STORYLINE AND SENSEMAKING

SUSTAINABILITY: CHANGING HUMAN IMPACT

Unit issue: The ways that humans interact with the environment can cause dramatic changes over time.

Overarching question/Suggested driving question: How do humans affect the environment over time?

Investigative phenomenon: Environmental change over time.

This four-activity sequence begins the *Science and Global Issues: Biology* course by having students investigate human effects on the natural environment in different parts of the world. Students are introduced to the issue for this introductory sequence: *The ways that humans interact with the environment can cause dramatic changes over time*. Students ask questions about the effects of humans on the environment and analyze data relating to those effects. They reflect on their own knowledge and observations of environmental change and discuss ways that human actions may or may or may not be considered sustainable. In the final activity of the sequence, students use a model to explore the effects of human actions on a specific environment and test their ideas for a sustainable solution.

This sequence provides an opportunity to initially assess and then further develop students' skills with the practices of *asking questions* and *developing and using models*. Students develop a definition of *sustainability*, which they will use throughout the course.

Storyline	Sensemaking Progression
Activity 1: Changing Landscapes **Guiding question:** How are human actions changing the environment over time? People contribute to environmental change in different ways in different parts of the world.	• Students build on their personal knowledge of changing landscapes by investigating how human actions affect the environment in various parts of the world. • Key sensemaking: Students *analyze and interpret data*, a science and engineering practice that they further develop throughout the *Science and Global Issues* course. Students analyze real-world data that reveals how humans have changed the environment over time in four different global regions, and the dominant drivers of those changes in each region. This key sensemaking opportunity occurs in Procedure Steps 2–8. • Students construct a working definition of *sustainability* as it relates to human actions and the environment. • Students ask questions about the role of human actions on the environment and the implications of those impacts over time. • Going forward: In the next activity, students consider ways to measure the impact of humans on one component of the environment: soil.

Storyline	Sensemaking Progression
Activity 2: Measuring Human Impact **Guiding question:** In what ways can human effects on the environment be measured? The impact of human actions on the environment can be measured in a number of ways.	• Students build on their knowledge of human impact on the environment by measuring the effect of land use on the organic matter in soil. • Students test the levels of organic matter in soil samples, and analyze and interpret the data. • Key sensemaking: Students determine the effect of human land use on soil quality and evaluate the sustainability of land use over time. This key sensemaking opportunity occurs in Build Understanding items 1 and 2. • Students consider the environmental, economic, and social impacts of another human action (shrimp farming) and further reflect on how these impacts can be measured. • Going forward: In the next activity, students consider a variety of indicators that can be used to measure human resource use and consider the sustainability of each indicator at a global level.
Activity 3: Our Global Community **Guiding question:** How can indicators be used to inform decisions about global sustainability? Indicators provide information about whether a community is using its resources sustainably.	• Students fill potential gaps in their knowledge about sustainability as it relates to the environment and resource use. • Students explore how indicators relate to the three pillars of sustainability and what such indicators can tell us about human actions. Students begin to understand that global access to resources varies widely across regions. • Key sensemaking: Students analyze regional indicator data and use their understanding to assess what patterns in data can reveal about the effects of human actions on the environment and sustainability. This key sensemaking opportunity occurs in Procedure Step 14. • To further make sense of the relationship between resource use and sustainability, students convert regional data to per capita data for two indicators. • Going forward: In the next activity, students model how different human actions can affect sustainability.
Activity 4: Sustaining the Commons **Guiding question: How do human choices affect sustainability?** How common resources are used by individuals is a critical part of global sustainability.	• Students have the opportunity to fill potential gaps in their knowledge of how individual and communal choices can impact the sustainability of a resource. • To better understand the effects of individual and group behavior on common resource use, students model a range of human actions, in the process realizing that setting limits on common resource use can be challenging. • Key sensemaking: Students *analyze and interpret data*, a science and engineering practice they will continue to develop throughout the *Science and Global Issues* course. After exploring different parameters of the model and then analyzing the data, students come to realize that sustaining a common resource will likely involve trade-offs. This key sensemaking opportunity occurs in Procedure Step 11 and Build Understanding item 6. • Going forward: In the Ecology unit, students deepen their understanding of sustainability as they explore the factors that influence ecosystem stability and change.

STORYLINE AND SENSEMAKING

ECOLOGY: LIVING ON EARTH

Unit issue: People rely on natural resources, including fish, for many reasons, including food, yet many fisheries are no longer sustainable..

Overarching question: How can we use our knowledge about ecology to make informed decisions about managing fisheries to be more sustainable?

This unit begins with students reviewing what they have learned thus far about how humans affect the environment, particularly through their use of resources; the questions students had about the effect of humans on the environment; and which of their questions have not yet been answered. Students are introduced to the issue for this unit: *people rely on natural resources, including fish, for many reasons, including food, yet many fishers are no longer sustainable.* Students' initial ideas and questions about fisheries are elicited, as are their initial ideas about how to gather evidence to address their questions. Students also begin to consider both local and global consequences if steps aren't taken to manage fisheries more sustainably.

Learning Sequence 1

Investigative phenomenon: Different populations of organisms can have a wide range of growth patterns over time.

Students investigate four example populations, including one directly related to fisheries. Students also identify examples of changes in populations in their local environment to help them understand the relevance of what they are investigating to their own lives. Students revisit these examples at the end of each activity in this learning sequence as they learn more about population growth and the factors that can limit it.

Suggested driving question: What are the factors that determine how many individuals of a population can exist in a given area?

Focal Performance Expectation: LS2-1

Storyline	Sensemaking Progression
Activity 1: Establishing a Baseline **Guiding question:** How do scientists estimate population size? This activity orients students to the unit issue and the investigative phenomenon for this learning sequence. The goal is for students to gain a basic understanding of how scientists monitor populations of organisms. To determine if a population of organisms is thriving or struggling, scientists must be able to assess population size and determine if the population is growing, shrinking, or remaining stable, which they do by comparing the population size at different points in time. Because it is rarely possible to count every individual, scientists use estimates or indicators of population size. Students explore two commonly used estimation methods—quadrat sampling and mark-and-recapture sampling—which rely on mathematical or proportional thinking. Students make sense of how scientists determine which method is appropriate for the organisms being studied, why repeated measures are necessary, and what patterns in population data can reveal about population growth and sustainability.	• Students begin asking questions about fisheries and what makes them sustainable or unsustainable. • Students develop initial ideas about the importance of establishing a population baseline in order to understand the effect of any change in the environment on a population of organisms. • Students investigate why comparing baseline population data to current population data helps us understand how changes in the environment affect populations. • Students recognize that direct population counts are sometimes impossible or impractical for many populations (e.g., fish), depending on the organisms' behaviors and characteristics. • Key sensemaking: After exploring how scientists use proportional reasoning to estimate population size, students use this type of reasoning to estimate the size of two sample populations. This key sensemaking opportunity occurs in Build Understanding item 1. • Going forward: In the next activity, students deepen their understanding of population growth patterns by using different models to determine whether a population is increasing, decreasing, or stable.

<table>
<tr><th>Storyline</th><th>Sensemaking Progression</th></tr>
<tr><td>Activity 2: Population Growth Models
Guiding question: What can patterns in data tell us about the status of a population of organisms?
Students begin to explore population growth and limits. All populations of organisms, from blue whales to bacteria, have the potential for exponential growth, which students first investigate using the exponential growth model. However, this model assumes ideal growth conditions (i.e., there are no limits to growth), a pattern that is rarely seen in nature due to typically limited resources, including food, space, and safety from predators. Students then explore the logistic growth model, which incorporates carrying capacity (the maximum number of individuals that can exist in a particular environment) and is generally more realistic. Understanding population growth patterns and models allows students to speculate about why knowing whether a population is increasing, decreasing, or stable would be important in fisheries management.</td><td>• Students explore the exponential population growth model and come to realize that this model unrealistically assumes that there are no limits to population growth.
• Students explore the logistic population growth model, which incorporates carrying capacity.
• Key sensemaking: Students make sense of the graphs presented in the previous activity in light of these two models by suggesting scenarios that could lead to the population growth patterns shown in the graphs. This key sensemaking opportunity occurs in Build Understanding item 4.
• Going forward: In the next activity, students explore population growth in greater depth and identify factors that have the greatest effect on the size of the song sparrow population introduced in Activity 1.</td></tr>
<tr><td>Activity 3: Factors Affecting Population Size
Guiding question: What factors affect population size in song sparrows?
Students learn more about specific factors that can affect population growth, using data from a very well studied population of birds. Birds are often easy to observe, catch, and otherwise monitor and thus are the subject of some of the most comprehensive ecological data records. These records provide an excellent opportunity to examine and determine the factors that affect population growth. This is especially true for the song sparrows introduced in Activity 1. What scientists have learned from studying birds can help us understand what is happening with other populations, including fisheries. To fully understand what is happening with a population, scientists need to understand the factors affecting the growth of that population, including those from their larger ecological community and surrounding ecosystem. Using a computer simulation based on data from the song sparrow studies, students explore the effects of a number of factors—both individually and in combination—on the song sparrow population. This model helps students begin to understand some of the complexities of monitoring population growth fluctuations, particularly in species that are less easy to study, such as fish.</td><td>• Students use a computer simulation to test their predictions of the effects of different factors on population size.
• Key sensemaking: Students use their findings from the simulation to make sense of the song sparrow population graph in Activity 1, hypothesizing a scenario that could result in the patterns shown in that data. This sensemaking opportunity occurs in Build Understanding item 1.
• Students apply their understanding of factors affecting the song sparrow population to make recommendations for increasing this population's carrying capacity.
• Key sensemaking: Students apply their understanding of song sparrows to another population, the yellow perch fishery. This sensemaking opportunity occurs in Build Understanding item 4.
• Going forward: In the next learning sequence, students begin to examine ecological concepts at larger scales; they figure out what an ecosystem comprises, and explore why some ecosystems have more biodiversity than others.</td></tr>
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Learning Sequence 2

Investigative phenomenon: Coral reefs do not all look the same and can be quite different from one another in several ways.

In the previous learning sequence, students discovered that many ecosystem factors (biotic, abiotic, intrinsic) affect the population size of an organism, using a population of song sparrows on an isolated island ecosystem as a case study. Students begin with the phenomena of one ecosystem type (coral reefs) that can look very different. Students examine several photographs of different healthy coral reefs; they share the similarities and differences they notice and suggest factors that might cause these differences. Students build their understanding of ecosystem similarities and differences by revisiting their ideas at the end of each activity in this learning sequence.

Suggested driving question: What are the factors that determine the biological diversity of an ecosystem?

