CollegeBoard Pre-AP®

Pre-AP® Biology

TEACHER RESOURCES

Units 1 and 2

ABOUT COLLEGE BOARD

College Board is a mission-driven not-for-profit organization that connects students to college success and opportunity. Founded in 1900, College Board was created to expand access to higher education. Today, the membership association is made up of over 6,000 of the world's leading educational institutions and is dedicated to promoting excellence and equity in education. Each year, College Board helps more than seven million students prepare for a successful transition to college through programs and services in college readiness and college success—including the SAT® and the Advanced Placement Program®. The organization also serves the education community through research and advocacy on behalf of students, educators, and schools.

For further information, visit **www.collegeboard.org**.

PRE-AP EQUITY AND ACCESS POLICY

College Board believes that all students deserve engaging, relevant, and challenging grade-level coursework. Access to this type of coursework increases opportunities for all students, including groups that have been traditionally underrepresented in AP and college classrooms. Therefore, the Pre-AP program is dedicated to collaborating with educators across the country to ensure all students have the supports to succeed in appropriately challenging classroom experiences that allow students to learn and grow. It is only through a sustained commitment to equitable preparation, access, and support that true excellence can be achieved for all students, and the Pre-AP course designation requires this commitment.

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The sentence-writing strategies used in Pre-AP lessons are based upon The Writing Revolution, Inc., a national nonprofit organization that trains educators to implement The Hochman Method, an evidence-based approach to teaching writing. The strategies included in Pre-AP materials are meant to support students' writing, critical thinking, and content understanding, but they do not represent The Writing Revolution's full, comprehensive approach to teaching writing. More information can be found at **www.thewritingrevolution.org**.

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UNIT 2

Evolution

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Introduction to Pre-AP Biology

About Pre-AP

Introduction to Pre-AP

Every student deserves classroom opportunities to learn, grow, and succeed. College Board developed Pre-AP® to deliver on this simple premise. Pre-AP courses are designed to support all students across varying levels of readiness. They are not honors or advanced courses.

Participation in Pre-AP courses allows students to slow down and focus on the most essential and relevant concepts and skills. Students have frequent opportunities to engage deeply with texts, sources, and data as well as compelling higher-order questions and problems. Across Pre-AP courses, students experience shared instructional practices and routines that help them develop and strengthen the important critical thinking skills they will need to employ in high school, college, and life. Students and teachers can see progress and opportunities for growth through varied classroom assessments that provide clear and meaningful feedback at key checkpoints throughout each course.

DEVELOPING THE PRE-AP COURSES

Pre-AP courses are carefully developed in partnership with experienced educators, including middle school, high school, and college faculty. Pre-AP educator committees work closely with College Board to ensure that the course resources define, illustrate, and measure grade-level-appropriate learning in a clear, accessible, and engaging way. College Board also gathers feedback from a variety of stakeholders, including Pre-AP partner schools from across the nation who have participated in multiyear pilots of select courses. Data and feedback from partner schools, educator committees, and advisory panels are carefully considered to ensure that Pre-AP courses provide all students with grade-level-appropriate learning experiences that place them on a path to college and career readiness.

PRE-AP EDUCATOR NETWORK

Similar to the way in which teachers of Advanced Placement® (AP®) courses can become more deeply involved in the program by becoming AP Readers or workshop consultants, Pre-AP teachers also have opportunities to become active in their educator network. Each year, College Board expands and strengthens the Pre-AP National Faculty—the team of educators who facilitate Pre-AP Readiness Workshops and Pre-AP Summer Institutes. Pre-AP teachers can also become curriculum and assessment contributors by working with College Board to design, review, or pilot the course resources.

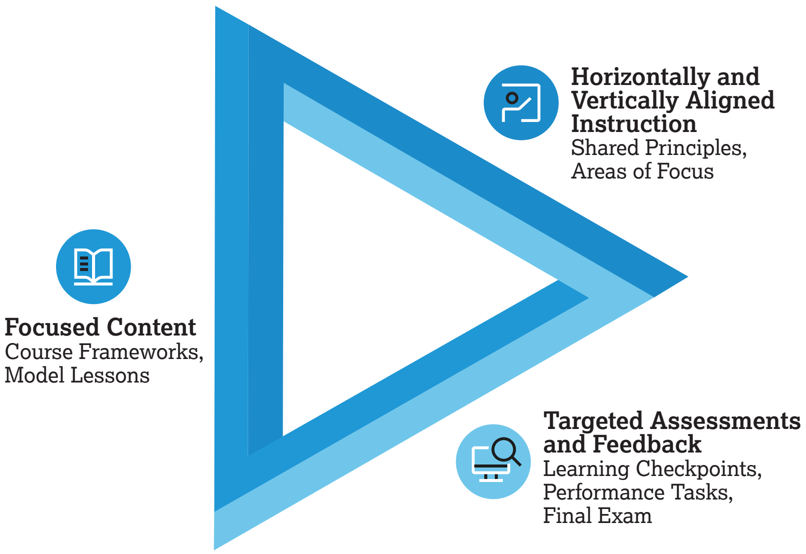
HOW TO GET INVOLVED

Schools and districts interested in learning more about participating in Pre-AP should visit **preap.org/join** or contact us at **preap@collegeboard.org**.

Teachers interested in becoming members of Pre-AP National Faculty or participating in content development should visit **preap.org/national-faculty** or contact us at **preap@collegeboard.org**.

Pre-AP Approach to Teaching and Learning

Pre-AP courses invite all students to learn, grow, and succeed through focused content, horizontally and vertically aligned instruction, and targeted assessments for learning. The Pre-AP approach to teaching and learning, as described below, is not overly complex, yet the combined strength results in powerful and lasting benefits for both teachers and students. This is our theory of action.



FOCUSED CONTENT

Pre-AP courses focus deeply on a limited number of concepts and skills with the broadest relevance for high school coursework and college and career success. The course framework serves as the foundation of the course and defines these prioritized concepts and skills. Pre-AP model lessons and assessments are based directly on this focused framework. The course design provides students and teachers with intentional permission to slow down and focus.

HORIZONTALLY AND VERTICALLY ALIGNED INSTRUCTION

Shared principles cut across all Pre-AP courses and disciplines. Each course is also aligned to discipline-specific areas of focus that prioritize the critical reasoning skills and practices central to that discipline.

SHARED PRINCIPLES

All Pre-AP courses share the following set of research-supported instructional principles. Classrooms that regularly focus on these cross-disciplinary principles allow students to effectively extend their content knowledge while strengthening their critical thinking skills. When students are enrolled in multiple Pre-AP courses, the horizontal alignment of the shared principles provides students and teachers across disciplines with a shared language for their learning and investigation and multiple opportunities to practice and grow. The critical reasoning and problem-solving tools students develop through these shared principles are highly valued in college coursework and in the workplace.

Close Observation and Analysis

Students are provided time to carefully observe one data set, text, image, performance piece, or problem before being asked to explain, analyze, or evaluate. This creates a safe entry point to simply express what they notice and what they wonder. It also encourages students to slow down and capture relevant details with intentionality to support more meaningful analysis, rather than rushing to completion at the expense of understanding.

Higher-Order Questioning

Students engage with questions designed to encourage thinking that is elevated beyond simple memorization and recall. Higher-order questions require students to make predictions, synthesize, evaluate, and compare. As students grapple with these questions, they learn that being inquisitive promotes extended thinking and leads to deeper understanding.

Evidence-Based Writing

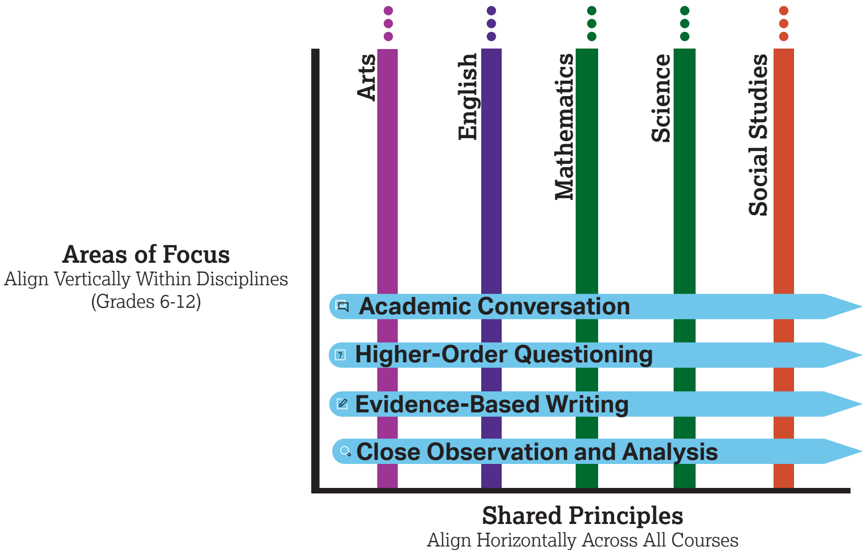
With strategic support, students frequently engage in writing coherent arguments from relevant and valid sources of evidence. Pre-AP courses embrace a purposeful and scaffolded approach to writing that begins with a focus on precise and effective sentences before progressing to longer forms of writing.

Academic Conversation

Through peer-to-peer dialogue, students' ideas are explored, challenged, and refined. As students engage in academic conversation, they come to see the value in being open to new ideas and modifying their own ideas based on new information. Students grow as they frequently practice this type of respectful dialogue and critique and learn to recognize that all voices, including their own, deserve to be heard.

AREAS OF FOCUS

The areas of focus are discipline-specific reasoning skills that students develop and leverage as they engage with content. Whereas the shared principles promote horizontal alignment across disciplines, the areas of focus provide vertical alignment within a discipline, giving students the opportunity to strengthen and deepen their work with these skills in subsequent courses in the same discipline.



For information about the Pre-AP science areas of focus, see page 15.

TARGETED ASSESSMENTS FOR LEARNING

Pre-AP courses include strategically designed classroom assessments that serve as tools for understanding progress and identifying areas that need more support. The assessments provide frequent and meaningful feedback for both teachers and students across each unit of the course and for the course as a whole. For more information about assessments in Pre-AP Biology, see page 56.

Pre-AP Professional Learning

Pre-AP teachers are required to engage in two professional learning opportunities. The first requirement is designed to help prepare them to teach their specific course. There are two options to meet the first requirement: the Pre-AP Summer Institute (Pre-APSI) and the Online Foundational Module Series. Both options provide continuing education units to educators who complete the training.

- The Pre-AP Summer Institute is a four-day collaborative experience that empowers participants to prepare and plan for their Pre-AP course. While attending, teachers engage with Pre-AP course frameworks, shared principles, areas of focus, and sample model lessons. Participants are given supportive planning time where they work with peers to begin to build their Pre-AP course plan.
- The Online Foundational Module Series is available to all teachers of Pre-AP courses. This 12- to 20-hour course supports teachers in preparing for their Pre-AP course. Teachers explore course materials and experience model lessons from the student's point of view. They also begin to plan and build their own course so they are ready on day one of instruction.

The second professional learning requirement is to complete at least one of the Online Performance Task Scoring Modules, which offer guidance and practice applying Pre-AP scoring guidelines to student work.

About the Course

Introduction to Pre-AP Biology

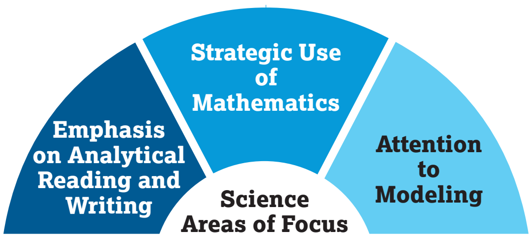
The Pre-AP Biology course emphasizes the integration of content with science practices—powerful reasoning tools that support students in analyzing the natural world around them. Having this ability is one of the hallmarks of scientific literacy and is critical for numerous college and career endeavors in science and the social sciences.

Rather than seeking to cover all topics traditionally included in a standard biology textbook, this course focuses on the foundational biology knowledge and skills that matter most for college and career readiness. The Pre-AP Biology Course Framework highlights how to guide students to connect core ideas within and across the units of the course, promoting the development of a coherent understanding of biological systems.

The components of this course have been crafted to prepare not only the next generation of biologists but also a broader base of biology-informed citizens who are well equipped to respond to the array of science-related issues that impact our lives at the personal, local, and global levels.

