable trait lead 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.
- Humans depend on the living world for the resources and other benefits provided by biodiversity. But human activity is also having adverse impacts on biodiversity through overpopulation, overexploitation, habitat destruction, pollution, introduction of invasive species, and climate change. Thus sustaining biodiversity so that ecosystem functioning and productivity are maintained is essential to supporting and enhancing life on Earth. Sustaining biodiversity also aids humanity by preserving landscapes of recreational or inspirational value.

Number of Instructional Days

Recommended number of instructional days: 18 (1 day = approximately 50 minutes)

Note—The recommended number of days is an estimate based on the information available at this time. Teachers are strongly encouraged to review the entire unit of study carefully and collaboratively to determine whether adjustments to this estimate need to be made.

Additional NGSS Resources

The following resources were consulted during the writing of this unit:

- NGSS appendices (L and M)
- *A Framework for K–12 Science Education*
- *Common Core State Standards for Mathematics* and *Common Core State Standards for Literacy in History/Social Studies, Science, & Technical Subjects*