Focal Performance Expectations: LS2-2, LS2-1

Storyline	Sensemaking Progression
Activity 4: Scaling Up: Ecosystems **Guiding question:** What defines an ecosystem? Students investigate ecosystem boundaries and scales. All ecosystems have biotic and abiotic components that interact in specific and sometimes complicated ways. Scientists draw boundaries around these interacting components to separate one system from another. Ecosystems also exist at different scales. Students look at four examples of ecosystems of varying scales, from the vast ocean sunlight zone to the tiny blowhole ecosystem of a humpback whale, and discover that sometimes one system (e.g., the whale respiratory system) can be a subsystem of a larger system (e.g., the ocean).	• Students know from the previous learning sequence that in order to understand what is happening to a population of organisms, scientists need to understand what is happening in the ecosystem around that population. • Students may not have a firm understanding of how ecologists define an ecosystem. • Students might not yet understand explicitly that ecosystems can exist at many different spatial scales. • Students explore four different ecosystems in order to define three things that all ecosystems have in common: components, interactions among those components, and boundaries. • Key sensemaking: Students use their understanding of different ecosystems to come to a consensus definition of an ecosystem. This key sensemaking opportunity occurs in Procedure Steps 6 and 7. *Teacher's Note:* Students return to this concept in subsequent activities, developing a deeper understanding of why there is such variety in ecosystems and why some of the same types of ecosystems can look very different. • Going forward: Students will build on their understanding of the definition of ecosystems throughout the remainder of the unit. Students will specifically apply their understanding of ecosystem boundaries in Activity 11, when they explore the role of salmon at the boundary of aquatic and terrestrial ecosystems.

Storyline	Sensemaking Progression
Activity 5: Patterns of Biological Diversity **Guiding question:** What patterns of biological diversity occur for different groups of organisms, and what might cause these patterns? At this point, students have an understanding that all ecosystems have common features and differences. In this activity, students look for patterns in data on species diversity in ecosystems to try to determine cause-and-effect relationships that might explain these patterns. They build on what they have learned about coral reef distribution related to temperature: Corals are generally found in warm water, but they can also be found in cooler waters and may not be found in some warm-water areas. Understanding that there are exceptions to the patterns in the data helps students realize that they need to analyze data for additional factors to fully explain the patterns they are seeing. Students look at distribution patterns for four groups of vertebrates in the U.S.: birds, mammals, reptiles, and amphibians. They compare these distribution patterns to data for several ecosystem factors to build on their understanding of how ecosystem interactions affect patterns of biological diversity.	• Students begin to fill any gaps in their understanding of why some places or ecosystems have more biological diversity than others. • Students develop an initial explanation for the biological diversity patterns they observe in one group of organisms: coral. They then analyze additional data and revise their explanations accordingly. • Key sensemaking: After examining a map of an abiotic factor, students develop initial explanations for the distribution of a group of vertebrates throughout the United States. They examine four additional maps and use that information to revise their initial explanations. This key sensemaking opportunity occurs in Build Understanding item 1. • Students add to their explanation of the investigative phenomenon for this learning sequence (Coral reefs do not all look the same and can be quite different from one another in several ways). • Going forward: In the next learning sequence, students examine factors that may disrupt ecosystems and cause biological diversity to decrease.

Learning Sequence 3

Investigative phenomenon: The population of Southern Resident orcas in the Pacific Northwest has not recovered, despite protection from hunting and capture.

Students look for patterns in population data and ask questions about what is happening with this population of whales. They observe an overall decline in the total Southern Resident orca population over the last 30 years and, in particular, a decline in the L pod since 2005, which they investigate over the course of this learning sequence. In later activities, students get more information about these whales, their environment, and the feeding relationships in the food web they belong to, and they use it as evidence to explain what is happening with this population of whales. Students revisit the investigative phenomenon at the end of most activities in this sequence as they learn more about how matter cycles and energy flows among organisms in an ecosystem.

Suggested driving question: What is happening with this population of orcas?

Focal Performance Expectations LS2-3, LS2-4

Storyline	Sensemaking Progression
Activity 6: Producers and Consumers **Guiding question:** How can you determine an organism's role in a food web from the organism's physical features? To deepen their understanding of ecosystem components and interactions, students investigate how organisms in an ecosystem interact with one another and their environment. They begin by observing the structures of microscopic plankton. They use their observations to determine that some organisms in an ecosystem produce their own food, and others must obtain food by consuming other organisms. The students' investigation of plankton helps them make sense of its role in the global ocean ecosystem. Students consider the role of phytoplankton as producers that form the basis of ocean food webs.	• Students build on their prior knowledge from middle school as they examine the feeding relationships between producers and consumers in an ecosystem. • Key sensemaking: Students use evidence to explain their ideas about the role that phytoplankton as producers play in ecosystems. This key sensemaking opportunity occurs in Build Understanding item 2. • Going forward: In the next activity, students investigate the cellular processes that take place as part of the interactions between organisms in a food web, and explain how these interactions allow energy to flow and matter to cycle in an ecosystem.
Activity 7: The Photosynthesis and Cellular Respiration Shuffle **Guiding question:** How does energy drive the cycling of matter in an ecosystem? Students have investigated at the macroscopic scale the concepts of some organisms producing their own food and others obtaining their food by consuming other organisms. Students now move to the microscopic scale, exploring the cellular processes—photosynthesis and cellular respiration—that occur within the bodies of living organisms as they obtain matter and release the energy needed for life functions. Students use the inputs and outputs of photosynthesis and cellular respiration to determine the roles these cellular processes play in the body of an organism and the relationships between them in an ecosystem. From this understanding, students are able to use evidence to construct an explanation for how these cellular processes cycle matter and allow energy to flow among organisms in the ecosystem.	• Students may not be familiar with, or may not remember learning in middle school, the inputs and outputs of photosynthesis and cellular respiration and the relationship between these cellular processes. • Key sensemaking: Students figure out the relationship between photosynthesis and cellular respiration by developing a model that shows these processes occurring among organisms in an ecosystem. This key sensemaking occurs throughout the Procedure in the Student Book and in Build Understanding item 2. • Going forward: In the next activity, students determine that photosynthesis is not the only cellular process that is foundational to cycling matter and driving energy flow among organisms in an ecosystem.

Storyline	Sensemaking Progression
Activity 8: Life in the Dark **Guiding question:** How do ecosystems without sunlight get the energy and matter needed for the system to survive? Students have now had the opportunity to build an initial understanding of the flow of energy and cycling of matter within a familiar ecosystem, where these processes are driven by energy from the Sun. Here they deepen their understanding by investigating an unfamiliar ecosystem where energy flow and matter cycling is driven instead by chemical energy through chemosynthesis. Students have the opportunity to revise their explanations from the previous activity, much the way that scientists had to revise their thinking when hydrothermal vents and their surrounding ecosystems were discovered. Students reinforce their understanding that fundamentally all ecosystems rely on the cycling of matter and the flow of energy, regardless of the energy source.	• Students likely do not know that some producers do not rely on the Sun or photosynthesis for energy. • Key sensemaking: Students revise their understanding and explanation of the flow of energy and cycling of matter in different ecosystems to include those that rely on chemosynthesis. This key sensemaking opportunity occurs in Build Understanding item 1. • Going forward: In the next activity, students explore the inefficiencies of energy transfer between organisms and how this affects ecosystems.
Activity 9: Modeling Energy Flow in Ecosystems **Guiding question:** How do scientists model the flow of energy among the biotic components of an ecosystem? Students have learned that the cellular processes that cycle matter and allow energy to flow among organisms and their environment can be driven by energy from the Sun or by chemical energy. They now take a deeper look at how energy flows among the biotic components of an ecosystem, specifically looking at energy transfer and inefficiencies. Students consider system models of energy flow in an ecosystem. They use information from scientific findings and proportional reasoning to justify a claim about which system model is the best representation of energy transfer in an ecosystem.	• A typical gap in students' knowledge is in the area of the inefficiency of energy transfer between the biotic components of an ecosystem. • Key sensemaking: At the start of the activity, students select a system model that they think best represents the flow of energy among the biotic components of an ecosystem. Students then read scientific findings about the inefficiency of energy transfer in ecosystems. As they consider the new information presented, they compare it to their previous thinking about the system model as a representation of energy flow in an ecosystem. Students ultimately arrive at a consensus as to which system model best represents energy flowing among the biotic components of an ecosystem. This key sensemaking opportunity occurs in Procedure Steps 13 and 14 in the Student Book. • Going forward: In the next activity, students consider how an organism that crosses ecosystem boundaries affects the energy flow in both ecosystems.

Storyline	Sensemaking Progression
Activity 10: Crossing Ecosystem Boundaries **Guiding question:** What happens to the flow of energy when an organism crosses ecosystem boundaries? At this point students understand that organisms in an ecosystem interact, and through their interactions they cycle matter and allow energy to flow. However, many organisms cross ecosystem boundaries and are part of multiple ecosystems. In this activity, students consider the important impact of the Chinook salmon on both ocean ecosystems and freshwater river ecosystems. Students use this information to expand their existing model of the ocean-based orca ecosystem, and develop and use a model to show the impact of the Chinook salmon on matter flowing and energy cycling in the river ecosystem. This activity concludes the third learning sequence.	• Students may not realize that when organisms cross ecosystem boundaries, they can affect how energy flows and matter cycles across different ecosystems. • Key sensemaking: Students use the new information they obtained about the Chinook salmon to develop a model of how this organism affects matter cycling and energy flowing in the river ecosystem. This key sensemaking step takes place in Procedure Step 3. • Going forward: In the next learning sequence, students consider how matter is cycled on a global scale and how ecosystem interactions are part of this larger cycle.

Learning Sequence 4

Investigative phenomenon: Earth's atmospheric carbon dioxide levels have cycled between 300 ppm and 180 ppm for the past 800,000 years ago, until recently.

In the first activity, the fluctuation is depicted in a graph showing Earth's atmospheric carbon dioxide levels from 800,000 years ago until about 100 years ago. During that time period, the levels fluctuated for hundreds of thousands of years, never going above 300 ppm or dropping below 180 ppm

Suggested driving question: What has caused atmospheric carbon dioxide levels to fluctuate in a stable cycle over the last 800,000 years?

Focal Performance Expectation: LS2-5

Storyline	Sensemaking Progression
Activity 11: Ecosystems and the Carbon Cycle **Guiding question:** What role do ecosystems play in the global carbon cycle? Thus far, students have examined the cycling of carbon into and out of the biotic components of an ecosystem, a process that happens over relatively short periods of time. It is important for them to understand that this fast cycle is only one component of the global carbon cycle that happens over vast periods of time and involves many other components. In this activity, students use data on carbon storage and movement to develop a model that explains how carbon cycles between all four of Earth's subsystems (biosphere, atmosphere, hydrosphere, and lithosphere). Students use their models to explain the cyclical pattern of atmospheric carbon dioxide levels from several hundred thousand years ago until approximately a hundred years ago. Students discover that the greatest flux happens between the biosphere and the atmosphere and that the greatest amount of carbon is stored in the lithosphere and hydrosphere.	• A typical gap in students' knowledge is the role that cellular respiration and photosynthesis play in the global cycling of carbon among Earth's subsystems. Students begin to fill that gap by developing a model for how carbon dioxide cycles between all four subsystems. • Key sensemaking: Students use their models of the carbon cycle to begin to make sense of the investigative phenomenon. This key sensemaking opportunity occurs in Build Understanding item 3. • Going forward: In the next activity, students use their new information about how human activity affects the global carbon cycle to revise their models and explanations of this cycle.
Activity 12: Rebalancing the Equation? **Guiding question:** To what extent can ecosystems help to address increased atmospheric carbon dioxide levels? Students return to the graph of atmospheric carbon dioxide they explored in the last activity, which now includes CO2 levels for the last 100 years. Students are presented with additional data on human-caused sources of CO2 emissions, which they use to revise their models and explanations for patterns in CO2 emissions over time. Students explore the feasibility of using ecosystems as part of the solution for addressing increased carbon dioxide in the atmosphere.	• Students are introduced to atmospheric carbon dioxide data for the past 100 years. • Students revise their models to incorporate additional data on sources of atmospheric CO_2 from human activity. • Key sensemaking: Students revise their carbon cycle models and explanations to incorporate data for atmospheric CO_2 levels in the last 100 years. This key sensemaking opportunity occurs in Procedure Step 4. • Students realize that ecosystems alone cannot address the increased atmospheric CO_2 levels and that further interventions are needed. • Going forward: In the next activity, students begin exploring other ways that human activity has led to disruptions in the environment and various ecosystems.