PRE-AP SCIENCE AREAS OF FOCUS

The Pre-AP science areas of focus, shown below, are science practices that students develop and leverage as they engage with content. They were identified through educator feedback and research about where students and teachers need the most curriculum support. These areas of focus are vertically aligned to the science practices embedded in other science courses in high school, including AP, and in college, giving students multiple opportunities to strengthen and deepen their work with these skills throughout their educational career. They also support and align to the NGSS and AP science practices of theory building and refinement.



Emphasis on Analytical Reading and Writing

Students engage in analytical reading and writing to gain, retain, and apply scientific knowledge and to carry out scientific argumentation.

In prioritizing analytical reading, Pre-AP Biology classrooms ask students to extract, synthesize, and compare complex information, often by moving between texts and multiple representations, such as tables and graphs. Through analytical writing activities, Pre-AP Biology students must integrate and translate that information to generate scientific questions, design methods for answering questions, and develop scientific arguments. Moreover, the application of these skills to the understanding of informal science texts, such as articles found in newspapers, online sources, and magazines, prepares students to be discerning consumers of scientific information.

Strategic Use of Mathematics

Students use mathematics strategically in order to understand and express the quantitative aspects of biology, to record and interpret experimental data, and to solve problems as they arise.

The ability to analyze and interpret data collected while investigating the natural world is a critical practice for scientists. Once collected, data must be translated into forms that can be analyzed in an attempt to reveal meaningful patterns and relationships. These patterns and relationships are not always immediately obvious, so students must become strategic in how they choose to apply mathematical and statistical thinking in order to analyze data.

Attention to Modeling

Students go beyond labeling diagrams to creating, revising, and using models to explain key patterns, interactions, and relationships in biological systems.

Modeling is a core practice for scientists as they use a variety of models to develop, refine, and communicate their ideas about the natural world. Engaging students in modeling also reinforces other scientific reasoning skills, such as data analysis and scientific argumentation. Modeling also helps illustrate for students how scientific knowledge is constructed and modified over time as new data and evidence emerge and models are revised based on this new information.

PRE-AP BIOLOGY AND CAREER READINESS

The Pre-AP Biology course resources are designed to expose students to a wide range of career opportunities that depend on biology knowledge and skills. Examples include not only careers within the life sciences, such as marine ecologist or wildlife geneticist, but also other endeavors where biology knowledge is relevant, such as the work of a park ranger or healthcare policymaker.

Career clusters that involve biology, along with examples of careers in biology or related to biology, are provided below. Teachers should consider discussing these with students throughout the year to promote motivation and engagement.

Career Clusters Involving Biology	
agriculture, food, and natural resources healthcare and health science human services manufacturing STEM (science, technology, engineering, and math)	
Examples of Biology Careers	**Examples of Biology Related Careers**
biology teacher/professor botanist ecologist genetic counselor marine biologist microbiologist neurologist primary care physician veterinarian zoologist	anthropologist biochemist dental assistant/dentist environmental scientist forensic scientist medical assistant nurse pharmacist physician assistant science writer

Source for Career Clusters: "Advanced Placement and Career and Technical Education: Working Together." Advance CTE and the College Board. October 2018. **https://careertech.org/resource/ap-cte-working-together.**

For more information about careers that involve biology, teachers and students can visit and explore the College Board's Big Future resources: **https://bigfuture.collegeboard.org/majors/biological-biomedical-sciences-biology-general**.

SUMMARY OF RESOURCES AND SUPPORTS

Teachers are strongly encouraged to take advantage of the full set of resources and supports for Pre-AP Biology, which is summarized below. Some of these resources must be used for a course to receive the Pre-AP Course Designation. To learn more about the requirements for course designation, see details below and on page 67.

COURSE FRAMEWORK

The framework defines what students should know and be able to do by the end of the course. It serves as an anchor for model lessons and assessments, and it is the primary document teachers can use to align instruction to course content. **Use of the course framework is required**. *For more details see page 22.*

MODEL LESSONS

Teacher resources, available in print and online, include a robust set of model lessons that demonstrate how to translate the course framework, shared principles, and areas of focus into daily instruction. **Use of the model lessons is encouraged but not required**. *For more details see page 54.*

LEARNING CHECKPOINTS

Accessed through Pre-AP Classroom (the Pre-AP digital platform), these short formative assessments provide insight into student progress. They are automatically scored and include multiple-choice and technology-enhanced items with rationales that explain correct and incorrect answers. **Use of one learning checkpoint per unit is required**. *For more details see page 56.*

PERFORMANCE TASKS

Available in the printed teacher resources as well as on Pre-AP Classroom, performance tasks allow students to demonstrate their learning through extended problem-solving, writing, analysis, and/or reasoning tasks. Scoring guidelines are provided to inform teacher scoring, with additional practice and feedback suggestions available in online modules on Pre-AP Classroom. **Use of each unit's performance task is required**. *For more details see page 58.*

PRACTICE PERFORMANCE TASKS

Available in the student resources, with supporting materials in the teacher resources, these tasks provide an opportunity for students to practice applying skills and knowledge as they would in a performance task, but in a more scaffolded environment. **Use of the practice performance tasks is encouraged but not required**. *For more details see page 59.*

FINAL EXAM

Accessed through Pre-AP Classroom, the final exam serves as a classroom-based, summative assessment designed to measure students' success in learning and applying the knowledge and skills articulated in the course framework. **Administration of the final exam is encouraged but not required**. *For more details see page 60.*

PROFESSIONAL LEARNING

Both the four-day Pre-AP Summer Institute (Pre-APSI) and the Online Foundational Module Series support teachers in preparing and planning to teach their Pre-AP course. **All Pre-AP teachers are required to either attend the Pre-AP Summer Institute or complete the module series. In addition, teachers are required to complete at least one Online Performance Task Scoring module**. *For more details see page 11.*

Course Map

PLAN

The course map shows how components are positioned throughout the course. As the map indicates, the course is designed to be taught over 140 class periods (based on 45-minute class periods), for a total of 28 weeks.

Model lessons are included for approximately 50% of the total instructional time, with the percentage varying by unit. Each unit is divided into key concepts.

TEACH

The model lessons demonstrate how the Pre-AP shared principles and science areas of focus come to life in the classroom.

Shared Principles
Close observation and analysis
Higher-order questioning
Evidence-based writing
Academic conversation

Science Areas of Focus
Emphasis on analytical reading and writing
Strategic use of mathematics
Attention to modeling

ASSESS AND REFLECT

Each unit includes two learning checkpoints and a performance task. These formative assessments are designed to provide meaningful feedback for both teachers and students. Opportunities for formative assessment are also provided throughout the model lessons.

Note: The final exam, offered during a six-week window in the spring, is not represented in the map.

UNIT 1 Ecological Systems

~25 Class Periods

Pre-AP model lessons provided for approximately 70% of instructional time in this unit

KEY CONCEPT ECO 1
Cycling of Matter in the Biosphere

KEY CONCEPT ECO 2
Population Dynamics

Learning Checkpoint 1

KEY CONCEPT ECO 3
Defining Ecological Communities

KEY CONCEPT ECO 4
Ecological Community Dynamics

KEY CONCEPT ECO 5
Changes in Ecological Communities

Learning Checkpoint 2

Performance Task for Unit 1

UNIT 2 Evolution

~20 Class Periods

Pre-AP model lessons provided for approximately 40% of instructional time in this unit

KEY CONCEPT EVO 1
Patterns of Evolution

KEY CONCEPT EVO 2
Mechanisms of Evolution

Learning Checkpoint 1

KEY CONCEPT EVO 3
Speciation

Learning Checkpoint 2

Performance Task for Unit 2

UNIT 3 Cellular Systems

~50 Class Periods

Pre-AP model lessons provided for approximately 40% of instructional time in this unit

KEY CONCEPT CELLS 1
Chemistry of Life

KEY CONCEPT CELLS 2
Cell Structure and Function

KEY CONCEPT CELLS 3
Cell Transport and Homeostasis

KEY CONCEPT CELLS 4
Organisms Maintaining Homeostasis

Learning Checkpoint 1

KEY CONCEPT CELLS 5
Cell Growth and Division

KEY CONCEPT CELLS 6
Photosynthesis

KEY CONCEPT CELLS 7
Cellular Respiration and Fermentation

Learning Checkpoint 2

Performance Task for Unit 3

UNIT 4 Genetics

~45 Class Periods

Pre-AP model lessons provided for approximately 35% of instructional time in this unit

KEY CONCEPT GEN 1
Structure of DNA

KEY CONCEPT GEN 2
DNA Synthesis

KEY CONCEPT GEN 3
Protein Synthesis

Learning Checkpoint 1

KEY CONCEPT GEN 4
Asexual and Sexual Passing of Traits

KEY CONCEPT GEN 5
Inheritance Patterns

KEY CONCEPT GEN 6
Biotechnology

Learning Checkpoint 2

Performance Task for Unit 4

Pre-AP Biology Course Framework

INTRODUCTION

Based on the Understanding by Design® (Wiggins and McTighe) model, the Pre-AP Biology Course Framework is back mapped from AP expectations and aligned to essential grade-level expectations. The course framework serves as a teacher's blueprint for the Pre-AP Biology instructional resources and assessments.

The course framework was designed to meet the following criteria:

- **Focused:** The framework provides a deep focus on a limited number of concepts and skills that have the broadest relevance for later high school, college, and career success.
- **Measurable:** The framework's learning objectives are observable and measurable statements about the knowledge and skills students should develop in the course.
- **Manageable:** The framework is manageable for a full year of instruction, fosters the ability to explore concepts in depth, and enables room for additional local or state standards to be addressed where appropriate.
- **Accessible:** The framework's learning objectives are designed to provide all students, across varying levels of readiness, with opportunities to learn, grow, and succeed.

COURSE FRAMEWORK COMPONENTS

The Pre-AP Biology Course Framework includes the following components:

Big Ideas

The big ideas are recurring themes that allow students to create meaningful connections between course concepts. Revisiting the big ideas throughout the course and applying them in a variety of contexts allows students to develop deeper conceptual understandings.

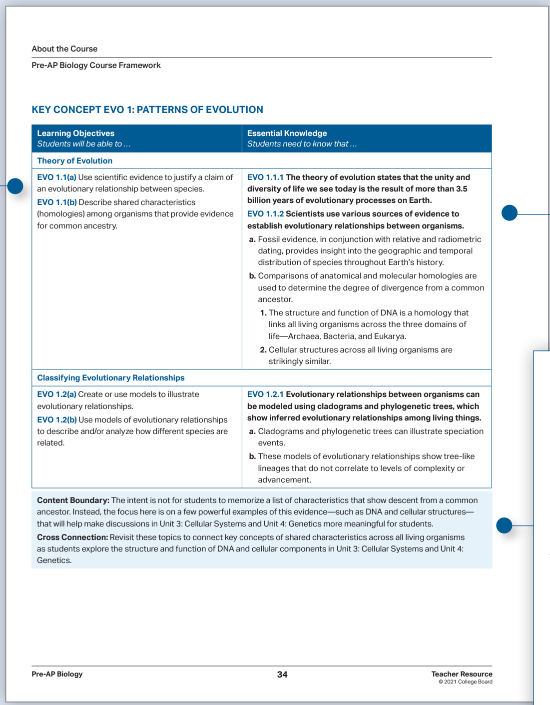
Enduring Understandings

Each unit focuses on a small set of enduring understandings. These are the long-term takeaways related to the big ideas that leave a lasting impression on students. Students build and earn these understandings over time by exploring and applying course content throughout the year.

Key Concepts

To support teacher planning and instruction, each unit is organized by key concepts. Each key concept includes relevant **learning objectives** and **essential knowledge statements** and may also include **content boundary and cross connection statements**. These are illustrated and defined below.

Learning Objectives:
These objectives define what a student needs to be able to do with essential knowledge in order to progress toward the enduring understandings. The learning objectives serve as actionable targets for instruction and assessments.



About the Course

Pre-AP Biology Course Framework

KEY CONCEPT EVO 1: PATTERNS OF EVOLUTION

Learning Objectives *Students will be able to …*	**Essential Knowledge** *Students need to know that …*
Theory of Evolution	
EVO 1.1(a) Use scientific evidence to justify a claim of an evolutionary relationship between species. **EVO 1.1(b)** Describe shared characteristics (homologies) among organisms that provide evidence for common ancestry.	EVO 1.1.1 **The theory of evolution states that the unity and diversity of life we see today is the result of more than 3.5 billion years of evolutionary processes on Earth.** EVO 1.1.2 **Scientists use various sources of evidence to establish evolutionary relationships between organisms.** **a.** Fossil evidence, in conjunction with relative and radiometric dating, provides insight into the geographic and temporal distribution of species throughout Earth's history. **b.** Comparisons of anatomical and molecular homologies are used to determine the degree of divergence from a common ancestor. **1.** The structure and function of DNA is a homology that links all living organisms across the three domains of life—Archaea, Bacteria, and Eukarya. **2.** Cellular structures across all living organisms are strikingly similar.
Classifying Evolutionary Relationships	
EVO 1.2(a) Create or use models to illustrate evolutionary relationships. **EVO 1.2(b)** Use models of evolutionary relationships to describe and/or analyze how different species are related.	EVO 1.2.1 **Evolutionary relationships between organisms can be modeled using cladograms and phylogenetic trees, which show inferred evolutionary relationships among living things.** **a.** Cladograms and phylogenetic trees can illustrate speciation events. **b.** These models of evolutionary relationships show tree-like lineages that do not correlate to levels of complexity or advancement.

Content Boundary: The intent is not for students to memorize a list of characteristics that show descent from a common ancestor. Instead, the focus here is on a few powerful examples of this evidence—such as DNA and cellular structures—that will help make discussions in Unit 3: Cellular Systems and Unit 4: Genetics more meaningful for students.

Cross Connection: Revisit these topics to connect key concepts of shared characteristics across all living organisms as students explore the structure and function of DNA and cellular components in Unit 3: Cellular Systems and Unit 4: Genetics.

Pre-AP Biology 34 Teacher Resource © 2021 College Board

Essential Knowledge Statements:
The essential knowledge statements are linked to one or more learning objectives. These statements describe the knowledge required to perform the learning objective(s).

Content Boundary and Cross Connection Statements:
When needed, content boundary statements provide additional clarity about the content and skills that lie within versus outside of the scope of this course.

Cross connection statements highlight important connections that should be made between key concepts within and across the units.

BIG IDEAS IN PRE-AP BIOLOGY

While the Pre-AP Biology framework is organized into four core units of study, the content is grounded in four big ideas, which are cross-cutting concepts that build conceptual understanding and spiral throughout the course. These ideas cut across all four units of the course and serve as the underlying foundation for the enduring understandings, key concepts, learning objectives, and essential knowledge statements that make up the focus of each unit.

The four big ideas that are central to deep and productive understanding in Pre-AP Biology are:

- The process of evolution drives the diversity and unity of life.
- Growth and reproduction in biological systems are dependent upon the cycling of matter and the transformation of energy.
- Biological systems, occurring at various scales, respond and adapt to stimuli in order to maintain dynamic homeostasis.
- Genetic mechanisms are essential to maintaining biological systems.

OVERVIEW OF PRE-AP BIOLOGY UNITS AND ENDURING UNDERSTANDINGS

Unit 1: Ecological Systems (ECO)	Unit 2: Evolution (EVO)
▪ Biological systems depend on the cycling of matter within and between Earth's systems. ▪ Most ecosystems rely on the conversion of solar energy into chemical energy for use in biological processes. ▪ The dependence on the availability of abiotic and biotic resources results in complex and dynamic interactions between organisms and populations. ▪ Changes to the environment can alter interactions between organisms.	▪ The theory of evolution states that all organisms descend from a common ancestor and share some characteristics. ▪ Biological evolution is observable as phenotypic changes in a population over multiple successive generations. ▪ Speciation, extinction, and the abundance and distribution of organisms occur in response to environmental conditions.
Unit 3: Cellular Systems (CELLS)	**Unit 4: Genetics (GEN)**
▪ Four classes of macromolecules serve as the primary building blocks of biological systems. ▪ Biological systems have specialized structures that enable specific functions necessary to sustain life. ▪ Biological systems must respond to changes in internal and external environments in order to maintain dynamic homeostasis. ▪ In order to sustain complex processes, biological systems must have mechanisms for growth and repair.	▪ The molecular structure of DNA enables its function of storing life's genetic information. ▪ Encoded in DNA is the heritable information responsible for synthesis of RNA, which makes gene expression possible. ▪ Organisms have diverse strategies for passing their genetic material on to the next generation. ▪ Models can be used to illustrate and predict the inheritance of traits.

Unit 1: Ecological Systems

Suggested Timing: Approximately 5 weeks

In this unit, students deepen and expand prior knowledge, gained in a middle school life science course, of how the cycling of matter and flow of energy regulate ecosystems. Students also apply proportional reasoning skills to examine data, especially bivariate data, in order to analyze and make scientific claims about patterns, relationships, and changes in the structure and distribution of ecological populations and communities. This unit provides students an opportunity to build on and deepen their understanding of the living and nonliving components that regulate the structure and function of ecological systems. Students should begin to gain an appreciation for the intricate and often fragile interdependent relationships that ecological communities rely on. Students also explore how communities change over time, both through naturally occurring processes and through human activities.

ENDURING UNDERSTANDINGS

Students will understand that …

- Biological systems depend on the cycling of matter within and between Earth's systems.
- Most ecosystems rely on the conversion of solar energy into chemical energy for use in biological processes.
- The dependence on the availability of abiotic and biotic resources results in complex and dynamic interactions between organisms and populations.
- Changes to the environment can alter interactions between organisms.

KEY CONCEPTS

- ECO 1: Cycling of Matter in the Biosphere
- ECO 2: Population Dynamics
- ECO 3: Defining Ecological Communities
- ECO 4: Ecological Community Dynamics
- ECO 5: Changes in Ecological Communities

KEY CONCEPT ECO 1: CYCLING OF MATTER IN THE BIOSPHERE

Learning Objectives *Students will be able to …*	**Essential Knowledge** *Students need to know that …*
Hydrologic Cycle	
ECO 1.1(a) Explain how the unique properties and phase changes of water enable and regulate biological reactions and/or processes. **ECO 1.1(b)** Create and/or use a model to explain how biological systems function in the hydrologic cycle as water is transferred, transported, and/or stored.	**ECO 1.1.1 Water cycles between abiotic and biotic systems in a process known as the hydrologic cycle.** **a.** The polar nature of water results in properties on which biological systems depend, such as dissolving organic and inorganic nutrients. **b.** The hydrologic cycle is driven by energy from the sun and gravity. **c.** The largest reservoir of water in the global hydrologic cycle is the world's oceans. **d.** Only a small portion of the water on Earth is fresh water, which is required for life by all terrestrial organisms, including humans.
Carbon and Nutrient Cycles	
ECO 1.2(a) Explain the importance of the cycling of carbon for biological systems. **ECO 1.2(b)** Create and/or use models to illustrate how organisms' capture and use of energy plays a role in the cycling of carbon in ecosystems. **ECO 1.2(c)** Explain the importance of the cycling of nutrients for biological systems. **ECO 1.2(d)** Create and/or use models to describe the cycling of nitrogen between biotic and abiotic systems.	**ECO 1.2.1 Elements that are building blocks of macromolecules are transported from abiotic to biotic systems through gaseous and sedimentary cycles.** **a.** The carbon cycle is a series of molecular transformations that includes photosynthesis and cellular respiration. **b.** The nitrogen cycle is a series of transformations that includes the conversion of nitrogen gas (the largest reservoir of nitrogen on Earth) into biologically available nitrogen-containing molecules (e.g., nitrates). **c.** Phosphorus is a critical element for organisms, as it helps make up numerous biomolecules (e.g., ATP, DNA).

Content Boundary: An understanding of the cycling of sulfur and phosphorus in the ecosystem is beyond the scope of this course. Students should understand why phosphorus is an important element, as it serves as a monomer in many important biomolecules (e.g., ATP, DNA), but the understanding of the cycle will not be assessed. Also, students should be able to model the nitrogen cycle from a general standpoint of how biotic and abiotic components interact and depend on one another. However, an understanding of all the chemical conversions during this cycle is beyond the scope of this course.

KEY CONCEPT ECO 2: POPULATION DYNAMICS

Learning Objectives *Students will be able to …*	**Essential Knowledge** *Students need to know that …*
Population Structure	
ECO 2.1(a) Explain the role abiotic and/or biotic resources play in defining the niche of a species. **ECO 2.1(b)** Collect and/or use data to predict population size, density, and/or distribution. **ECO 2.1(c)** Create and/or use models to illustrate how environmental changes can alter the availability of biotic and/or abiotic resources.	**ECO 2.1.1 Species live in a defined range of abiotic and biotic conditions, or niche.** **a.** Sunlight serves as the primary energy input for most ecosystems. **b.** Species have a range of tolerance for abiotic resources and conditions (e.g., sunlight, nutrients, pH, temperature). **c.** Biotic conditions, such as the behavior of social groups or intraspecific competition for mates and food, also influence population structure. **d.** Environmental changes can alter the availability of abiotic and biotic resources and conditions (e.g., climate changes, drought, fire, floods).
Population Growth	
ECO 2.2(a) Use data to explain the growth of a population. **ECO 2.2(b)** Explain the relationship between resource availability and a population's growth pattern. **ECO 2.2(c)** Explain how competition for resources shapes populations.	**ECO 2.2.1 Population growth patterns are influenced by the availability of resources and the interactions that occur within and between populations of species.** **a.** All organisms have the potential for exponential growth, but few organisms demonstrate this growth pattern. **b.** Both density-dependent (e.g., nutrients and food) and density-independent (e.g., weather, natural disasters) factors regulate population growth. **c.** The availability of a single resource may limit the survival of an organism or population (e.g., nitrates in soil are a limiting factor for plant growth). **d.** Due to dynamic resource availability, many populations fluctuate around their carrying capacity, thus demonstrating a logistical growth pattern. **ECO 2.2.2 Populations demonstrate diverse growth strategies.** **a.** r-selected species are typically short-lived. Therefore, they invest energy in producing many offspring during reproduction but provide little to no care for those offspring. **b.** K-selected species typically live longer. Therefore, they have fewer offspring during reproduction but invest energy in the care of those offspring to ensure survival.

Learning Objectives *Students will be able to …*	**Essential Knowledge** *Students need to know that …*
Food Webs and Transfer of Energy in Ecosystems	
ECO 2.3(a) Create and/or use models to explain the transfer of energy through the food web of a community. **ECO 2.3(b)** Analyze data about species distributions to make predictions about the availability of resources. **ECO 2.3(c)** Make predictions about the energy distribution in an ecosystem based on the energy available to organisms.	**ECO 2.3.1 Energy availability helps shape ecological communities.** **a.** Typically, only 10 percent of the total energy in a given trophic level is available to organisms in the next higher trophic level. **b.** The metabolic activity required to utilize the energy available in any given trophic level results in a loss of thermal energy to the environment, as heat. **c.** The energy available to organisms decreases from lower-order trophic levels (primary producers) to higher-order trophic levels (tertiary consumers).

Content Boundary: Students should begin to gain a conceptual understanding of how populations grow (e.g., exponential versus logistical growth). However, many students may not be able to distinguish the subtle mathematical differences between these two growth curves, especially in early generations. Therefore, assessment questions about growth patterns will be limited to what influences these types of growth; calculations of growth curves are beyond the scope of this course.

Cross Connection: Students should have strong familiarity with food webs from middle school life science. This course should give students opportunities to make connections and extend their understanding of characteristics of organisms and food webs to deeper conceptual knowledge about how energy is transferred through diverse ecosystems.

KEY CONCEPT ECO 3: DEFINING ECOLOGICAL COMMUNITIES

Learning Objectives *Students will be able to …*	**Essential Knowledge** *Students need to know that …*
Importance of Biodiversity	
ECO 3.1(a) Describe how ecological processes rely on the biological diversity of the community. **ECO 3.1(b)** Given a specific biome, describe the ecological services that are provided that benefit humans.	**ECO 3.1.1 Reductions in local and global biodiversity can significantly alter the stability of ecosystem processes and services.** **a.** Biologically diverse ecological communities are more resilient to environmental changes. **b.** Ecosystems rely on biological diversity to sustain necessary processes, such as cycling of nutrients and transfer of energy through food webs. **c.** Diverse ecosystems provide many necessary services that humans rely on, such as climate regulation, carbon storage, filtration of drinking water, pollination, and flood/erosion control.
Types of Ecological Communities	
ECO 3.2(a) Describe differences in the abiotic and/or biotic factors that shape aquatic and terrestrial communities. **ECO 3.2(b)** Use data to make predictions about how abiotic and/or biotic factors shape an ecological community.	**ECO 3.2.1 Terrestrial biomes are classified by geographic locations and the abiotic factors that shape the unique ecological communities.** **a.** Two major abiotic factors that help define terrestrial biomes are climate (temperature, precipitation) and soil type. **b.** Ecological communities in terrestrial biomes are shaped by the availability and abundance of the abiotic factors in that region. **ECO 3.2.2 Aquatic biomes can generally be classified according to their salt concentrations: oceanic, brackish, and freshwater.** **a.** Ecological communities in aquatic biomes are shaped by water depth (amount of sunlight), salinity, temperature, nutrients, and flow rates (currents). **b.** Estuaries are brackish ecological communities, as they form in areas where freshwater rivers meet the sea. Their ecological communities are uniquely shaped by the ocean tides. **c.** The three major freshwater communities are rivers/streams, lakes/ponds, and freshwater wetlands.