Learning Sequence 5

Investigative phenomenon: Ecosystem health can vary.

Students examine a map of ecosystems throughout the world that are under varying levels of threat from disruptions. They make note of any patterns they see and ask questions about those patterns. Over the course of the learning sequence, students explore several kinds of anthropogenic and natural ecosystem disruptions. They gain an understanding of why one particular ecosystem—the Aral Sea—is considered collapsed, and they examine whether another ecosystem—the Great Lakes—may soon become unstable. Students examine a variety of strategies to improve and maintain ecosystem health, and consider how this relates to the unit issue of sustainable fisheries. Students finish the unit by designing, evaluating, and refining a strategy to maintain the ecosystem health and sustainability of a fictitious fishery.

Suggested driving question: What causes some ecosystems to be stable and others to be at risk?

Focal Performance Expectations: LS2-6, LS2-7

Storyline	Sensemaking Progression
Activity 13: Ecosystems at the Tipping Point **Guiding question:** How do different factors influence how ecosystems respond to disruptions? Students examine significant disruptions in two ecosystems—one that has mostly recovered and one that is considered collapsed. Students are introduced to the concepts of ecosystem resilience and resistance. Students examine factors involved in ecosystem recovery or collapse from significant disruption.:	• Having investigated human impact on the global carbon cycle, students begin to make sense of other ways that humans affect the environment, focusing on human causes of ecosystem disruptions and the short- and long-term effects of these disruptions. • Students take a deeper look at an ecosystem that collapsed entirely following an anthropogenic disruption. • Key sensemaking: Students develop an evidence-based argument to support or rebut a claim about the impact of a particular disruption on the Aral Sea. This key sensemaking opportunity occurs in Build Understanding item 1. • Going forward: In the next activity, students explore another ecosystem, the U.S. Great Lakes, and consider whether it could also collapse.
Activity 14: The Great Lakes Ecosystem **Guiding question:** Is the health of the Great Lakes ecosystem at risk? Students are introduced to another ecosystem: the Great Lakes in the United States. Students learn about anthropogenic disruptions that have taken place in the past 200 years, and they identify the cause-and-effect relationships that led to changes in the aquatic food web. Students consider the possibility of new invasive species being introduced to the lake: two species of carp that could increase the disruption to the ecosystem, particularly the food web. Students evaluate the claim that this invasion would lead to a permanent change, and possibly a collapse, of the ecosystem.	• Students build on their previous learning about the effects of natural and anthropogenic disruptions on ecosystems. • Students investigate the Great Lakes ecosystem and how a series of disruptions have affected the food web of this ecosystem. • Key sensemaking: Students research the possible impacts of the introduction of two invasive carp species on the Great Lakes ecosystem and argue for or against the possibility of this causing an ecosystem collapse. This key sensemaking opportunity occurs in Build Understanding item 1. • Students examine possible engineering solutions to prevent this disruption. • Going forward: In the next activity, students explore how people can design or engineer solutions to the issues that fisheries are grappling with, and consider how to make fisheries more sustainable.

Storyline	Sensemaking Progression
Activity 15: Is Aquaculture a Solution? **Guiding question:** How can the sustainability challenges connected to aquaculture be addressed? Students move from looking at ecosystems in collapse or at a tipping point to determining what solutions might be possible for one resulting sustainability challenge: declining fisheries. They consider one of the commonly suggested solutions to meet the growing demand for seafood: aquaculture. They investigate some of the sustainability challenges associated with aquaculture and begin to think about what might be done to make aquaculture sustainable.	• Students may have gaps in their knowledge about the benefits and trade-offs of aquaculture as a potential solution to sustainable fisheries. • Students explore a model that demonstrates some of the potential challenges of salmon farming. • Key sensemaking: Students use evidence from the model and other sources to begin developing a list of criteria and constraints for sustainable aquaculture. This key sensemaking opportunity takes place in Build Understanding item 5. • Going forward: In the next activity, students explore two case studies of sustainable fisheries and expand their understanding of possible solutions.
Activity 16: Sustainable Fisheries Case Studies **Guiding question:** What can you learn from past and current examples about making fisheries more sustainable? Students transition from examining a traditional aquaculture system to learning about four sustainable fisheries-management models: aquaculture, marine reserves, maximum sustainable yield, and partial fishing area closures. Students use their understanding of sustainability, fisheries management, ecosystem dynamics, and design solutions, criteria, and constraints to analyze the four models and consider the applicability of each in making a third fictitious fishery sustainable.	• This activity provides students with the opportunity to address a possible knowledge gap about successful models of sustainable fisheries-management practices. • Students explore four examples of sustainable fisheries management. • Key sensemaking: Students analyze evidence from the case studies to predict how the practices from these examples might apply in another fishery. This key sensemaking opportunity takes place in Procedure Step 4. • Going forward: In the final activity, students apply what they have learned to design, test, evaluate, and refine a possible solution for making a fishery sustainable.
Activity 17: Making Sustainable Fisheries Decisions **Guiding question:** Which fisheries-management strategy is the best choice for the sustainability of the Avril Gulf tuna industry? In this culminating activity for the unit, students apply what they have learned about ecosystem dynamics to design, test, and refine a solution for sustainable fisheries.	• Students incorporate what they have learned in the unit to design and test a solution for making a fishery more sustainable. • Key sensemaking: Students use their experience with the design and testing of potential solutions to evaluate and refine a plan for increasing the sustainability of a fishery. This key sensemaking opportunity takes place in Procedure Step 10. • Going forward: In the Cells unit, students learn about cellular biology and how it is connected to sustainability.

STORYLINE AND SENSEMAKING

CELLS: IMPROVING GLOBAL HEALTH

Unit issue: Human health is increasingly subject to emerging global patterns, including extreme heat events, changes in the frequency of disease, and climate effects on the food supply.

Overarching question: What are the challenges to human health in a changing world?

In this unit, students explore the idea that living organisms have to maintain certain internal conditions in order to live in a changing environment. Students focus on the importance of a stable internal temperature, adequate hydration, and quality nutrition as key factors in maintaining normal functioning. They investigate how human survival relies on being able to maintain internal stability (homeostasis) during change. Students construct an understanding of the structures and functions of various levels of organization in an organism's body systems in maintaining homeostasis.

Learning Sequence 1

Investigative phenomenon: Human health is affected by emerging global patterns, such as the changing climate.

Challenges such as extreme heat events are resulting in more heat-related deaths, both in the U.S. and globally. Students generate questions about and initial explanations for how body systems maintain stability in changing external environments. Students consider and evaluate factors necessary for maintaining a living system's internal state. In the first two activities in this learning sequence, students investigate the importance of hydration at both the macroscopic and the microscopic levels. In the final activity in this sequence (which is also the final lesson of the unit), students revisit the broader issue of the effect of emerging global patterns on human health.

Suggested driving question: How are emerging global patterns, such as changing climate patterns, likely to affect human health?

Focal Performance Expectations: LS1-2, LS1-3, LS2-7

Storyline	Sensemaking Progression
Activity 1: Survival Needs **Guiding question:** What is most necessary to keep the human body functioning in extreme heat? Students explore the health effects of extreme heat on the human body and its ability to survive. Students engage in a desert survival scenario that models some of the conditions that stress the human body during an extreme heat event. Students determine what items are most essential to keep the human body functioning in extreme heat. They begin to reflect on how the human body responds to external change.	• Students generate questions about the unit issue: *Human health is increasingly subject to emerging global patterns, including extreme heat events, changes in the frequency of disease, and climate effects on the food supply.* • Students explore the challenges of maintaining human life under extreme conditions and encounter the idea that systems within an organism work to maintain conditions within an optimal range conducive to maintaining life. • Key sensemaking: Students come to the realization that the body has some ability to maintain stable internal conditions when external conditions change, but this ability is limited when the body is challenged by extreme conditions. They generate questions and tentative explanations about how body systems maintain stability in changing external environments. This key sensemaking opportunity takes place in Build Understanding item 3. • Going forward: In the next activity, students investigate the effects of dehydration on cells and how changing conditions affect the human body at the level of the cell, tissue, and whole organism.

Storyline	Sensemaking Progression
Activity 2: Everyday Hydration **Guiding question:** How does lack of water affect an organism? Students focus on hydration as a key factor for maintaining a living system's internal conditions. They further examine the impact of extreme heat events by modeling the effect of dehydration. Students look at how a lack of water affects organisms at both the macroscopic and the microscopic levels.	• In middle school life science, students learned that multicellular organisms have levels of organization, progressing from cells to tissues, to organs, to organ systems, to whole organisms, and that these levels of organization work together to perform specific functions. Students draw on that content—in particular NGSS Middle School Performance Expectations LS1-1, LS1-2, and LS1-3—to begin to investigate how living organisms maintain homeostasis under changing conditions. • Students explore the importance of maintaining internal temperature and hydration within specific ranges in order to maintain life. However, students are unlikely to have much understanding of how changes outside these ranges disrupt the body's structure and function at the various levels of organization. • Students explore the effects of dehydration on cells and tissues, looking at both the whole organism and cells in plant tissue. • Key sensemaking: Students explore how a disruption at the cellular level affects the tissues and the whole organism. This key sensemaking opportunity takes place in Build Understanding items 2 and 4. • Going forward: In the next activity, students consider different models of how systems within an organism interact to maintain homeostasis, particularly when there are disruptions.

Learning Sequence 2

Investigative phenomenon: Global patterns related to the prevalence of disease are changing.

Students investigate the impact of these changing patterns on additional aspects of human health:

- Disease disrupts the normal functioning of body systems. Such disruptions of homeostasis affect all levels of organization, from whole organism to cell.
- Homeostasis is essential for normal body functioning and is a result of multiple systems interacting at all levels of organization: cells, tissues, organs, organ systems, and the whole body.

Suggested driving question: How are changing global patterns likely to affect the functioning of the human body and its systems?