Content Boundary: Students should gain an understanding of the type of abiotic and biotic components of ecosystems that shape communities of living organisms. They should be able to describe how these components differ for terrestrial and aquatic ecosystems. However, a deep knowledge of chemical regulatory processes (e.g., dissolved oxygen in aquatic systems) is beyond the scope of this course.

Cross Connection: Students should connect key concepts of the carbon cycle from earlier in the unit to the importance of ecosystems, such as forests and oceans, as reservoirs for carbon.

KEY CONCEPT ECO 4: ECOLOGICAL COMMUNITY DYNAMICS

Learning Objectives *Students will be able to …*	**Essential Knowledge** *Students need to know that …*
Interspecific Competition	
ECO 4.1(a) Explain how competition shapes community characteristics. **ECO 4.1(b)** Use data to analyze how competition influences niche-partitioning in an ecological community. **ECO 4.1(c)** Create and/or use models to explain predictions about the possible effects of changes in the availability of resources on the interactions between species.	**ECO 4.1.1 Competition between species drives complex interactions in ecosystems.** **a.** Predator and prey populations respond dynamically to each other. **b.** Keystone species have a dramatic impact on the structure and diversity of ecological communities (e.g., trophic cascade). **c.** Competition will lead to the exclusion of all but one species when two or more species attempt to occupy the same niche. **d.** Niche-partitioning is a means of reducing competition for resources.
Symbiosis	
ECO 4.2(a) Describe what type of symbiotic relationship exists between two organisms. **ECO 4.2(b)** Explain how a symbiotic relationship provides an advantage for an organism by reducing one or more environmental pressures.	**ECO 4.2.1 Competition in ecosystems has led to symbiotic relationships where two or more species live closely together.** **a.** Mutualistic relationships often form to provide food or protection for both of the organisms involved. **b.** Parasitic relationships benefit only one organism in the relationship (the symbiont) and harm the host. **c.** Commensalism is a kind of relationship that benefits only one organism in the relationship (the symbiont); the host is neither harmed nor helped.

KEY CONCEPT ECO 5: CHANGES IN ECOLOGICAL COMMUNITIES

Learning Objectives *Students will be able to …*	**Essential Knowledge** *Students need to know that …*
Natural Changes in Biodiversity	
ECO 5.1(a) Explain how natural changes in the ecosystem affect ecosystem dynamics. **ECO 5.1(b)** Create and/or use models to make predictions about how changes in biodiversity affect local ecosystems. **ECO 5.1(c)** Analyze data to make predictions about the effects on biodiversity in response to environmental changes.	**ECO 5.1.1 Ecosystem biodiversity is influenced by several naturally occurring factors that alter the environment.** **a.** Changes in energy, nutrient, and niche availability influence an ecosystem's biodiversity. **b.** Major disturbances (e.g., forest fires, hurricanes, volcanic eruptions) initiate ecological succession. **c.** Mass extinctions open new, available niches for colonization and therefore can have significant impacts on biodiversity (e.g., the mammalian diversity explosion post-dinosaur extinction, 65 million years ago). **d.** Keystone species and ecosystem engineers (e.g., elephants, beavers) dramatically affect biodiversity in the ecosystem.
Human-Induced Changes in Biodiversity	
ECO 5.2(a) Use evidence to support the claim that changes in ecosystems have resulted from human activities. **ECO 5.2(b)** Given a human activity, predict the potential biological consequences for an ecosystem's biodiversity. **ECO 5.2(c)** Create and/or use models to design solutions that mitigate the adverse effects of a human-induced environmental change on the biodiversity of an ecosystem.	**ECO 5.2.1 Human activities (e.g., urbanization, farming, tree harvesting) also alter availability of nutrients, food, and niches for species and therefore affect population and community dynamics.** **a.** Human activities include anthropogenic climate change, the introduction of invasive species, habitat destruction, and air/water pollution. **b.** The effects of human-induced environmental changes and their impact on species are the subject of a significant amount of current scientific research.

Content Boundary: There are numerous examples of human-induced changes to ecosystems. The focus here is on identifying a few examples of how human activities affect interactions in ecological systems by reducing biodiversity. Understanding topics such as desertification and salinization resulting from human activity are beyond the scope of this course.

Unit 2: Evolution

Suggested Timing: Approximately 4 weeks

In this unit, students explore the diverse types of data and multiple lines of evidence that have informed our understanding of the theory of evolution over time. Students should have a general familiarity with concepts associated with evolution from middle school life science. This course is designed to build on that general understanding to provide a foundation in the mechanisms of evolution. This includes both small-scale evolution (changes in the relative frequency of a gene in a population from one generation to the next) and large-scale evolution (speciation events over many generations).

ENDURING UNDERSTANDINGS

Students will understand that …

- The theory of evolution states that all organisms descend from a common ancestor and share some characteristics.
- Biological evolution is observable as phenotypic changes in a population over multiple successive generations.
- Speciation, extinction, and the abundance and distribution of organisms occur in response to environmental conditions.

KEY CONCEPTS

- EVO 1: Patterns of Evolution
- EVO 2: Mechanisms of Evolution
- EVO 3: Speciation

KEY CONCEPT EVO 1: PATTERNS OF EVOLUTION

Learning Objectives *Students will be able to …*	**Essential Knowledge** *Students need to know that …*
Theory of Evolution	
EVO 1.1(a) Use scientific evidence to justify a claim of an evolutionary relationship between species. **EVO 1.1(b)** Describe shared characteristics (homologies) among organisms that provide evidence for common ancestry.	**EVO 1.1.1 The theory of evolution states that the unity and diversity of life we see today is the result of more than 3.5 billion years of evolutionary processes on Earth.** **EVO 1.1.2 Scientists use various sources of evidence to establish evolutionary relationships between organisms.** **a.** Fossil evidence, in conjunction with relative and radiometric dating, provides insight into the geographic and temporal distribution of species throughout Earth's history. **b.** Comparisons of anatomical and molecular homologies are used to determine the degree of divergence from a common ancestor. **1.** The structure and function of DNA is a homology that links all living organisms across the three domains of life—Archaea, Bacteria, and Eukarya. **2.** Cellular structures across all living organisms are strikingly similar.
Classifying Evolutionary Relationships	
EVO 1.2(a) Create or use models to illustrate evolutionary relationships. **EVO 1.2(b)** Use models of evolutionary relationships to describe and/or analyze how different species are related.	**EVO 1.2.1 Evolutionary relationships between organisms can be modeled using cladograms and phylogenetic trees, which show inferred evolutionary relationships among living things.** **a.** Cladograms and phylogenetic trees can illustrate speciation events. **b.** These models of evolutionary relationships show tree-like lineages that do not correlate to levels of complexity or advancement.

Content Boundary: The intent is not for students to memorize a list of characteristics that show descent from a common ancestor. Instead, the focus here is on a few powerful examples of this evidence—such as DNA and cellular structures—that will help make discussions in Unit 3: Cellular Systems and Unit 4: Genetics more meaningful for students.

Cross Connection: Revisit these topics to connect key concepts of shared characteristics across all living organisms as students explore the structure and function of DNA and cellular components in Unit 3: Cellular Systems and Unit 4: Genetics.

KEY CONCEPT EVO 2: MECHANISMS OF EVOLUTION

Learning Objectives *Students will be able to …*	**Essential Knowledge** *Students need to know that …*
Natural Selection Theory	
EVO 2.1(a) Describe the scientific discoveries that informed the theory of natural selection.	**EVO 2.1.1 Key discoveries made by several scientists contributed significantly to Darwin's understanding of biological evolution.** **a.** Several naturalists, such as Lamarck and Wallace, contributed models of evolution that informed Darwin's theories. **b.** Darwin's ideas about evolution were influenced by the work of geologists Hutton and Lyell, whose work highlighted the slow-acting geological processes that shape Earth's features.
Selective Mechanisms	
EVO 2.2(a) Describe how selective pressures in the environment can affect an organism's fitness. **EVO 2.2(b)** Explain how selective pressures in the environment could cause shifts in phenotypic and/or allele frequencies. **EVO 2.2(c)** Use data to describe how changes in the environment affect phenotypes in a population. **EVO 2.2(d)** Predict how allelic frequencies in a population shift in response to a change in the environment.	**EVO 2.2.1 Darwin's theory of natural selection is that a selective mechanism in biological evolution may lead to adaptations.** **a.** Abiotic ecosystem components (e.g., nutrients) and biotic ecosystem components (e.g., predators) act as selective pressures. **b.** Favorable traits in a given environment lead to differential reproductive success, or fitness, and over time can produce changes in phenotypic and/or allele frequencies. **c.** Heritable traits that increase an organism's fitness are called adaptations. **d.** Over time, the relative frequency of adaptations in a population's gene pool can increase. **e.** Patterns of natural selection can include phenomena such as coevolution, artificial selection, and sexual selection. **EVO 2.2.2 Favorable traits are relative to their environment and subject to change.** **a.** Changes in the environment happen both naturally (e.g., floods, fires, climate change) and through human-induced activities (e.g., pollution, habitat destruction, climate change).

Cross Connection: Revisit these topics in Unit 4: Genetics to connect key concepts involving genetic processes. Mutation types in DNA sequence, replication errors, and the random nature of independent assortment can lead to phenotypic variations on which natural selection can act. Also, connect key concepts to Unit 1: Ecological Systems. Changes in resources (e.g., nutrients from biogeochemical cycles and predator–prey interactions) can act as selective pressures on organisms.

KEY CONCEPT EVO 3: SPECIATION

Learning Objectives *Students will be able to …*	**Essential Knowledge** *Students need to know that …*
Mechanisms of Speciation	
EVO 3.1(a) Explain how geographic separation events can lead to the formation of new species. **EVO 3.1(b)** Describe mechanisms that contribute to reproductive separation that could lead to speciation.	**EVO 3.1.1 Speciation occurs when populations of the same species are separated, resulting in reduced gene flow, which over time allows populations to become genetically distinct from one another.** **a.** Geographic separation: a physical barrier (e.g., rivers changing course, glacial movement, continental drift). **b.** Habitat specialization: niche differentiation from others in the population. **c.** Behavioral separation: different mating habits, times, or locations from others in the population. **d.** Mechanical separation: structural differences in sex organs that make individuals within a population unable to reproduce with one another.
Rates of Speciation	
EVO 3.2(a) Describe factors that affect the rate of speciation. **EVO 3.2(b)** Use evidence to support the claim that rates of speciation have varied throughout Earth's history. **EVO 3.2(c)** Explain how environmental change can result in the extinction of a species.	**EVO 3.2.1 Rates of speciation and extinction have fluctuated throughout Earth's history in response to changing environmental conditions.** **a.** Gradualism is a model of evolution whereby lineages accumulate small genetic changes over time. **b.** Punctuated equilibrium indicates that periods of stability for species can be punctuated with periods of rapid speciation, or splitting of lineages. **c.** Extinction events that occur simultaneously across numerous species, within a relatively short period of geologic time, are known as mass extinctions. **d.** There have also been human-induced extinctions due to overharvesting and/or changes in habitat (e.g., great auk, passenger pigeon).

Content Boundary: Assessments will not require students to recall dates of major mass extinction events. Instead, the focus here should be on a few diverse examples of evidence that illustrate scientists' current understanding of the rate of speciation and extinction and how that shapes biodiversity.

Unit 3: Cellular Systems

Suggested Timing: Approximately 10 weeks

Students are introduced to cellular structure and function in middle school life science. Therefore, this unit deepens and expands students' knowledge as they explore how cellular structures function together to support a cellular system that grows and develops, responds to a changing environment, and obtains and uses energy. Through concepts of homeostasis, students should gain an appreciation for how interdependent cellular structures are on one another to maintain proper cellular functions. Students then build on their knowledge of cellular systems as they examine how specific structures participate in the process of capturing, storing, and using energy to drive cellular processes. They also connect their understanding of ecological roles of organisms, from Unit 1: Ecological Systems, to the various types of cellular energy processes—photosynthesis, cellular respiration, and fermentation. Concepts in the cellular systems unit may be difficult for some students due to the microscopic, seemingly intangible nature of these ideas and phenomena. One way this course addresses this challenge is through introducing systems-based thinking early on, in Unit 1: Ecological Systems. Now, in Unit 3, students are equipped to use systems-based thinking to develop productive analogies for cellular systems, which can aid in comprehension.

ENDURING UNDERSTANDINGS

Students will understand that …

- Four classes of macromolecules serve as the primary building blocks of biological systems.
- Biological systems have specialized structures that enable specific functions necessary to sustain life.
- Biological systems must respond to changes in internal and external environments in order to maintain dynamic homeostasis.
- In order to sustain complex processes, biological systems must have mechanisms for growth and repair.

KEY CONCEPTS

- CELLS 1: Chemistry of Life
- CELLS 2: Cell Structure and Function
- CELLS 3: Cell Transport and Homeostasis
- CELLS 4: Organisms Maintaining Homeostasis
- CELLS 5: Cell Growth and Division
- CELLS 6: Photosynthesis
- CELLS 7: Cellular Respiration and Fermentation

KEY CONCEPT CELLS 1: CHEMISTRY OF LIFE

Learning Objectives *Students will be able to …*	**Essential Knowledge** *Students need to know that …*
Biomolecules	
CELLS 1.1(a) Differentiate between the major macromolecules based on their structure and/or function. **CELLS 1.2(a)** Explain the role macromolecules play in supporting cellular function.	**CELLS 1.1.1 The four classes of organic macromolecules are proteins, carbohydrates, lipids, and nucleic acids. Each class has unique chemical structures.** **a.** These organic macromolecules are primarily made up of just a few elements—carbon, hydrogen, nitrogen, oxygen, sulfur, and phosphorus. **b.** Most macromolecules are polymers that are made up of specific, smaller subunits called monomers. **CELLS 1.2.1 Each class of macromolecule carries out specific functions in biological systems.** **a.** Carbohydrates serve as the primary source of energy for organisms in the forms of glycogen and starch, and as structural support in plant cell walls in the form of cellulose. **b.** Lipids are used as a source of energy and as building blocks of biological membranes. **c.** Proteins are responsible for numerous cellular functions, such as catalyzing reactions, providing structure, and aiding in cell transport and signaling. **d.** Nucleic acids are responsible for storing and transferring genetic information in the form of DNA and RNA.
Enzymes	
CELLS 1.3(a) Describe the effect of enzymes on the rate of chemical reactions in biological systems. **CELLS 1.3(b)** Predict how a change in pH and/or temperature will affect the function of an enzyme.	**CELLS 1.3.1 Enzymes are proteins that are catalysts in biochemical reactions and essential for maintaining life processes.** **a.** The rate of a chemical reaction is affected by the concentration of substrates and enzymes. **b.** Enzymes have specific shapes that bind to specific substrates in a precise location called the active site. **c.** Enzymes function optimally in a specific pH and temperature range.

Learning Objectives *Students will be able to ...*	**Essential Knowledge** *Students need to know that ...*
Cellular Energy Requirements	
CELLS 1.4(a) Explain the role of ATP in supporting processes in biological systems. **CELLS 1.4(b)** Explain why different species demonstrate diverse energy and nutrient requirements. **CELLS 1.4(c)** Use data to predict the energy requirements of diverse species.	**CELLS 1.4.1 Cells transfer and use energy from a variety of molecules in order to perform cellular functions.** **a.** ATP is a high-energy molecule used in the cell to carry out many cellular processes. **b.** The amount of energy available to organisms from the breakdown of macromolecules varies based on their chemical composition. **CELLS 1.4.2 Because organisms have diverse ecological roles, they also have diverse energy requirements.**

Content Boundary: While students should recognize that sulfur is one of the most common elements in living systems, a deeper understanding of the role sulfur plays in biological systems is beyond the scope of this course.

Deep understanding of bond energy is beyond the scope of this course. However, students should have a basic understanding that in order to break any bond, energy must be absorbed. Conversely, in order to form any bond, energy must be released. Therefore, energy is available to biological systems when more stable bonds are formed in chemical reactions; the high-energy bonds in ATP are an example of this.

Cross Connection: Students should connect key concepts to Unit 1: Ecological Systems. The cycling of matter in the biosphere provides the building blocks for development of macromolecules. Students should make connections between the role of enzymes in biological systems and how those systems can be affected by mutations during replication—specifically, when these mutations result in changes to enzymes produced during protein synthesis (Unit 4: Genetics). Students should expand on that understanding to see how changes in proteins (enzymes) influence an organism's fitness, connecting to key concepts in Unit 2: Evolution.

KEY CONCEPT CELLS 2: CELL STRUCTURE AND FUNCTION

Learning Objectives *Students will be able to …*	**Essential Knowledge** *Students need to know that …*
Cell Structure and Function	
CELLS 2.1(a) Provide evidence to support the claim that all biological systems demonstrate some shared characteristics. **CELLS 2.2(a)** Develop and/or use models to compare and contrast cell structures of different cells.	**CELLS 2.1.1 The cell is the basic unit of biological systems, and there are some shared characteristics among all cells.** **a.** All cells possess a plasma membrane, ribosomes, genetic material, and cytoplasm. **b.** All cells result from the division of preexisting cells. **CELLS 2.2.1 Cells have specialized structures that perform specific functions.** **a.** Some cells (eukaryotes) have a nucleus that houses their DNA. **b.** Cell structures can be organized based on four primary functions: **1.** Energy transfer (e.g., chloroplasts, mitochondria). **2.** Production of proteins (e.g., ribosomes, ER, Golgi apparatus). **3.** Storage and recycling of materials (e.g., lysosomes, vacuoles, vesicles). **4.** Support and movement (e.g., cell walls, cytoskeleton, flagella).
Specialized Cells	
CELLS 2.3(a) Explain how cell structures in different types of organisms enable specialized cell functions. **CELLS 2.3(b)** Describe how cell structures support an organism's ecological role.	**CELLS 2.3.1 Multicellular organisms have specialized cells that perform a wide variety of functions.** **a.** During development, cells become specialized and develop into higher-order systems (i.e., tissues, organs). **b.** Specialized cells perform a wide variety of unique functions for organisms (e.g., muscle cells, red blood cells). **CELLS 2.3.2 Cell structures can differ across organisms and often give insight into an organism's ecological role.** **a.** Prokaryotes lack a nucleus and membrane-bound organelles, whereas eukaryotes possess a nucleus and complex, membrane-bound organelles. **b.** Within the Eukarya domain, cellular structures and functions differ among organisms. **1.** Plant cells have large, central vacuoles and chloroplasts that enable photosynthesis. **2.** Some cells have rigid cell walls (e.g., fungi, plants).

Content Boundary: Assessments will not require students to recall an exhaustive list of organelles and their functions. Instead the focus is on how an organelle's function sustains specific biological systems. Therefore, ideally, deeper understanding of organelles is developed in context throughout the course based on their function (e.g., nucleus—genetic processes, mitochondria—respiration, chloroplast—photosynthesis, ribosomes—protein synthesis, lysosomes—transport).

KEY CONCEPT CELLS 3: CELL TRANSPORT AND HOMEOSTASIS

Learning Objectives *Students will be able to …*	**Essential Knowledge** *Students need to know that …*
Cell Membrane Structure	
CELLS 3.1(a) Explain how cell membranes function in maintaining dynamic homeostasis for biological systems. **CELLS 3.1(b)** Create and/or use models to explain the structure and function of cell membrane components.	**CELLS 3.1.1 Cells have phospholipid membranes that are selectively permeable.** **a.** All cells have membranes that separate the cell from the external environment; some cells also have a cell wall for structure and protection. **b.** Membranes consist of a phospholipid bilayer with numerous proteins embedded within and across the surfaces of the membrane. **c.** Carbohydrate chains attach to some surface proteins, and together they contribute to cell-to-cell chemical identification.
Cell Transport	
CELLS 3.2(a) Use data to investigate how various solutes and/or solvents passively move across membranes. **CELLS 3.2(b)** Explain how materials move into or out of the cell across the cell membrane. **CELLS 3.2(c)** Create and/or use representations and/or models to predict the movement of solutes into or out of the cell.	**CELLS 3.2.1 Cells depend on the structure of the cell membrane to move materials into and out of the cell in order to maintain dynamic homeostasis.** **a.** Passive transport involves the movement of solutes across the membrane along the concentration gradient, without the use of additional energy. **b.** Active transport involves the movement of solutes across the membrane against their concentration gradients with the use of additional energy. **c.** Bulk transport of molecules across the membrane is accomplished using endocytosis or exocytosis.
Cell Size and Diffusion	
CELLS 3.3(a) Describe how the size of a cell affects its ability to function efficiently.	**CELLS 3.3.1 Diffusion is most efficient when the surface area is high and the volume is low.** **a.** Small cell size creates a surface-area-to-volume ratio that enables more efficient diffusion. **b.** The surface-area-to-volume ratio gets smaller as the cell gets larger.

Cross Connection: Students should make connections to key concepts from Unit 1: Ecological Systems. The cycling of matter contributes to the type of materials that the cell will transport to sustain necessary functions and support cellular energy processes.

KEY CONCEPT CELLS 4: ORGANISMS MAINTAINING HOMEOSTASIS

Learning Objectives *Students will be able to …*	**Essential Knowledge** *Students need to know that …*
Organ/Tissue Systems	
CELLS 4.1(a) Describe how organ systems work together to maintain homeostasis. **CELLS 4.1(b)** Predict the consequence of a disruption in homeostasis.	**CELLS 4.1.1 Multicellular organisms rely on tissues and organ systems to transport nutrients and waste in order to maintain dynamic homeostasis.** **a.** Animals have organ systems that work together to transport nutrients and excrete waste. **1.** The digestive system is needed to derive nutrients and basic building blocks (monomers) from food, which are required for cellular functioning and growth. **2.** The respiratory system is needed for gas exchange to obtain oxygen and remove carbon dioxide. **3.** The circulatory system is needed to transport oxygen and nutrients to cells. **4.** The excretory system is needed to remove toxins and nitrogenous wastes from the body and to maintain water balance with the help of the circulatory system. **b.** Plants have specialized vascular tissues and cells that transport nutrients, water, and waste. **1.** Plants depend on xylem to transport water and nutrients for photosynthesis from the roots to the leaves and on phloem to transport sugars from the leaves to the rest of the plant. **2.** Plants excrete waste products from photosynthesis through the stomata in their leaves.
Response to Stimuli	
CELLS 4.2(a) Describe the benefits associated with tropisms and/or taxes in organisms in response to an external stimulus. **CELLS 4.2(b)** Predict how an organism might respond to a change from the external environment in order to maintain homeostasis.	**CELLS 4.2.1 Organisms have positive or negative responses to external stimuli in their environment in order to maintain dynamic homeostasis.** **a.** Plants exhibit tropisms that determine direction of growth toward or away from a stimulus, such as light, chemicals, gravity, touch, and water. **b.** Animals exhibit taxes that enable them to move in response to a stimulus, such as food, light, or pH.

Content Boundary: It is not the intent for students to develop a deep understanding of body systems. The focus here is on using a few key systems—digestive, respiratory, circulatory, and excretory—as a means to understanding how systems work together to support overall functions in a multicellular organism. These systems help deepen students' understanding about cellular energy, eliminating waste, and the role of diffusion in those processes. The nervous and endocrine systems are beyond the scope of this course.

Content Boundary: Understanding of the role of hormones (e.g., auxin) in plant tropisms is beyond the scope of this course.