Focal Performance Expectations: LS1-2, LS1-3, LS2-7

Storyline	Sensemaking Progression
Activity 3: Homeostasis Disrupted **Guiding question:** What happens when disease disrupts a body's normal functioning? Students examine how infectious and noninfectious disease affects human body systems. They read case studies of three different infectious and noninfectious diseases, which model how negative feedback loops maintain homeostasis in body temperature (disrupted during heatstroke), blood glucose levels (disrupted by diabetes), and fluid levels (disrupted by diarrhea caused by rotavirus) and how disease disrupts these feedback loops. Students identify which human body systems interact to maintain each of these functions.	• Students may not realize that systems interact to perform body functions—in particular, that functions of a particular system (e.g., digestive) interact and contribute to the functions of other systems (e.g., circulatory). • Students have explored the effects of temperature change and dehydration at the level of the organism, cells, and tissues. However, they have not yet explored these effects at the system level, nor do they understand the mechanisms through which systems interact to restore stability when conditions in the body begin to change. • Students learn how internal systems respond to changing conditions by examining models of feedback loops within the human body, and consider how these body systems can fail to maintain the organism within the optimal conditions. • Key sensemaking: The class discusses how systems interact to maintain homeostasis and identifies how these normal mechanisms are disrupted by disease. This key sensemaking opportunity takes place in Build Understanding items 2 and 4. • Going forward: In the next activity, students further explore the role of levels of organization within the body and interacting body systems in maintaining homeostasis.

Storyline	Sensemaking Progression
Activity 4: Body Systems in Balance **Guiding question:** How do levels of a human body system work together to perform body functions? At this point, students have an understanding that human health is dependent on different levels of organization (cells, tissues, organs, systems) working together to perform functions within an organism. Students examine the structural and functional relationships among the levels by focusing on the cardiovascular, digestive, endocrine, and respiratory systems. They use a model to further explore individual parts of each system and their interaction with other levels of the same system, learning how a disruption to each system affects the functioning of that system and how homeostasis can be restored. Students discuss how both interacting systems and medical interventions restore homeostasis (e.g., diabetes can be managed by diet and by taking insulin). Students further develop the idea that feedback mechanisms maintain homeostasis and mediate behaviors.	• Students continue to develop their understanding of the hierarchical nature of human body systems and the mechanisms through which systems interact to restore stability when conditions in the body begin to change. • Students use a model to make sense of the different levels of organization in the human body system. Using images and text on cards to construct a hierarchy of relationships from cells to tissues, organs, and systems, students determine how levels of a system work together at different scales to perform a function. • Key sensemaking: Students distinguish among systems by function, and figure out what happens when homeostasis is disrupted in each system and how it might be restored. This key sensemaking opportunity takes place in Procedure Steps 7 and 10 and Build Understanding items 2 and 3. • Going forward: In the next activity, students gather evidence on how information at the cellular level can be an indicator of health at the organism level.
Activity 5: Evidence of Disease **Guiding question:** How do diseases affect organisms at the cellular level? To more deeply understand that human health depends on different levels of organization working together, students read about how the symptoms of disease may first be observed at the system or body level. Students then look for evidence of disruption due to disease at the cellular level. They examine microscope slides of human blood to reveal evidence of ways that the body has been disrupted. Students make conclusions about the possible mechanisms for the disruption of the feedback loops essential for homeostasis.	• Students build on what they have learned about how body systems respond to changing external and internal conditions and how these systems can fail to maintain the organism within optimal conditions. • Students use the evidence they gather of how disruption due to disease or illness can be found at different levels of a body system to explain the relationships between levels of organization and how these relationships are affected by disease. • Key sensemaking: By identifying elements of the disease at the cell, tissue, and system levels, students make sense of how systems work together at different levels to perform specific functions and how that functioning can be disrupted. This key sensemaking opportunity takes place in Build Understanding items 2 and 4. • Going forward: In the next activity, students further explore the functions of specialized cells and how disease affects these cells.

<table>
<tr><th>Storyline</th><th>Sensemaking Progression</th></tr>
<tr><td>Activity 6: Specialized Cells and Disease

Guiding question: How does disease disrupt the normal functions of specialized cells, tissues, and organs?

Students build on their understanding of how body systems work together at various levels to carry out cellular functions as they engage in a computer simulation to explore different types of cells and how their specialized structures allow them to perform specific functions. Students then develop and use visual models to construct possible explanations for how these functions are disrupted by specific diseases.</td><td>• Students may know from middle school that all living things are made up of cells and that cells work together to form tissues and organs that are specialized for particular body functions. They are unlikely to have developed an understanding of how systems of specialized cells help carry out essential functions of life. In addition, students will likely not have an understanding of how the systems function on a cellular level, with cellular components such as proteins playing key roles in carrying out cellular functions that regulate homeostasis.
• In the previous activity, students may have begun to wonder about what is happening inside cells to cause the disruptions from disease or illness that they observed.
• Students figure out how cellular structural components drive such functions as circulation, respiration, and sugar uptake to regulate homeostasis.
• Students develop and use cellular function models to make sense of how diseases may disrupt normal cellular function in different systems.
• Key sensemaking: Students begin to make sense of how disrupting cellular functions in specialized cells can disrupt homeostasis. This key sensemaking opportunity takes place in Build Understanding items 1 and 2.
• Going forward: In the next activity, students apply what they've learned about interacting body systems to one specific disease—COVID-19—and make sense of how both treatments and prevention can restore and maintain homeostasis.</td></tr>
<tr><td>Activity 7: Homeostasis and Medical Treatment

Guiding question: In what ways does modern medicine help maintain human health?

Students apply key understandings about homeostasis and the roles of interacting systems at different levels of organization in the body to the effects of COVID-19. They examine a feedback loop on breathing that highlights normal functioning of the human body. Students complete a reading on the SARS-CoV-2 coronavirus: how it affects interacting body systems and how medical treatments can restore and maintain homeostasis.</td><td>• Students have learned about the hierarchical nature of human body systems and the mechanisms through which systems interact to restore stability when conditions in the body begin to change.
• Students apply their understanding of interacting body systems to the effects of COVID-19 on the body. They investigate how this disease disrupts homeostasis, and explore medical treatment options.
• Key sensemaking: Students construct an explanation to build on and round out their understanding of the hierarchical organization of interacting systems that provide specific functions within multicellular organisms. This key sensemaking opportunity takes place in Build Understanding item 3.
• Going forward: In the next activity, students plan and conduct an investigation to provide evidence that feedback mechanisms maintain homeostasis.</td></tr>
</table>

Storyline	Sensemaking Progression
Activity 8: Feedback Loops in Humans **Guiding question:** How do body systems interact to restore homeostasis? Students consider the increasing incidence of global respiratory disease. They apply their knowledge of how body systems work together as they plan and conduct an investigation on how human body systems—specifically, the circulatory and respiratory systems—interact to maintain homeostasis. This activity complete the second learning sequence in this unit, focused on the investigative phenomenon that *global patterns related to the prevalence of disease are changing.*	• Students have learned about the hierarchical nature of human body systems and the mechanisms through which systems interact to restore stability when conditions in the body begin to change. • Students plan and conduct an investigation to establish the relationship between circulatory and respiratory function during exercise. • Key sensemaking: Students gather evidence that feedback mechanisms maintain homeostasis. This key sensemaking opportunity takes place in Procedure Step 10 and Build Understanding item 1. • Going forward: In the next learning sequence, students shift their focus to the need for nutrition to maintain homeostasis and how human health is affected by a changing food supply.

Learning Sequence 3

Investigative phenomenon: Human health is dependent on the energy and matter derived from food.

In this learning sequence, students turn their focus to the effects of food availability, consumption, and nutrition on human health. Students explore how emerging global patterns, such as changes to the supply and quality of food, affect the sustainability of human health, as they respond to the driving question for this sequence. They build on their understanding of photosynthesis and cellular respiration from Ecology: Living on Earth as they examine how organisms obtain and use energy and matter on a cellular and molecular scale. Students also apply what they learn to the qualities of a healthy human diet.

Suggested driving question: How do changes to the human food supply and its quality affect sustainability?

Focal Performance Expectations: LS1-3, LS1-5, LS1-6, LS1-7, LS2-3, LS2-5, LS2-7

Storyline	Sensemaking Progression
Activity 9: Global Nutrition **Guiding question:** How does food availability and quality affect human health? Students begin to explore how global changes are likely to affect the future food supply and quality. Students consider the characteristics of a healthy food supply by looking at food consumption in 12 countries. They compare the total number of calories and the amount of protein and fat consumed in different parts of the world. Students consider to what extent people are meeting their basic nutritional needs. They examine both undernourishment (undernutrition) and obesity (overnutrition) in terms of energy balance and changes in body mass due to storage of excess matter derived from food. Students investigate the importance of micronutrients and the effects of a lack of micronutrients on a country-by-country basis, and they apply what they have learned to suggest how climate change might lead to problems with the supply of healthy food.	• Although students are likely to be aware that people need enough food to live, they are unlikely to be aware of what is required for a healthy food supply, nor are they likely to be fully aware of global disparities in food availability. • Key sensemaking: Students relate caloric and protein intake to over- and undernutrition and realize that food must supply more than just calories to be nutritious. This key sensemaking opportunity takes place in Procedure Steps 6 and 10 and Build Understanding items 1 and 3. • Students relate nutrition to homeostasis. • Going forward: In the next activity, students explore what Calories are and investigate a way to determine the amount of energy stored in food.

Storyline	Sensemaking Progression
Activity 10: Burning Calories **Guiding question:** How do scientists measure the Calories in various foods? Students continue their investigation into the energy content and nutritional value of food. Students begin to explore systems and subsystems models to track the movement of energy released from food during the chemical reactions of combustion and cellular respiration. Students measure the energy stored in food by completely burning a food sample. They calculate the amount of thermal energy transferred, based on measurements of the volume of water and the temperature change produced. Students conclude that the breakdown of food for energy via the process of cellular respiration transfers only some of the chemical energy in food into thermal energy. They make sense of graphs that show the energy changes that accompany the changes in matter that take place during cellular respiration, and begin to develop the idea that much of the energy is harnessed as a form of chemical energy that is easily used by cells.	• Students are likely to know that food provides energy and that food calories are an indicator of the energy stored in food, but they are unlikely to know how the body converts the energy stored in food into thermal energy (to maintain body temperature) and usable chemical energy (to fuel such cellular activities as movement, transport, and synthesis of large molecules such as proteins). • Students burn a food item and use the resulting temperature change in water to calculate an estimate of the calories in the food. Students then use this evidence to develop a more detailed model of cellular respiration. • Key sensemaking: Students figure out that the energy stored in food can be transferred into other forms (in this case, thermal energy) and that this energy is conserved and can be measured and tracked. They compare the reactions of combustion and cellular respiration and select a graph that they think best represents the energy changes accompanying the changes in matter that take place during cellular respiration. This key sensemaking opportunity occurs in Procedure Steps 11 and 12 and Build Understanding item 3. • Going forward: In the next activity, students examine historical science experiments that led to a more complete understanding of the inputs and outputs of photosynthesis.
Activity 11: How Plants Make Food **Guiding question:** How did scientists gather and interpret evidence for how plants provide energy for living organisms? Students build on the idea that an organism's need for food is dependent on plant cells, which are specialized to make their own food. Students further examine the process of photosynthesis through conclusions drawn from a number of science experiments, and consider how the body of knowledge on photosynthesis has grown over time and continues to grow. Students demonstrate their understanding of photosynthesis by constructing a model that illustrates how this process transforms light energy into the stored chemical energy used by almost all living organisms.	• Students may confuse the roles of photosynthesis and respiration. • Students explore how basic concepts of photosynthesis were discovered over time. • Key sensemaking: Students match scientific conclusions to experiments and develop an understanding of how the body of knowledge about photosynthesis was built over time. This key sensemaking opportunity takes place during Procedure Steps 2–4. • Going forward: In the next activity, students design a lab to investigate variables that affect the rate of photosynthesis, and make connections between their investigation and the possible effects of a changing climate.