KEY CONCEPT CELLS 5: CELL GROWTH AND DIVISION

Learning Objectives *Students will be able to …*	**Essential Knowledge** *Students need to know that …*
Cell Cycle: Interphase	
CELLS 5.1(a) Describe the importance of the growth phases in the cell cycle. **CELLS 5.1(b)** Explain how the cell cycle is regulated.	**CELLS 5.1.1 Generally, the cell spends 90 percent of its time in interphase.** **a.** During the growth phases of interphase (G1 and G2) the cell is producing new organelles and proteins. There are cell division checkpoints at the end of both of these phases. **b.** During the synthesis phase of interphase, DNA uncoils to replicate itself. Afterward, each chromosome consists of two double-stranded copies of identical DNA.
Cell Cycle: Cell Division	
CELLS 5.2(a) Explain why chromosome duplication must occur prior to mitotic division. **CELLS 5.2(b)** Create and/or use models to explain the phases of mitosis. **CELLS 5.2(c)** Predict consequences for biological systems if cell cycle regulation is altered.	**CELLS 5.2.1 Multicellular organisms use mitotic cell division in order to replace dying or damaged cells.** **a.** Mitosis, the fourth phase of the cell cycle, consists of a series of sub-phases (prophase, metaphase, anaphase, and telophase) whereby the parent nucleus produces two genetically identical daughter nuclei. **b.** There is a cell division checkpoint during metaphase. **c.** Cancer cells form when cell division continues without regulation.
Viruses	
CELLS 5.3(a) Describe the structural differences between viruses and cells. **CELLS 5.3(b)** Explain how viruses affect functions in biological systems.	**CELLS 5.3.1 Viruses must utilize cellular machinery in biological systems in order to replicate their genetic material.** **a.** Viruses lack the ability to perform reactions that require energy, such as replicating their own genetic material. **b.** Viruses bind to and release their genetic material into host cells, which allows the cellular machinery to be hijacked to produce viral proteins and genomes. **c.** Viral infection may disrupt biological systems by manipulating cell cycle regulation and altering the normal synthesis of proteins, causing disease or cell death in organisms.

Content Boundary: The focus on the cell cycle, including mitosis, is not on memorizing phases in the appropriate order, but rather how those individual phases support other vital functions that sustain biological systems. Students should see the need for cells to grow in size and increase the number of organelles prior to cellular division. They should also understand why regulating cell size through mitotic division is necessary. This keeps cell sizes small in order to support diffusion rates and improve efficiency of cellular processes.

KEY CONCEPT CELLS 6: PHOTOSYNTHESIS

Learning Objectives *Students will be able to …*	**Essential Knowledge** *Students need to know that …*
Photosynthesis	
CELLS 6.1(a) Explain why the products of photosynthesis are ecologically important. **CELLS 6.1(b)** Create and/or use models to explain the process of converting solar energy into chemical energy through photosynthesis. **CELLS 6.1(c)** Use data to describe what factors affect rates of photosynthesis.	**CELLS 6.1.1 Photosynthetic organisms have the cellular structures to absorb solar radiation and convert it into chemical energy.** **a.** Photosynthetically active radiation wavelengths occur in the visible light spectrum. **b.** Photosynthetic organisms have specialized pigments, membranes, and/or organelles that absorb solar radiation and convert it into chemical energy. **c.** Photosynthetic organisms rely on properties of water, such as cohesion, adhesion, and surface tension, which result in capillary action. **d.** Photosynthesis is divided into two stages: light-dependent and light-independent reactions. **1.** Light-dependent reactions require sunlight energy and H_2O to transfer energy to ATP and NADPH. A byproduct of this process is oxygen. **2.** Light-independent reactions use CO_2, ATP, and NADPH to produce sugars.

Content Boundary: The intent is not for students to memorize details of chemical reactions that occur during photosynthesis. Instead the focus here is on understanding the role of the main reactants and byproducts (as defined in the essential knowledge) at each stage of energy transfer. A deep understanding of photosystems I and II and specific steps of the Calvin cycle is beyond the scope of this course.

KEY CONCEPT CELLS 7: CELLULAR RESPIRATION AND FERMENTATION

Learning Objectives *Students will be able to …*	**Essential Knowledge** *Students need to know that …*
Cellular Respiration	
CELLS 7.1(a) Explain why the cellular energy processes in producers and consumers are dependent on one another. **CELLS 7.1(b)** Create and/or use models to explain how consumers obtain usable energy from the products of photosynthesis. **CELLS 7.1(c)** Describe how consumers store the energy acquired through cellular respiration.	**CELLS 7.1.1 Cellular respiration is a series of enzymatic reactions that utilize electron carrier molecules to synthesize ATP molecules.** **a.** Transfer of energy through cellular respiration begins with the carbon compounds generated by producers during photosynthesis. **b.** Glycolysis, an anaerobic process that occurs in the cytoplasm, uses glucose and two molecules of ATP to produce NADH, pyruvic acid, and four molecules of ATP. **c.** The Krebs cycle, an aerobic process that occurs in the mitochondria, uses pyruvic acid to produce ATP and electron carriers called NADH and $FADH_2$. Carbon dioxide is produced as a waste product during these chemical reactions. **d.** The electron transport chain transfers the high-energy electrons from NADH and $FADH_2$ to oxygen, producing H_2O. **e.** The build-up of hydrogen ions in the inner mitochondrial space produces a gradient that allows the production of 36–38 ATP molecules from each glucose molecule.
Fermentation	
CELLS 7.2(a) Explain the biological importance of fermentation. **CELLS 7.2(b)** Describe how energy transfer in the cell occurs under anaerobic conditions in consumers.	**CELLS 7.2.1 Organisms have processes for the transfer of energy under completely anaerobic conditions.** **a.** Fermentation allows for production of two molecules of ATP during glycolysis if no oxygen is present. **b.** Two common forms of fermentation are alcohol and lactic acid. **1.** Yeast uses alcohol fermentation to transfer energy from glucose and to release CO_2 as a byproduct. This is an economically important process because it is used to make many food products. **2.** Bacterial and animal cells are able to utilize lactic acid fermentation to transfer energy from glucose in the absence of oxygen.

Content Boundary: The focus for this key concept is on the understanding of how the products from photosynthesis enable the process of cellular respiration. It is more important for students to be able to use reactants and products to explain the interdependence between photosynthesis and cellular respiration than to memorize a series of steps that occur during these processes.

Cross Connection: In discussing electron transport chain processes whereby intermembrane proteins (enzymatic) allow movement of hydrogen ions, students should make connections to key concepts involving the role of proteins, membrane structures, and diffusion from earlier in this unit.

Unit 4: Genetics

Suggested Timing: Approximately 9 weeks

Similar to the study of cellular systems, many key concepts in genetics can be somewhat abstract for students because they are on a scale that cannot be seen with the eye. Therefore, in order to better visualize genetic processes, such as DNA and protein synthesis, in this unit students engage with models, diagrams, and computer simulations. Students build on prior basic understanding of the passing of traits, from middle school life science, by developing a strong foundational understanding of the molecular processes responsible for the passing of traits. They also use mathematics and pedigree models to analyze and predict inheritance patterns, and explore current biotechnology associated with the study and manipulation of genes.

ENDURING UNDERSTANDINGS

Students will understand that …

- The molecular structure of DNA enables its function of storing life's genetic information.
- Encoded in DNA is the heritable information responsible for synthesis of RNA, which makes gene expression possible.
- Organisms have diverse strategies for passing their genetic material on to the next generation.
- Models can be used to illustrate and predict the inheritance of traits.

KEY CONCEPTS

- GEN 1: Structure of DNA
- GEN 2: DNA Synthesis
- GEN 3: Protein Synthesis
- GEN 4: Asexual and Sexual Passing of Traits
- GEN 5: Inheritance Patterns
- GEN 6: Biotechnology

KEY CONCEPT GEN 1: STRUCTURE OF DNA

Learning Objectives *Students will be able to …*	**Essential Knowledge** *Students need to know that …*
Race to Discover DNA	
GEN 1.1(a) Explain how models of DNA changed over time as new scientific evidence emerged, resulting in the final consensus model.	**GEN 1.1.1 Several scientists' models of DNA contributed to the final consensus model of DNA's structure produced by Watson and Crick.** **a.** Chargaff observed 1:1 ratios between certain nitrogenous bases in DNA's nucleotides (A-T, G-C). **b.** Franklin's work showed that DNA was in the shape of a helix and suggested that the nitrogenous bases were near the center. **c.** Watson and Crick built the consensus model of DNA known today.
The Structure of DNA	

GEN 1.2(a) Describe how DNA is organized differently in prokaryotes and eukaryotes.
GEN 1.2(b) Describe the monomers necessary for cells to build DNA.
	GEN 1.2.1 DNA is the genetic material found in all living organisms.
	a. Living systems obtain the monomers, such as nitrogen, to build DNA strands using products from metabolic reactions.
	b. In prokaryotes, genomic DNA is organized into a single, circular chromosome.
	c. In eukaryotes, genomic DNA is organized into multiple, linear chromosomes found in the nucleus.
	  1. DNA is a double helix with the two strands running in opposite directions (antiparallel).
	  2. Nitrogenous base pairing occurs in between the two strands, each of which contains a sugar–phosphate backbone.

Content Boundary: Assessments will not require students to recall a list of scientists and their contributions to the discovery of the structure of DNA. The focus here is on how scientific knowledge (e.g., work from Pauling, Chargaff, Franklin, Watson, and Crick) developed over time, finally leading to the understanding of the consensus model of DNA.

Cross Connection: Connect key concepts from the cycling of matter in the biosphere (Unit 1: Ecological Systems) and the chemistry of life (Unit 3: Cellular Systems) to help students understand where the building blocks to make these nucleic acids (both DNA and RNA) come from.

KEY CONCEPT GEN 2: DNA SYNTHESIS

Learning Objectives *Students will be able to …*	**Essential Knowledge** *Students need to know that …*
DNA Synthesis (Replication)	
GEN 2.1(a) Describe the importance of DNA synthesis. **GEN 2.1(b)** Create and/or use models to explain how DNA synthesis occurs. **GEN 2.1(c)** Explain the function of enzymes in DNA synthesis.	**GEN 2.1.1 All living cells have a mechanism for DNA synthesis (replication) in order to pass on genetic information to new cells.** **a.** Each of the two strands of DNA serves as a template for a new complementary strand in a semiconservative process of replication. **b.** DNA helicase and DNA polymerase are the primary enzymes required for the replication process.

Content Boundary: Understanding of in-depth DNA replication processes, such as formation of leading and lagging strands, Okazaki fragments, and DNA polymerase working in the 5′-to-3′ direction, is beyond the scope of this course.

KEY CONCEPT GEN 3: PROTEIN SYNTHESIS

Learning Objectives *Students will be able to …*	**Essential Knowledge** *Students need to know that …*
RNA Structure	
GEN 3.1(a) Explain structural differences between RNA and DNA.	**GEN 3.1.1 The unique structure of RNA enables its function in protein synthesis.** **a.** Types of RNA may vary in structure, but they all have important structural differences from DNA: **1.** All types of RNA contain the sugar ribose instead of deoxyribose. **2.** All types of RNA contain the nitrogen base uracil instead of thymine. **3.** mRNA is single-stranded instead of double-stranded like DNA.
RNA Transcription	
GEN 3.2(a) Describe how heritable information stored in DNA is transferred to RNA through transcription.	**GEN 3.2.1 RNA synthesis, or transcription, results in three forms of the polymer.** **a.** RNA synthesis occurs in the cytoplasm of prokaryotes and in the nucleus of eukaryotes. **b.** During transcription, a single strand of DNA is used as a template to synthesize a complementary strand of RNA. **c.** RNA transcription results in the synthesis of messenger RNA (mRNA), transfer RNA (tRNA), and ribosomal RNA (rRNA).

Learning Objectives *Students will be able to …*	Essential Knowledge *Students need to know that …*
Translation	
GEN 3.3(a) Explain the role of mRNA in protein synthesis. **GEN 3.3(b)** Identify the role of amino acids in protein synthesis. **GEN 3.3(c)** Create and/or use models to demonstrate how the information in genes is expressed as proteins. **GEN 3.3(d)** Explain how the structure of DNA relates to an organism's phenotype and genotype.	**GEN 3.3.1 Gene expression includes the process of protein synthesis, which requires transcribing heritable information stored in DNA and translating it into polypeptides.** **a.** Genes are certain sections of DNA on chromosomes that contain the instructions for making specific proteins, and make up an organism's genotype and determine its phenotype. **b.** Information carried on genes in the template strand of DNA is transcribed into a strand of mRNA during transcription. **c.** Translation of mRNA into the sequence of amino acids (protein) occurs with the help of ribosomes in the cytoplasm. **1.** mRNA is read by the ribosome three bases at a time (a codon), which corresponds to a specific amino acid that the ribosome incorporates into a growing polypeptide chain. **2.** Translation begins and ends with specific start and stop codons. **3.** The particular sequence of amino acids determines the shape and function of the expressed protein.
Mutations	
GEN 3.4(a) Describe how changes in DNA sequences may affect protein structure and function. **GEN 3.4(b)** Create and/or use models to explain the consequences of changes in DNA. **GEN 3.4(c)** Analyze data to make predictions about how changes in DNA affect an organism's phenotype.	**GEN 3.4.1 Mutations are heritable changes to DNA sequences.** **a.** Mutations are random changes in DNA sequences that may occur as a result of errors during replication or the effects of environmental mutagens (e.g., UV light, x-rays, and carcinogens). **b.** A change in a DNA sequence occurs when a nucleotide is substituted into the original sequence (causing a point mutation) or inserted into or deleted from the sequence (causing a frameshift mutation). **c.** Depending on how the changes impact gene expression, mutations may cause negative disruption in gene and protein function, have little to no effect on organisms, or produce beneficial variation.

Content Boundary: It is important for students to realize that all forms of RNA are made from DNA and to understand how forms of RNA work together to make proteins. However, assessments will not require students to recall a step-by-step list of the process. Instead, they should focus on how the structure of each form of RNA fits its role in protein synthesis and why this process is important (for how genotypes determine phenotypes). Students should understand that only some regions of DNA carry genetic information for proteins (genes). However, specifics about introns and exons are beyond the scope of this course.

Cross Connection: Make connections to key concepts from Unit 2: Evolution of how mutations serve as sources of genetic variation on which natural selection mechanisms work.

KEY CONCEPT GEN 4: ASEXUAL AND SEXUAL PASSING OF TRAITS

Learning Objectives *Students will be able to …*	**Essential Knowledge** *Students need to know that …*
Asexual Reproduction	
GEN 4.1(a) Explain why asexual reproductive strategies do not lead to genetic diversity. **GEN 4.1(b)** Explain the advantage(s) of asexual reproduction strategies for organisms.	**GEN 4.1.1 Most unicellular and some multicellular organisms can reproduce through asexual processes that do not increase genetic variation in the population.** **a.** Binary fission is a form of asexual cell division that results in a symmetrical genetic clone of the parent cell (e.g., bacteria, amoebas). **b.** Budding is a form of asexual cell division that results in a diploid, asymmetrical genetic clone of the parent cell (e.g., corals, yeast). **c.** Some forms of parthenogenesis are a form of asexual reproduction in some species, where offspring are produced by females without the genetic contribution of a male (e.g., bees, lizards, sharks). **d.** Asexual reproduction can be performed without the need to find mates and can lead to rapid proliferation of a population over time.
Sexual Reproduction (Meiosis)	
GEN 4.2(a) Explain why reduction division must occur to produce gametes. **GEN 4.2(b)** Explain how meiotic cellular division followed by fertilization leads to genetic diversity within a population. **GEN 4.2(c)** Create and/or use models to explain how chromosome number is halved during meiosis.	**GEN 4.2.1 Some unicellular and most eukaryotic organisms reproduce sexually, requiring a process called meiosis that results in genetic variation in the population.** **a.** Meiotic division requires two distinct nuclear divisions in order to reduce one diploid (2N) cell into four haploid (N) cells. **1.** During the first division in meiosis, homologous chromosomes pair together in a tetrad and crossing-over occurs, which increases genetic variation. **2.** At the end of the first division (meiosis I), homologous chromosomes are separated and two daughter cells are formed. **3.** At the end of the second meiotic division (meiosis II), the two cells are separated into four genetically diverse haploid cells, which in animals differentiate into gametes. **b.** Sexual reproduction occurs via fertilization, when sperm and egg gametes fuse and form a zygote, restoring the diploid number of chromosomes.

Learning Objectives *Students will be able to …*	Essential Knowledge *Students need to know that …*
Chromosomal Disorders	
GEN 4.3(a) Describe how some organisms have structurally altered chromosomes in their genome. **GEN 4.3(b)** Predict how altered chromosome numbers may affect organisms.	**GEN 4.3.1 Chromosomal disorders occur when the structure or number of chromosomes has been altered, which often impairs normal function and development in organisms.** **a.** Unequal crossing-over events can lead to chromosomal disorders. **b.** Random nondisjunction events may occur in meiosis when chromosomes fail to separate. This may result in viable offspring with an abnormal number of chromosomes.

Content Boundary: Students will not be assessed on the molecular details of the asexual reproductive strategies of budding and binary fission, nor on which organisms utilize asexual reproduction. The focus here is on how this reproductive strategy leads to the genetic clone of the parent cell, the impact on gene pool diversity, and why that process is advantageous for the organism at that time.

Cross Connection: Students should make connections to key concepts in Unit 1: Ecological Systems and Unit 2: Evolution, recognizing how changes in the environment and natural selection act on variation in traits that emerge through meiosis. These processes lead to phenotypic variation in species and populations.

KEY CONCEPT GEN 5: INHERITANCE PATTERNS

Learning Objectives *Students will be able to …*	**Essential Knowledge** *Students need to know that …*
Inheritance Patterns	
GEN 5.1(a) Explain the relationship between genotype and phenotype. **GEN 5.1(b)** Describe the type of inheritance pattern based on data and/or use of models.	**GEN 5.1.1 Investigation of Mendelian, or single-gene, traits reveals the basis for understanding patterns of inheritance.** **a.** Many of an organism's traits (phenotype) are determined by the organism's genes (genotype), which are passed from one generation to the next. **b.** Somatic cells of sexually reproducing organisms have two copies of each gene (one inherited from each parent). **c.** Each gene copy may have variants called alleles. **d.** If present, dominant alleles are expressed, whereas recessive alleles are expressed only in the absence of a dominant allele. **GEN 5.1.2 Most traits do not follow Mendelian inheritance patterns.** **a.** Some traits are determined by genes on sex chromosomes, and some are influenced by environmental factors. **b.** Most of our traits involve the interactions of multiple genes. **1.** Codominance occurs when both alleles of homologous chromosomes are fully expressed. **2.** Incomplete dominance occurs when neither of the alleles from a homologous chromosome pair are completely dominant.
Predicting Inheritance	
GEN 5.2(a) Create and/or use models to analyze the probability of the inheritance of traits. **GEN 5.2(b)** Predict the inheritance of traits that do not follow Mendelian patterns. **GEN 5.2(c)** Use a pedigree to predict the inheritance of a trait within a family.	**GEN 5.2.1 The inheritance of certain traits from parents to offspring can be predicted using models.** **a.** Rules of probability can be applied to make predictions about the passage of alleles from parent to offspring using mathematical models (Punnett squares). **b.** Pedigrees are useful tools for modeling inheritance patterns to examine and/or make predictions about inheritance of a specific trait from one generation to the next.

Content Boundary: Students will be expected to know non-Mendelian inheritance patterns, such as codominance and incomplete dominance. However, epistatic genes are beyond the scope of this course.

KEY CONCEPT GEN 6: BIOTECHNOLOGY

Learning Objectives *Students will be able to ...*	**Essential Knowledge** *Students need to know that ...*
GEN 6.1(a) Use data to examine inheritance and/or chromosomal disorders. **GEN 6.1(b)** Describe techniques used to manipulate DNA. **GEN 6.1(c)** Explain potential benefits and/or consequences of manipulating DNA of organisms.	**GEN 6.1.1 Biotechnology enables scientists to study and engineer heritable traits of organisms.** **a.** Karyotypes are used to examine inheritance and help identify and predict possible chromosomal genetic disorders. **b.** Diverse methods, including PCR, gel electrophoresis, and DNA profiling, are used to study organisms' DNA. **c.** Genetic engineering techniques (e.g., cloning, GMOs) can manipulate the heritable information of DNA, resulting in both positive and negative consequences.

Content Boundary: Students will not be assessed on a deep understanding of the molecular processes for manipulating DNA. Instead the focus should be on giving a high-level understanding of common processes that allow development of appropriate quantities of DNA to be studied and manipulated. Also, students should learn about exciting new advancements in this field.

Pre-AP Biology Model Lessons

Model lessons in Pre-AP Biology are developed in collaboration with biology educators across the country and are rooted in the course framework, shared principles, and areas of focus. Model lessons are carefully designed to illustrate on-grade-level instruction. Pre-AP strongly encourages teachers to internalize the lessons and then offer the supports, extensions, and adaptations necessary to help all students achieve the lesson goals.

The purpose of these model lessons is twofold:

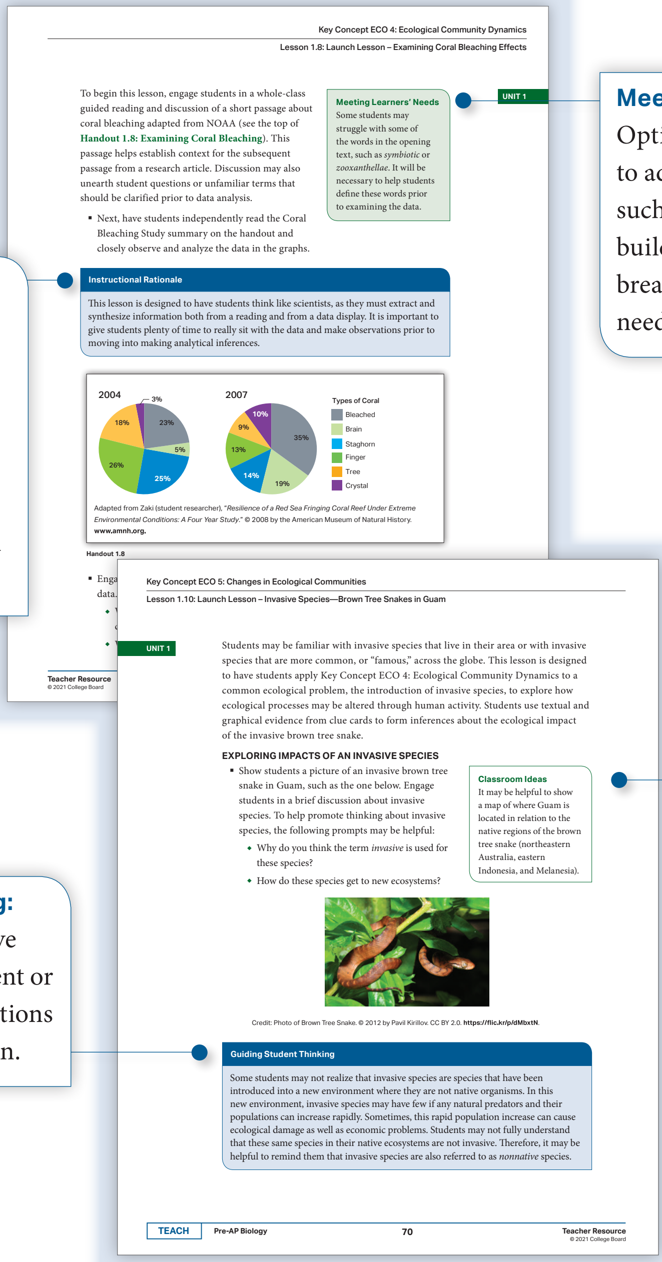
- **Robust instructional support for teachers:** Pre-AP Biology model lessons are comprehensive lesson plans that, along with accompanying student resources, embody the Pre-AP approach to teaching and learning. Model lessons provide clear and substantial instructional guidance to support teachers as they engage students in the shared principles and areas of focus.
- **Key instructional strategies:** Commentary and analysis embedded in each lesson highlight not just what students and teachers do in the lesson, but also how and why they do it. This educative approach provides a way for teachers to gain unique insight into key instructional moves that are powerfully aligned with the Pre-AP approach to teaching and learning. In this way, each model lesson works to support teachers in the moment of use with students in their classroom.

Teachers have the option to use any or all model lessons alongside their own locally developed instructional resources. Model lessons target content areas that tend to be challenging for teachers and students. While the lessons are distributed throughout all four units, they are concentrated more heavily in the beginning of the course to support teachers and students in establishing a strong foundation in the Pre-AP approach to teaching and learning.

SUPPORT FEATURES IN MODEL LESSONS

The following support features recur throughout the Pre-AP Biology lessons, to promote teacher understanding of the lesson design and provide direct-to-teacher strategies for adapting lessons to meet their students' needs:

- Instructional Rationale
- Guiding Student Thinking
- Meeting Learners' Needs
- Classroom Ideas



Key Concept ECO 4: Ecological Community Dynamics

Lesson 1.8: Launch Lesson – Examining Coral Bleaching Effects

UNIT 1

To begin this lesson, engage students in a whole-class guided reading and discussion of a short passage about coral bleaching adapted from NOAA (see the top of **Handout 1.8: Examining Coral Bleaching**). This passage helps establish context for the subsequent passage from a research article. Discussion may also unearth student questions or unfamiliar terms that should be clarified prior to data analysis.