Storyline	Sensemaking Progression
Activity 12: Photosynthesis and the Environment **Guiding question:** How do changing conditions affect the rate of photosynthesis in plants? Students further explore the relationship between photosynthesis and food quality and supply as they consider how changing external conditions affect food production. Students plan and conduct an experiment to investigate the effect of a single variable on the rate of photosynthesis. Students determine how the production of gas during photosynthesis can be used to test whether different variables increase or decrease the rate of photosynthesis. They begin to explore how light energy is transformed into stored chemical energy at the cellular level.	• Students may confuse the roles of photosynthesis and respiration and may think that plants obtain their energy directly from the Sun during photosynthesis, as opposed to through respiration. • In the previous activity, students may have generated questions about how plants grow under different conditions. • In Part A, students learn one approach for measuring the rate of photosynthesis. • In Part B, students plan and conduct an investigation to gather evidence of how a variable affects the rate of photosynthesis. • Key sensemaking: Students draw on their results to more fully understand the variables that increase and decrease the rate of photosynthesis. This key sensemaking opportunity takes place in Build Understanding items 1–3. • Students consider how their investigation in this activity relates to food sustainability. • Going forward: In the next activity, students examine data from recent scientific studies showing the known and projected impact of a changing climate on food production.
Activity 13: Feeding the World's Population **Guiding question:** How are global changes affecting the food supply? Students further explore the investigative phenomenon and driving question for this learning sequence by analyzing scientific projections on the future and quality of the global food supply. Students examine eight data sets, generating questions about each and determining patterns in the data. They apply their new knowledge to the relationship between these global changes and the sustainability of the food supply.	• Students apply their understanding of the importance of food as a source of matter and energy to the phenomenon of challenges to human health in a changing world and the sustainability of the food supply. • Students make sense of patterns and trends in eight data sets, and describe how their conclusions are supported by specific evidence (i.e., data). • Key sensemaking: Students generate questions and preliminary conclusions about the relationship between global changes and the sustainability of the food supply. This key sensemaking opportunity takes place during Build Understanding item 1. • Going forward: In the next activity, students continue to focus on the role of food as a source of matter and energy as they plan and conduct an investigation to explore variables that affect the rate of cellular respiration in beans.

Storyline	Sensemaking Progression
Activity 14: Investigating Cellular Respiration **Guiding question:** How do various factors in the environment affect the rate of cellular respiration in plants? Students review their current understanding of the process of cellular respiration, and develop a preliminary model of this process within the cells of plants and animals. Students brainstorm environmental variables that might affect cellular respiration, and design investigations to test their hypotheses about the effects of these variables on cellular respiration in beans. Students relate their results to the investigative phenomenon for this learning sequence: *Human health is dependent on the energy and matter derived from food.*	• Students might have the idea that plants do not respire or that they only respire in the dark, when they are not conducting photosynthesis. • Students may not fully understand that plants continually conduct cellular respiration, and they may not understand how plants affect and are affected by global changes in climate and carbon dioxide levels. • Students conduct investigations to explore cellular respiration conducted by beans, which use the energy they store inside to live and begin growing and developing into a plant. • Key sensemaking: Students figure out that cellular respiration in plants occurs under varied conditions, including in the dark, although the rate may vary under certain conditions, such as temperature variations. Students engage in this key sensemaking opportunity throughout the Procedure and synthesize their sensemaking in Build Understanding item 3. • Students apply the results of their investigations to suggest ways that plant growth and cellular respiration might be affected by global changes in Build Understanding item 7. • Going forward: In the next activity, students investigate how chemical reactions such as respiration and combustion can transfer stored energy through the rearrangement of molecules.
Activity 15: Energy for Life **Guiding question:** How does cellular respiration produce usable energy? Students build on what they have learned about cellular respiration to investigate how chemical reactions can transfer stored energy. Students model the combustion of methane, record the energy changes as bonds in the reactants are broken and bonds in the products are formed, and calculate the overall energy change—all of which helps them more fully understand how a chemical reaction such as combustion or respiration can transfer energy through the rearrangements of molecules. Students read about how cellular respiration transfers chemical energy stored in food to energy that can be used by the cell. Students use what they learn to enhance their models of the flow of energy and matter during cellular respiration.	• Students have observed the release of energy from food but are likely to still have questions about where this energy comes from and how organisms use this energy. • Students investigate the energy input needed to break bonds and the energy output from forming new bonds during a simple chemical reaction—the combustion of methane. • Students use mathematical computation to figure out that the energy released during cellular respiration is an outcome of the difference in chemical energy between the reactants and products. They use this new understanding to revise their graphical models of the energy changes during cellular respiration from an earlier activity. • Key sensemaking: Students draw on their investigation of the bond changes during combustion and what they learn from a reading to develop a model for what happens to the energy released from cellular respiration. This key sensemaking opportunity takes place in Build Understanding item 4. • Going forward: In the next activity, students investigate different ways that cells use the matter in substances they obtain from food.

Activity 16: Matter for Cells **Guiding question:** How does an organism use the matter in food? Students categorize and sequence cards that provide information about the substances (matter) in food and how cells use these substances as building blocks to synthesize carbohydrates and proteins for their own functioning and growth. Students observe that cells use the substances in food in three ways: to meet the cells' immediate needs, to synthesize the large molecules needed to carry out the cells' functions, and to synthesize large molecules that can be stored until the organism needs them. Students use what they learn to develop a model showing how cells use the matter in the substances they obtain from food.	• Students should be aware from middle school (MS-PS3.D and MS-LS1.C) that the body uses the small molecules produced by food breakdown for energy and for matter to produce carbon-containing molecules, but students are unlikely to understand how cells produce the molecules they need. • Students use molecular models to figure out that amino acids cannot be made from sugars alone. • Key sensemaking: Students gather and synthesize information from Matter from Food cards to figure out how substances in food are used in cells to build the complex carbon-based substances the body needs to function and grow. This key sensemaking opportunity occurs in Procedure Steps 7–9. • Students review what they have learned about how the body uses food for matter and energy. • Going forward: In the next activity, students apply what they have learned to design an integrated approach to solutions for a variety of global health challenges.

Learning Sequence 1 (continued and completed)

Investigative phenomenon: Human health is affected by emerging global patterns, such as the changing climate.

Challenges such as extreme heat events are resulting in more heat-related deaths, both in the U.S. and globally. Students generate questions about and initial explanations for how body systems maintain stability in changing external environments. Students consider and evaluate factors necessary for maintaining a living system's internal state. In the final lesson of this learning sequence and the unit, students revisit the broader issue of the effect of emerging global patterns on human health.

Suggested driving question: How are emerging global patterns, such as changing climate patterns, likely to affect human health?

Focal Performance Expectations: LS1-2, LS1-3, LS2-7

Storyline	Sensemaking Progression
Activity 17: Designing Solutions: World Health **Guiding question:** What solutions can you design for improving global health? The unit culminates with a return to the broader focus of human health. Students apply their scientific learning to emerging global patterns, including extreme heat events, changes in the frequency of disease, and climate effects on the food supply. Students consider the stakeholders involved in some of these issues and determine what can be done to reduce such impacts by designing, evaluating, and refining solutions for global health challenges.	• Students have learned about the cellular mechanisms of noninfectious and infectious illness and the need for food as a source of matter and energy, which is basic to all living things. • Students are introduced to an integrated approach to human health care, and they relate their understanding of sustainability to this approach. • Key sensemaking: Students apply their understanding of human health at the global, community, organismal, and cellular levels to design an integrated approach to a solution for a global health issue. This key sensemaking opportunity takes place in Procedure Steps 7–10.

STORYLINE AND SENSEMAKING

GENETICS: FEEDING THE WORLD

Unit issue: People rely on genetically engineered crop plants to maintain a global food supply, but the use of this technology can impact sustainability.

Overarching question: How do genetically engineered crops affect the sustainability of food production?

This unit begins with students reviewing their initial ideas and questions from Sustainability: Changing Human Impact, about the issue of creating genetically modified organisms (GMOs). Students are presented with data about the increase in herbicide-resistant weed species in the U.S. following the introduction of herbicide-resistant soy crops. This brings them to the unit issue: *People rely on genetically engineered crop plants to maintain a global food supply, but the use of this technology can affect the sustainability of food production*. Students may ask questions about how weeds could become herbicide-resistant and what this means for sustainable food production. During the unit, students consider an overarching question: *How do genetically engineered crops affect the sustainability of food production?* They also begin to consider the consequences for people locally and globally if steps aren't taken to manage genetically engineered crops for sustainability.

Learning Sequence 1

Investigative phenomenon: How did superweeds get into Farmer Green's corn fields?
Students explore this phenomenon through the story of Farmer Green, who is finding that when he sprays herbicides on his corn fields, the weeds aren't dying as they have in the past—they are herbicide-resistant, or "superweeds." Students analyze a map and timeline of superweed reportings and herbicide applications in Farmer Green's corn fields and fields in neighboring counties, and they read about how Farmer Green's crop yield is lower than previous years due to the presence of superweeds and his worries about his future income. Students realize that in order for Farmer Green to understand what to do, he needs to understand how superweeds could have gotten into his fields in the first place.

Suggested driving question: How did superweeds get into Farmer Green's corn fields?

Focal Performance Expectations: LS1-1, LS1-4, LS3-1, LS3-2, LS3-3

Storyline	Sensemaking Progression
Activity 1: Superweeds! Where did they come from? **Guiding question:** What are the different ways that superweeds could have gotten into Farmer Green's corn fields? This activity orients students to the unit issue and the investigative phenomenon for this learning sequence. Students brainstorm, generate, and consider different ways that superweeds could have gotten into Farmer Green's fields. Some students may argue that the superweeds' seeds were physically moved there (planted there by humans or seeds spread by animals), others may suspect wind or insect pollination, and others may think that the weeds spread via other normal breeding patterns. Students may also suggest that a combination of methods are responsible for the spread of the superweeds.	• Students may not be familiar with the different ways that plants reproduce and disperse seeds. • Students analyze and interpret data to understand the pattern and timeline of superweeds spreading to Farmer Green's fields. • Key sensemaking: Students engage in argument from evidence to evaluate possible ways that superweeds could have gotten into the farmer's fields. This key sensemaking step takes place in Procedure Steps 2 and 3. • Going forward: In the next activity, students explore the processes required to generate GMOs and relate this to what is happening in Farmer Green's fields.

Storyline	Sensemaking Progression
Activity 2: Creating Genetically Modified Organisms **Guiding question:** How do scientists genetically modify an organism? Students begin to build their understanding of how GMOs are created by genetically modifying a population of *Escherichia coli* (*E. coli*). They insert two genes into the bacteria: one for green fluorescent protein (GFP) and one for ampicillin resistance. This provides an opportunity for students to use genetic engineering techniques similar to those used to create GMOs and to work with *E. coli*, which is a model organism for genetics research and for developing biotechnology applications.	• Students may have little understanding of how GMOs are created. • To develop an understanding of the general process of genetic modification of organisms, students modify *E. coli* to express GFP and ampicillin resistance. • Students explore how genetic modification of microorganisms is being applied in manufacturing biofuels. • Key sensemaking: Students demonstrate their understanding by developing an explanation of the process of genetic modification and its outcomes. This key sensemaking opportunity takes place in Build Understanding item 1. • Going forward: In the next activity, students explore mitosis and its role in reproducing the herbicide-resistance gene within a population of superweeds.
Activity 3: Mitosis and Asexual Reproduction **Guiding question:** If a genetically modified cell undergoes mitosis, how likely is it that the daughter cells will inherit the inserted gene? Students build on their understanding of GMOs and learn about mitosis and asexual reproduction by working with an online simulation and chromosome models. Drawing on this understanding, they predict the percentage of asexually produced offspring that will inherit an inserted gene from a genetically modified parent. Students learn how the process of mitosis ensures that if a fertilized seed contains a modified gene, 100% of the daughter cells—and therefore the entire plant—will also contain and express that gene.	• Students may not understand how crop plants can breed with weedy relatives and pass genetically modified traits on to weeds. • Students explore how the process of mitosis plays a role in the inheritance of GMOs, such as superweeds. • Students investigate the process of mitosis by generating and using models. • Key sensemaking: Students draw on their models to explain why when a fertilized egg cell that contains a modified gene replicates, all the subsequent daughter cells will also contain the gene. This key sensemaking opportunity occurs in Build Understanding item 1. • Going forward: In the next activity, students generate explanations about genetic inheritance that support their understanding of how superweeds could inherit a modified gene for herbicide resistance from a crop plant.
Activity 4: Breeding Corn **Guiding question:** How can information about the genetic makeup of plants help farmers predict what genes crops will inherit? Students begin to explore how sexual reproduction results in inheritance of specific genes. Using the traditional model of the Punnett square, students analyze and predict the results of genetic crosses for one trait and are introduced to the concept of *selective breeding* as one way to improve crops. Students connect this understanding to the phenomenon of superweeds by predicting inheritance patterns of a gene for herbicide resistance	• To understand how genes are passed from parents to offspring, students determine the patterns of genotypes in offspring resulting from a cross, using a Punnett square for one trait. • Key sensemaking: Students apply their understanding of inheritance of single traits to make predictions about the inheritance of a gene for herbicide resistance. This key sensemaking opportunity occurs in Build Understanding item 5. • Going forward: In the next activity, students extend and apply their understanding of predicted cross outcomes by generating Punnett squares for two traits.

Storyline	Sensemaking Progression
Activity 5: Breeding Corn for Two Traits **Guiding question:** How do scientists predict the possible genetic combinations of offspring for two traits? Students continue their investigation of patterns of heredity, expanding their model from the last activity to explore two inherited traits. Students deepen their understanding of heredity and crop breeding by reading about the history of selective breeding in corn.	• Students may have gaps in their knowledge about the complexity of crosses involving more than one gene. • Students extend and apply their understanding of monohybrid crosses to dihybrid crosses and predict cross outcomes in terms of offspring genotypes. • Students apply their knowledge of crosses to begin to evaluate the benefits and trade-offs of selective breeding. • Key sensemaking: Students use their findings to generate and support arguments about how superweeds could inherit resistance to more than one kind of herbicide. This key sensemaking opportunity occurs in Build Understanding item 3. • Going forward: In the next activity, students develop a consensus explanation of how superweeds most likely arrived in the farmer's corn fields and were able to spread.
Activity 6: How Did This Happen? Class Consensus **Guiding question:** Why isn't herbicide working on the weeds in Farmer Green's corn fields? Students draw on their understanding of genetic inheritance to generate a class consensus explanation of how superweeds most likely arrived in the farmer's corn fields and were able to spread.	• Students may have gaps in their understanding about the molecular mechanisms underlying herbicide resistance and how transgene migration occurs (which is addressed in the next learning sequence). • To better understand the impact of GMOs, students apply what they've learned to consider how the presence of superweeds could affect the sustainability of food production. • Key sensemaking: Students apply their understanding of genes and traits to come to an evidence-based class consensus for the most likely explanation of how superweeds spread to Farmer Green's corn fields. This key sensemaking opportunity occurs in Teaching Step 4. • Going forward: In the next learning sequence, students investigate exactly how superweeds became herbicide-resistant.

Learning Sequence 2

Investigative phenomenon: Superweeds are appearing in different locations far apart from one another. Students learn that superweeds are appearing in seemingly independent locations across the country without a predictable pattern. To understand how superweeds are generated, students read and analyze text and develop models that explain how herbicide resistance works at the molecular level in plant cells. Students examine data on how cells differentiate and pass their genetic information to offspring. To confirm their suspicions that Farmer Green's superweeds contain the herbicide-resistance gene, students conduct gel electrophoresis to compare Farmer Green's field sample to other samples.

Suggested driving question: How did superweeds become herbicide-resistant?

Focal Performance Expectations: LS1-1, LS1-4, LS3-1, LS3-2

Storyline	Sensemaking Progression
Activity 7: Protein Synthesis: Transcription and Translation **Guiding question:** How does a cell make proteins with the information from DNA? To better understand the molecular process of protein synthesis, students use a combination of cards, physical models, and computer simulations to explore transcription and translation. Students apply their learning as they model what happens inside a plant's cell when a genetic modification is introduced.	• Students may have gaps in their knowledge of the role of DNA in protein synthesis, how protein synthesis occurs, and how a change in DNA might lead to a change in the protein produced. • Students develop their understanding of protein synthesis through hands-on and virtual models. • Key sensemaking: Students apply their understanding of protein synthesis and generate a model that describes how genetic modification affects a plant at the molecular, cellular, and trait levels. This key sensemaking opportunity occurs in Procedure Step 16. • Going forward: In the next activity, students add to their understanding of when and why different proteins are made as they use models to better understand cell differentiation and gene expression.
Activity 8: Cell Differentiation and Gene Expression **Guiding question:** If all cells in the same organism have the same genes, why don't they all make the same proteins? To better understand the role of genes and proteins in different cells, students investigate gene expression as it relates to cell differentiation in four human cell types. They consider how various physiological events affect gene expression in each of the four cell types.	• Students may not understand how cells in the same organism can produce different types of proteins, despite having identical DNA. • Students develop their understanding of gene expression by using a model to explore how genes are expressed or repressed in different types of cells, depending on particular cellular events. • Key sensemaking: Students use a model to explain cell differentiation and gene expression This key sensemaking opportunity takes place in Build Understanding item 5. • Going forward: In the next activity, students revise and refine their genetic modification models to include how they think herbicide-resistant plants are generated at the level of DNA, genes, and proteins.

<table>
<tr><th>Storyline</th><th>Sensemaking Progression</th></tr>
<tr><td>Activity 9: Explaining Herbicide Resistance in Weeds
Guiding question: What happens to cause a weed to produce offspring with the gene for herbicide resistance?
Students develop their initial ideas and apply their understanding from Activity 2 of how GMOs are generated by revisiting their genetic modification models from Activity 7. Students revise and refine their models to include how they think herbicide-resistant plants are generated at the level of DNA, genes, and proteins.</td><td>• Students may not fully understand how herbicide resistance is linked to gene expression and protein production.
• Students explore two possible ways for plants to become herbicide-resistant.
• Key sensemaking: Students revise their models from Activity 7 to incorporate protein synthesis and gene expression. This key sensemaking opportunity occurs in Procedure Step 3.
• Going forward: In the next activity, students explore the molecular mechanisms that underlie herbicide resistance to deepen their understanding of this trait and to expand on the explanations they started in Activity 7.</td></tr>
<tr><td>Activity 10: Molecular Mechanism of Herbicide Resistance
Guiding question: How does a change in a plant's DNA make the offspring of that plant herbicide-resistant?
To determine exactly how herbicide resistance works in plants, students read about enzymes, how they function within a cell, and how mutations in enzyme genes can result in conditions such as herbicide resistance. Students generate a physical model of EPSPS, an enzyme required for plant growth that is a target for herbicides. Students refine their herbicide-resistance models from Activities 7 and 9 to include information specific to the EPSPS enzyme's function.</td><td>• Students likely have an initial understanding of herbicide resistance in plants, but may still need to deepen their understanding of how this works on a molecular level.
• Students develop their understanding of the molecular mechanisms of herbicide resistance by using physical models to compare the structure of normal and genetically modified EPSPS, an enzyme required for plant growth and a target for herbicides.
• Key sensemaking: Students revise their explanations from Activities 7 and 9 to demonstrate their more detailed understanding of the molecular mechanism of enzyme modification for herbicide resistance. This key sensemaking opportunity occurs in Procedure Step 10.
• Going forward: In the next activity, students further develop their comprehension of transgene migration as they learn about meiosis and sexual reproduction.</td></tr>
<tr><td>Activity 11: Meiosis and Sexual Reproduction
Guiding question: How do organisms pass their genetic information to their offspring?
Students engage in an online computer simulation to investigate how chromosomes divide during meiosis, which aids in their developing understanding of how genes are passed from one generation to the next. Students learn about crossing over and how it increases the variability of possible gametes produced by a parent. They apply what they have learned about meiosis to determine the probability that an inserted gene is passed from a parent to a daughter cell through meiosis.</td><td>• Students may have a gap in their understanding of the differences between mitosis and meiosis, particularly as meiosis relates to the likelihood of a modified gene being passed from parent to offspring.
• Students use models to help them understand the process of meiosis and the likelihood of a modified gene being passed from parent to offspring in this process.
• Key sensemaking: Students compare processes that can lead to genetic variation in organisms. This key sensemaking opportunity occurs in Procedure Step 13.
• Going forward: In the next activity, students explore how the mechanisms of meiosis and sexual reproduction support their explanations of transgene migration in plants.</td></tr>
</table>

Storyline	Sensemaking Progression
Activity 12: Genes and Chromosomes **Guiding question:** What happens to genes and chromosomes during meiosis and sexual reproduction? To better understand genetic variation as a result of meiosis, students investigate how chromosomal behaviors, such as independent segregation and crossing over, explain the independent assortment of some traits and the linkage of others. Students also learn about nondisjunction and the outcomes of abnormal numbers of certain chromosomes. Students apply their understanding to explain how a modified gene for herbicide resistance can be segregated into a crop plant's sperm cell (pollen) and fertilize a weed's egg cell, leading to herbicide-resistant weed offspring.	• Students may still need to make connections between the levels of molecular mechanisms and the components involved in sexual reproduction and the inheritance of traits. • Students connect their understanding of meiosis to fertilization and genetic variation in the resulting offspring. • Key sensemaking: Students develop a model to show how a modified gene can be passed from parent to offspring through meiosis. This key sensemaking opportunity occurs in Build Understanding item 2. • Going forward: In the next activity, students analyze DNA evidence from gel electrophoresis to determine whether gene migration from crops to weeds could have occurred in the superweeds in Farmer Green's fields.
Activity 13: Which Plant Is Genetically Modified? **Guiding question:** Which weed samples contain the herbicide-resistance gene? Students return to the guiding question from Activity 1: *What are the different ways that superweeds could have gotten into Farmer Green's corn fields?* Students gather evidence to determine if herbicide-resistant genes were transferred to weedy relatives of crop plants to generate the superweeds that Farmer Green observed in his fields. To determine which plants are genetically modified for herbicide resistance, students run and interpret a gel electrophoresis test with weed samples from several farms, using a sample of genetically modified canola as a positive control.	• Students apply what they have learned to decide if transgene migration occurred in Farmer Green's fields, and generate an explanation of how it might have happened. • Students analyze evidence from a gel to determine if the weed samples from the farmer's fields are genetically modified. • Key sensemaking: Students develop an argument to respond to a claim about the origin of the herbicide-resistant plants in Farmer Green's fields. This key sensemaking opportunity occurs in Build Understanding item 2. • Going forward: In the next activity, students explore what is known about how the presence of superweeds affects biodiversity and what questions still remain.

Learning Sequence 3

Investigative phenomenon: Some farmers are not experiencing issues with superweeds nor a decline in pollinators, possibly due to alternative farming techniques.
Students examine data that describes changes in biodiversity as a result of superweeds, and they explore the consequences of these changes on food production. Students consider the benefits and trade-offs of GMOs, make recommendations about the use of GMOs, and compare and contrast different methods of farming for sustainable food production.

Suggested driving question: Are genetically modified organisms the solution for sustainable global food production?

Focal Performance Expectations: LS2-7, LS3-3, LS4-3, LS1-1

Storyline	Sensemaking Progression
Activity 14: Genetically Modified Organsisms and Biodiversity **Guiding question:** How do superweeds affect biodiversity? To better understand how the presence of superweeds affects local biodiversity, students analyze data that shows how weed and insect populations have changed prior to and after reports of superweeds being present in fields. Students record what they learned and what questions still remain about how superweeds affect biodiversity.	• Students may have gaps in their understanding of the connection between the presence of superweeds and changes in local biodiversity. • Students use data analysis to build their understanding of the effects of the presence of superweeds on local biodiversity. • Key sensemaking: Students develop explanations to demonstrate their understanding of how GMO use can create changes in local biodiversity and the implications of these changes. This key sensemaking step takes place in Build Understanding items 1–3. • Going forward: In the next activity, students evaluate the benefits and trade-offs of GMOs.
Activity 15: Benefits and Trade-Offs of Genetically Modified Organisms **Guiding question:** What are some of the benefits and trade-offs of using genetically modified organisms? To better understand how GMOs affect local biodiversity, students determine the benefits and trade-offs of genetic modification. Students collect evidence to support their ability to make recommendations and, if appropriate, to seek alternative solutions. Students read four case studies that highlight some benefits and trade-offs of GMOs. The class then considers the evidence and discusses the benefits and trade-offs of GMOs.	• Students consider potential benefits and trade-offs of genetic modification, based on what they have learned in the unit thus far. • Students gather and organize additional evidence of benefits and trade-offs from a series of case studies on the uses of genetic modification. • Key sensemaking: Students synthesize their thinking about the benefits and trade-offs of genetic modification through small-group and class discussions. This key sensemaking opportunity takes place in Procedure Steps 10 and 11. • Going forward: In the next activity, students use the knowledge they have accumulated to craft a recommendation as to whether a county should grow genetically modified soy.

Storyline	Sensemaking Progression
Activity 16: Evaluating Genetically Modified Organisms **Guiding question:** Should the Panel on Genetic Modification approve the planting of genetically modified soybeans in Farmer Green's county? To better understand the benefits and trade-offs of GMOs, students analyze and interpret data gathered from four scientific studies on a fictitious genetically modified soybean. Students evaluate and compare the studies and examine the potential benefits and trade-offs of growing this GMO. To demonstrate their understanding, students generate an evidence-based recommendation about whether a county that relies heavily on soybean crops should grow the genetically modified soy.	• Students build their understanding of the potential impacts of a genetically modified crop by reviewing four scientific studies. • Key sensemaking: Students synthesize their understanding of the use of genetically modified crops by using data analysis and evaluating trade-offs to generate evidence-based recommendations about the use of genetically modified soy to an agricultural council. This key sensemaking opportunity occurs in Procedure Step 9. • Going forward: In the next activity, students explore four proposed alternative farming methods and make a recommendation about the proposal they think will best ensure sustainable food production and biodiversity in Farmer Green's county.
Activity 17: Alternatives to Farming Genetically Modified Organisms **Guiding question:** How can farmers support sustainable food production? In this culminating activity for the unit, students read about four farming proposals being considered by an agricultural board that ensures sustainable food production and biodiversity in Farmer Green's county. Drawing on what they've learned in this unit, students participate in a Walking Debate and make a recommendation supported by evidence about which proposal should go forward. Students independently write a final recommendation to Farmer Green and the agricultural board.	• Students weigh the benefits and trade-offs of different alternative farming options for protecting sustainable food production and biodiversity in Farmer Green's county. • Key sensemaking: Students apply their understanding to generate a recommendation supported by evidence from the unit. This key sensemaking opportunity occurs in Procedure Step 4 and in all four Build Understanding items.

STORYLINE AND SENSEMAKING

EVOLUTION: MANAGING CHANGE

Unit issue: Human activity can have evolutionary consequences for both biodiversity and ourselves.

Overarching question: How do human activities affect the evolution of other species, and what are the consequences for both biodiversity and for ourselves?

Students are introduced to the issue for this unit by considering infectious diseases. Students begin by considering tuberculosis, a disease that has a long shared evolutionary history with humans. They learn that the rate at which new diseases are evolving is increasing. Students' initial ideas and questions about the emergence of infectious diseases are elicited. Students also begin to consider how human activity may be affecting this evolutionary process and thereby affecting the three pillars of sustainability.

Learning Sequence 1

Investigative phenomenon: Salamanders along the Pacific Coast of North America show tremendous variability in color, despite all being members of the same species.

Students are oriented to the first learning sequence through the first investigative phenomenon: *Salamanders along the Pacific Coast of North America show tremendous variability in color, despite all being members of the same species.* Students periodically revisit this scenario in the first learning sequence. By Activity 6: Increasing Timescales, students are able to explain how and why this variability exists.

Suggested driving question: What is happening to cause variability in color among salamanders?

Focal Performance Expectations: LS2-8, LS4-1, LS4-2, LS4-3, LS4-4, LS4-5

Storyline	Sensemaking Progression
Activity 1: Changing Environments **Guiding question:** How do populations respond over time to a changing environment? Students explore evolution by natural selection in marine iguanas in the Galápagos Islands—how the iguanas' environment, natural history, and social structure work together to favor the evolution of large body size in males to defend territories and increase access to mates, and of large body size in females to be able to produce more eggs (offspring). Students also learn that body size is stabilized by selection favoring more moderate body size during times of food scarcity and environmental stress, when the largest individuals cannot maintain their body size.	• Students understand from middle school how evolution by natural selection occurs in simple scenarios, but they might not understand how competing selection pressures can affect traits in a wild population. • Key sensemaking: Students explore the selection pressures affecting body size in marine iguanas during times of food abundance vs. food scarcity. This key sensemaking step takes place in Build Understanding item 1. • Going forward: In the next activity, students consider how a changing climate may have consequences for other organisms—specifically, aquatic plants—and the implications for sustainability.

Storyline	Sensemaking Progression
Activity 2: Increasing Temperatures **Guiding question:** How might increasing temperatures affect populations of aquatic plants over time? To understand how temperature affects different populations, students investigate the rate of photosynthesis in aquatic plants at different temperatures. In this laboratory, students compare two plant species that grow near the surface of ponds and near the bottom of ponds, respectively. This is an opportunity for students to investigate how changes in temperature—like those seen with climate change—can affect how plants make food, which can then lead to changes in populations. Students make connections between their observations and bigger questions about how changes in temperature will affect sustainability.	• Students have an understanding of how global warming affects photosynthesis in plants from Cells: Improving Global Health, but they may not have considered how plants may vary in their responses and therefore how natural selection may affect plant traits over time. • Students measure the rate of photosynthesis in two aquatic plant species in different temperature conditions in order to develop an understanding of how changes in temperature can affect populations differently. • Key sensemaking: Students explain how variations among individuals in a species might lead to changes in the population over time, with some traits becoming more common. This key sensemaking takes place in Build Understanding item 2. • Going forward: In the next activity, students explore how another kind of trait—social behavior—can evolve in response to environmental conditions.
Activity 3: Social Behavior **Guiding question:** What other traits can evolve in response to environmental conditions? Students add to their understanding of how changing environments can lead to changes in structural traits (e.g., body size) and physiological traits (e.g., the rate of photosynthesis) as they consider another trait that evolves in response to environmental factors: social behavior. Students explore the social behavior trait of alarm-calling in two group-living mammal species: black-tailed prairie dogs and meerkats.	• Students have now explored the evolution of structural and metabolic traits, but they may not fully appreciate that behavioral traits can evolve by natural selection. • Key sensemaking: Students explore the evolution of alarm calls in two social mammal species and construct an argument for how this trait evolved in both species. This key sensemaking step takes place in Build Understanding Item 1. • Going forward: In the next activity, students add the role of genetics to their developing understanding of evolution by natural selection, focusing on the theorized relationship between cystic fibrosis and TB.
Activity 4: Genetic Variation and Change **Guiding question:** What is the role of genetic variation in evolution? Students explore how changes in a population's appearance occur at the level of genes and are passed from one generation to the next. Using a computer simulation, students examine the factors that contribute to genetic variation in a population by focusing on the theorized relationship between cystic fibrosis and TB.	• Students should understand that genetic variations, particularly genetic mutations, provide the basis for natural selection that can lead to heritable variation and evolution. • Students may have little understanding of how a potentially lethal genetic mutation can provide resistance to an infectious disease. • Key sensemaking: Students explore how a highly infectious disease (TB) helped to maintain a potentially lethal genetic mutation (cystic fibrosis) in a population over time. This key sensemaking step takes place in Build Understanding item 3. • Students make connections between a population's level of wealth and the genetic variation within that population. • Going forward: In the next activity, students draw on their growing understanding to explain what is required for evolution by natural selection to occur.

Storyline	Sensemaking Progression
Activity 5: Is It Evolution? **Guiding question:** What is required for evolution by natural selection to occur? Drawing on their growing understanding of how populations change over time due to changing environments, students revisit some familiar and novel scenarios and argue about which changes are evolutionary in nature (changes to a population that can be passed from one generation to the next) and which are ecological in nature (changes that occur within a population and are not passed from one generation to the next). Students determine what is required for evolution by natural selection to occur.	• Students may have little understanding of the difference between actual evolution vs. ecological changes. • To explain the difference between evolutionary changes and ecological changes, students analyze several examples of changes among species. • Key sensemaking: Students apply their understanding of evolutionary changes to identify and explain why a scenario involving environmental change is or is not an example of evolution by natural selection. This key sensemaking takes place in Procedure Step 5 and in Build Understanding item 1. • Going forward: In the next activity, students extend their understanding of evolutionary changes by considering adaptations by natural selection that happen over long periods of time.
Activity 6: Increasing Timescales **Guiding question:** What happens when evolution happens over longer periods of time? Students are presented with a snapshot of speciation in progress as they explore what happens as salamanders migrate and encounter distinct environmental conditions. Students then consider a second scenario, that of anoles in the Caribbean, which allows them to see how evolution by natural selection acting over longer periods of time has already resulted in speciation.	• So far, students have explored natural selection operating over relatively short periods of time. • Key sensemaking: Students explain how natural selection acting over long periods of time and over many generations can lead to speciation. This key sensemaking opportunity is in Build Understanding item 1. • Going forward: In the next activity, students explore evolution over deep time and learn how scientists collect and evaluate evidence about evolutionary changes that occurred millions of years ago.

Learning Sequence 2

Investigative phenomenon: Life on Earth is constantly changing—sometimes over short spans of time, and sometimes over long spans of time.

In the first learning sequence, students investigated relatively recent cases of evolution by natural selection and speciation. In this learning sequence, students examine evolution—both speciation and extinction—over a much longer timescale. They begin by examining a graph showing that the rate of extinction over the last 600 million years has not been constant. They learn that the rate of extinction is sometimes much greater than the background rate of extinction.

Suggested driving question: Why are some species more likely to evolve or go extinct than others, and how might humans be affecting these processes?

Focal Performance Expectations: LS2-7, LS4-1, LS4-5

Storyline	Sensemaking Progression
Activity 7: Extinction **Guiding question:** What factors cause species to go extinct? Students begin to explore evolutionary processes over deep time, examining patterns of life-forms beginning 542 million years ago and up to the recent past. Students look closely at patterns of extinction and come to understand that extinction is a natural part of the evolutionary process. Students learn about the five mass extinction events and evaluate explanations for what caused each event. Students consider factors favoring the emergence of new life-forms.	• Until this point in the unit, students have focused primarily on evolution by natural selection over relatively short periods of time. • In this activity, students expand their horizons by exploring patterns of evolution, including both extinction and speciation, over deep time until recently. • Key sensemaking: Students explain what factors caused the extinction of species and entire life-forms in the past, and consider how confident they are of these explanations. This key sensemaking step is in Build Understanding item 4. • Students consider factors leading to the emergence of new life-forms over time. • Going forward: In the next activity, students consider the role of humans in accelerating the rate of extinction, and they evaluate the evidence for a sixth mass extinction.
Activity 8: The Anthropocene **Guiding question:** What is the role of human activity in the extinction process? Students consider the role of humans in accelerating the rate of extinctions, thereby also affecting evolutionary processes. Students evaluate the evidence for a sixth mass extinction and think about which human activities are contributing to the loss of biodiversity. They consider how humans might be affected by these extinctions through the lens of sustainability.	• Students may know about extinctions from hundreds of millions of years ago until the recent past, but they may have never considered how humans may be affecting the rate of extinction. • Students analyze data about extinctions in the age of humans, including rates and causes of extinction. • Key sensemaking: Students argue about whether the current rate of extinction is leading to a sixth mass extinction caused by human activity. This key sensemaking takes place in Build Understanding item 3. • Students consider whether humans may also be affecting the rate of speciation. • Going forward: In the next activity, students explore additional types of evidence that support the theory of evolution.

Storyline	Sensemaking Progression
Activity 9: Evidence and the Theory of Evolution **Guiding question:** What other kinds of evidence support the theory of evolution? Students explore additional types of evidence on the theory of evolution, including embryology, comparative anatomy, and genetics, and reflect on the types of evidence presented in the first learning sequence. Students draw on what they've learned so far to create an infographic about two kinds of evidence that support the theory of evolution.	• So far in the unit, students have explored evidence for evolution based on natural history observations and experimentation and on the fossil record, but they may be less familiar with other types of evidence. • Students obtain information about some additional types of evidence about evolution. • Key sensemaking: Students create an infographic communicating how two types of evidence support the theory of evolution. This key sensemaking takes place in Build Understanding item 2. • Students identify the strengths and limitations of different types of evidence and how the evidence is used collectively to support the theory of evolution. • Going forward: In the next activity, students explore a real-world application of evolutionary evidence as they make decisions about conservation.
Activity 10: Applying Evolutionary Thinking **Guiding question:** How do scientists use evidence of evolution to make decisions about conservation? Students explore how evolutionary evidence is used in a practical way by analyzing and interpreting data from comparative anatomy and genetics and drawing on that data to make a recommendation about which area of a fictional island should be conserved. Students weigh the data along with additional information about the different areas of the island, and they consider the trade-offs of their decision.	• Students may not be familiar with the application of evolutionary thinking to a practical problem, such as conservation. • Key sensemaking: Students analyze and interpret data that demonstrates the evolutionary relationships among primates on an island. This key sensemaking takes place in Procedure Step 6. • Students consider the data they analyzed, other factors about the island, and the trade-offs of each decision as they make their recommendation for conservation. • Going forward: In the next activity, students explore how human actions can cause evolutionary changes as they investigate a medical case of antibiotic-resistant TB.

Learning Sequence 3

Investigative phenomenon: Chinook salmon body size has been declining over time.

In this learning sequence, students explicitly explore the evolutionary impact that humans can have on other species. Students examine graphs showing the average body size in Chinook salmon over time and the mean age of Chinook salmon in freshwater and saltwater environments. Students observe that the salmon's mean body size has declined sharply from 1980 to 2010, that the mean age of salmon in saltwater environments has declined sharply over the same period, and that the mean age of salmon in freshwater environments has fluctuated but generally has declined somewhat. Students share their initial ideas about what might be causing these declines. In later activities, students make sense of how this and other examples illustrate how human activities can lead to changes in other species' natural selection: By altering the environment, humans can affect the evolution of other species. Students also figure out that sometimes these evolutionary changes in other species can cause problems for people.

Suggested driving question: What is causing the decline in Chinook salmon body size, and does human activity play a role?

Focal Performance Expectations: LS4-2, LS4-4, LS4-6, ETS1-3, ETS1-4, LS2-7

Storyline	Sensemaking Progression
Activity 11: The Evolution of Resistance **Guiding question:** Why are microbes more difficult to eradicate now than in the past? Students explore how human actions can cause evolutionary changes as they investigate a medical case of antibiotic-resistant TB. Students conduct research on how antibiotic use has changed over time and how bacteria develop resistance. They explain the effects of these evolutionary changes in the context of sustainability. In the role of laboratory technicians, students conduct a procedure to determine if a patient has antibiotic-resistant TB.	• Students were introduced to the concept of antibiotic resistance in Activity 5: Is It Evolution?, but they may not know how it develops at the level of bacterial genes. • Students conduct Internet research to explain how antibiotic use has changed over time, how antibiotic resistance develops, and why it is a problem. • Key sensemaking: Students draw on the research they conducted and what they've learned in this activity to determine the best explanation for why a patient's TB treatment is no longer working. This key sensemaking takes place in Procedure Steps 8 and 23. • Students explain how antibiotic resistance can negatively impact sustainability. • Going forward: In the next activity, students explore the increasing rate of emerging diseases through an evolutionary lens.
Activity 12: Emerging Diseases **Guiding question:** Why are new diseases evolving at an increasing rate? Students explore the increasing rate of emerging diseases through an evolutionary lens, which helps them more deeply understand how human actions can cause evolutionary changes and how these changes, in turn, affect people. Students gain an understanding of how evolutionary thinking helps explain, predict, and potentially prevent future pandemics.	• Students now understand that existing human pathogens are evolving in response to our actions, but they may not realize that new human pathogens are evolving at an increasing rate. • Students use Stop to Think questions to make sense of information about the increasing rate of emerging diseases. • Key sensemaking: Students explain how evolutionary thinking helps us understand why the rate of emerging diseases is increasing and how future pandemics might be prevented. This key sensemaking step takes place in Build Understanding item 1. • Going forward: In the next activity, students explore the effects of human activity on evolution in a familiar context: fisheries.

Storyline	Sensemaking Progression
Activity 13: Shrinking Salmon **Guiding question:** How is human activity affecting the evolution salmon and therefore the three pillars of sustainability? Students consider the effects of human activity on evolution in another context: fisheries. Students learn that the body size of Chinook salmon is declining, due to natural selection favoring individuals that return to their streams earlier (i.e., younger and smaller). Students consider several human activities that might be driving this change. They develop a system model to help them analyze the problem, which they come to realize is especially complex because of the salmon's anadromous life cycle. Students consider the impact of this problem on the three pillars of sustainability and what might be done to address it.	• Students are familiar with the role of Chinook salmon in both ocean and stream ecosystems from the Ecology unit. • Students learn that salmon body size is declining due to changing evolutionary selection pressures imposed by human activity, which has an adverse impact on both biodiversity and human systems. • Key sensemaking: Students create a system model to make sense of this problem and to consider potential solutions. This key sensemaking takes place in Procedure Steps 3 and 4. • Going forward: In the next activity, students engage in a computer simulation of four different factors that may affect salmon size.
Activity 14: Mitigating Change **Guiding question:** How can we design a solution to the "shrinking salmon" problem? Students continue to explore the "shrinking salmon" problem by using a computer simulation to examine how changing environmental variables affect body size in a hypothetical population of Chinook. Students identify the primary drivers that select for smaller body size, all of which are due to human impact on the ocean and stream environments. Students develop a possible solution for this complex problem, and consider the feasibility and trade-offs of their solution in terms of the three pillars of sustainability.	• Students have developed a system model to delineate the "shrinking salmon" problem, but they have only briefly considered possible solutions. • Students engage in a computer simulation to examine the evolutionary effect of environmental factors • Key sensemaking: Students draw on the simulation to develop and refine a solution to this complex problem, based on a set of criteria and constraints. This key sensemaking opportunity takes place in Procedure Step 17. • Going forward: In the final activity of the unit, students create a presentation explaining how a particular human activity affects evolutionary change, the negative impact of this change on biodiversity and sustainability, and what strategies might mitigate or prevent this impact.
Activity 15: Human Impact on Evolution **Guiding question:** How can evolutionary biology be used to promote sustainability and biodiversity? As the culminating activity for the unit, students choose one human activity they have learned about and create a presentation explaining how this activity affects evolutionary change, the impact of these changes on biodiversity and sustainability, and what strategies might mitigate or prevent this negative impact.	• Students may not know all the criteria for identifying a reliable Internet resource. • Key sensemaking: Students conduct research and construct a presentation that explains their focal topic in terms of its impact on evolution and how evolutionary changes affect biodiversity and sustainability. This key sensemaking step takes place in Procedure Step 2. • Students offer strategies to eliminate or reduce the negative impact of consequences resulting from their focal topic. • Students conclude the unit by reflecting on how their thinking about evolution has changed.