- Next, have students independently read the Coral Bleaching Study summary on the handout and closely observe and analyze the data in the graphs.

Meeting Learners' Needs
Some students may struggle with some of the words in the opening text, such as *symbiotic* or *zooxanthellae*. It will be necessary to help students define these words prior to examining the data.

Instructional Rationale
This lesson is designed to have students think like scientists, as they must extract and synthesize information both from a reading and from a data display. It is important to give students plenty of time to really sit with the data and make observations prior to moving into making analytical inferences.

Adapted from Zaki (student researcher), "*Resilience of a Red Sea Fringing Coral Reef Under Extreme Environmental Conditions: A Four Year Study.*" © 2008 by the American Museum of Natural History. www.amnh.org.

Handout 1.8

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Key Concept ECO 5: Changes in Ecological Communities

Lesson 1.10: Launch Lesson – Invasive Species—Brown Tree Snakes in Guam

UNIT 1

Students may be familiar with invasive species that live in their area or with invasive species that are more common, or "famous," across the globe. This lesson is designed to have students apply Key Concept ECO 4: Ecological Community Dynamics to a common ecological problem, the introduction of invasive species, to explore how ecological processes may be altered through human activity. Students use textual and graphical evidence from clue cards to form inferences about the ecological impact of the invasive brown tree snake.

EXPLORING IMPACTS OF AN INVASIVE SPECIES

- Show students a picture of an invasive brown tree snake in Guam, such as the one below. Engage students in a brief discussion about invasive species. To help promote thinking about invasive species, the following prompts may be helpful:
  - Why do you think the term *invasive* is used for these species?
  - How do these species get to new ecosystems?

Classroom Ideas
It may be helpful to show a map of where Guam is located in relation to the native regions of the brown tree snake (northeastern Australia, eastern Indonesia, and Melanesia).

Credit: Photo of Brown Tree Snake. © 2012 by Pavil Kirillov. CC BY 2.0. https://flic.kr/p/dMbxtN.

Guiding Student Thinking
Some students may not realize that invasive species are species that have been introduced into a new environment where they are not native organisms. In this new environment, invasive species may have few if any natural predators and their populations can increase rapidly. Sometimes, this rapid population increase can cause ecological damage as well as economic problems. Students may not fully understand that these same species in their native ecosystems are not invasive. Therefore, it may be helpful to remind them that invasive species are also referred to as *nonnative* species.

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Meeting Learners' Needs: Optional differentiation strategies to address diverse learning needs, such as ideas for just-in-time skill building during a lesson or ways to break a task into smaller tasks, if needed, to make it more accessible.

Instructional Rationale: Insight into the strategic design and purpose of the instructional choices, flow, and scaffolding within the model lesson. Rationales often describe how a concept is continued later in the lesson or unit.

Classroom Ideas: Tips related to the logistics of the instruction, such as suggestions for alternative laboratory materials, or ways to alleviate pacing concerns.

Guiding Student Thinking: Ways to facilitate productive student thinking and prevent or address student misconceptions in critical areas of the lesson.

Pre-AP Biology Assessments for Learning

Pre-AP Biology assessments function as a component of the teaching and learning cycle. Progress is not measured by performance on any single assessment. Rather, Pre-AP Biology offers a place to practice, to grow, and to recognize that learning takes time. The assessments are updated and refreshed periodically.

LEARNING CHECKPOINTS

Based on the Pre-AP Biology Course Framework, the learning checkpoints require students to examine data, models, diagrams, and short texts—set in authentic contexts—in order to respond to a targeted set of questions that measure students' application of the key concepts and skills from the unit. All eight learning checkpoints are automatically scored, with results provided through feedback reports that contain explanations of all questions and answers as well as individual and class views for educators. Teachers also have access to assessment summaries on Pre-AP Classroom, which provide more insight into the question sets and targeted learning objectives for each assessment event.

The following tables provide a synopsis of key elements of the Pre-AP Biology learning checkpoints.

Format	Two learning checkpoints per unit Digitally administered with automated scoring and reporting Questions target both concepts and skills from the course framework
Time Allocated	Designed for one 45-minute class period per assessment
Number of Questions	11–14 questions per assessment ▪ 9–12 four-option multiple choice ▪ 2–5 technology-enhanced questions

Domains Assessed	
Learning Objectives	Learning objectives within each key concept in the course framework
Skills	Three skill categories aligned to the Pre-AP science areas of focus are assessed with regular frequency across all eight learning checkpoints: ▪ emphasis on analytical reading and writing ▪ strategic use of mathematics ▪ attention to modeling

Question Styles	Question sets consist of two to three questions that focus on a single stimulus or group of related stimuli, such as texts, graphs, or tables. Questions are set in authentic biological contexts. *Please see page 62 for a sample question set that illustrates the types of questions included in Pre-AP learning checkpoints and the Pre-AP final exam.*

PERFORMANCE TASKS

Each unit includes one performance-based assessment designed to evaluate the depth of student understanding of key concepts and skills that are not easily assessed in a multiple-choice format.

Performance tasks in the ecology and cellular systems units mirror the AP free-response question style. Students demonstrate their understanding of content by analyzing scientific texts, data, and models in order to develop analytical written responses to open-ended questions.

Performance tasks in the evolution and genetics units actively engage students in hands-on data analysis and modeling skills as they demonstrate their understanding of key concepts in those two units.

Both types of performance tasks give students an opportunity to closely observe and analyze real-world biological problems and apply the skills and concepts from across the course units.

These tasks, developed for students across a broad range of readiness levels, are accessible while still providing sufficient challenge and the opportunity to practice the analytical skills that will be required in AP science courses and for college and career readiness. Teachers participating in the official Pre-AP Program will receive access to online learning modules to support them in evaluating student work for each performance task.

Format	One performance task per unit Administered in print Educator-scored using scoring guidelines
Time Allocated	Approximately 45 minutes or as indicated
Number of Questions	An open-response task with multiple parts

Domains Assessed	
Key Concepts	Key concepts and prioritized learning objectives from the course framework
Skills	Three skill categories aligned to the Pre-AP science areas of focus: ▪ emphasis on analytical reading and writing ▪ strategic use of mathematics ▪ attention to modeling

PRACTICE PERFORMANCE TASKS

Practice performance tasks in each unit provide students with the opportunity to practice applying skills and knowledge in a context similar to a performance task, but in a more scaffolded environment. These tasks include strategies for adapting instruction based on student performance and ideas for modifying or extending tasks based on students' needs.

Performance Assessments At-a-Glance

Unit	Performance Assessment	Title	Teacher Access	Student Access
Unit 1 Ecological Systems	Practice Performance Task	Termites, Guardians of the Soil	Teacher Resources: Units 1 & 2	Student Resources: Unit 1
	Performance Task	Exploring Species Interactions in the Great Barrier Reef		Teacher-distributed handout
Unit 2 Evolution	Practice Performance Task	Tusklessness in African Elephants	Teacher Resources: Units 1 & 2	Student Resources: Unit 2
	Performance Task	The Flashy Guppy Data Analysis		Teacher-distributed handout

FINAL EXAM

Pre-AP Biology includes a final exam featuring multiple-choice and technology-enhanced questions as well as an open-response question. The final exam is a summative assessment designed to measure students' success in learning and applying the knowledge and skills articulated in the Pre-AP Biology Course Framework. The final exam's development follows best practices such as multiple levels of review by educators and experts in the field for content accuracy, fairness, and sensitivity. The questions on the final exam have been pretested, and the resulting data are collected and analyzed to ensure that the final exam is fair and represents an appropriate range of the knowledge and skills of the course.

The final exam is designed to be delivered on a secure digital platform in a classroom setting. Educators have the option of administering the final exam in a single extended session or two shorter consecutive sessions to accommodate a range of final exam schedules.

Multiple-choice and technology-enhanced questions are delivered digitally and scored automatically with detailed score reports available to educators. This portion of the final exam is designed to build on the question styles and formats of the learning checkpoints; thus, in addition to their formative purpose, the learning checkpoints provide practice and familiarity with the final exam. The open-response question, modeled after the performance tasks, is delivered as part of the digital final exam but is designed to be scored separately by educators using scoring guidelines that are designed and vetted with the question.

The following tables provide a synopsis of key elements of the Pre-AP Biology Final Exam.

Format	Digitally administered Questions target both concepts and skills from the course framework A scientific calculator feature is enabled on the platform, but its use is not required.
Time Allocated	One 105-minute session or two sessions of 60 minutes and 45 minutes
Number of Questions	30–35 questions ▪ four-option multiple-choice questions ▪ technology-enhanced questions ▪ one multipart open-response question

Scoring	▪ automatic scoring for multiple-choice and technology-enhanced questions ▪ educator scoring for open-response question ▪ comprehensive score reports with individual student and class views for educators

Domains Assessed	
Content	Key concepts and prioritized learning objectives from the course framework
Skills	Three skill categories aligned to the Pre-AP science areas of focus: ▪ emphasis on analytical reading and writing ▪ strategic use of mathematics ▪ attention to modeling

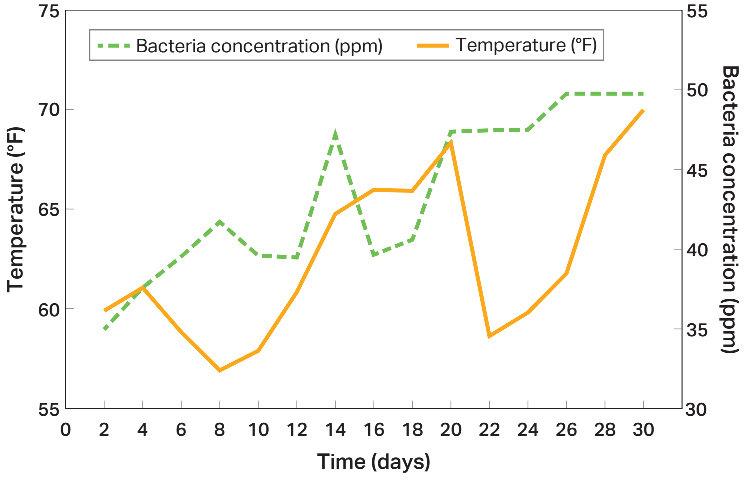
Question Styles	Question sets consist of two to three questions that focus on a single stimulus or group of related stimuli, such as texts, graphs, or tables. Questions are set in authentic biological contexts. *Please see page 62 for a sample question set that illustrates the types of questions included in Pre-AP learning checkpoints and the Pre-AP final exam.*

SAMPLE ASSESSMENT QUESTIONS

The following questions are representative of what students and educators will encounter on the learning checkpoints and final exam.

ANALYZING SCIENTIFIC DATA

Clostridium perfringens is a species of heterotrophic bacteria that is commonly found consuming decaying organic matter in the sediments of freshwater lakes. An investigation was conducted into the effect of temperature on growth of *C. perfringens.* Researchers recorded the temperature of a 1-liter sample of lake water and the concentration of bacteria in the water over a 30-day period. The data are represented in the graph.



Examination of 1-liter samples of lake water over a 30-day period

1. Which of the following statements best describes the relationship between temperature and growth of the bacterial population?
   (A) Temperature has a direct effect on the growth of the bacterial population since both the temperature and bacteria concentration are highest at day 30.
   (B) Temperature has a negative effect on the growth of the bacterial population since there are instances when temperature increases and bacteria concentration decreases.
   (C) Temperature is a limiting resource for the growth of the bacterial population since the bacterial concentration line is nearly always above the temperature line.
   (D) Resources other than temperature can limit the growth of the bacterial population since there is not a direct correlation between water temperature and bacteria concentration.

Assessment Focus

Question 1 requires students to extract relevant information from a text, analyze data, and use quantitative reasoning to construct an argument about the relationship between an abiotic resource, light, and the growth of a population.

Correct Answer: D

Learning Objective:

ECO 2.2(b) Explain the relationship between resource availability and a population's growth pattern.

Area of Focus: Strategic Use of Mathematics

2. The biologists are interested in analyzing other environmental conditions that may regulate the growth of the bacterial population. Which of the following is the LEAST likely to affect the population growth of the bacteria in the lake?

(A) Amount of sunlight reaching the lake bottom

(B) Dissolved oxygen level in the lake

(C) Amount of decaying organic matter in the sediments

(D) pH of the lake water

Assessment Focus

Question 2 extends student thinking from the first question as it asks students to demonstrate their understanding of the abiotic and biotic niche requirements for heterotrophic organisms that may be responsible for the trends in data.

Correct Answer: A

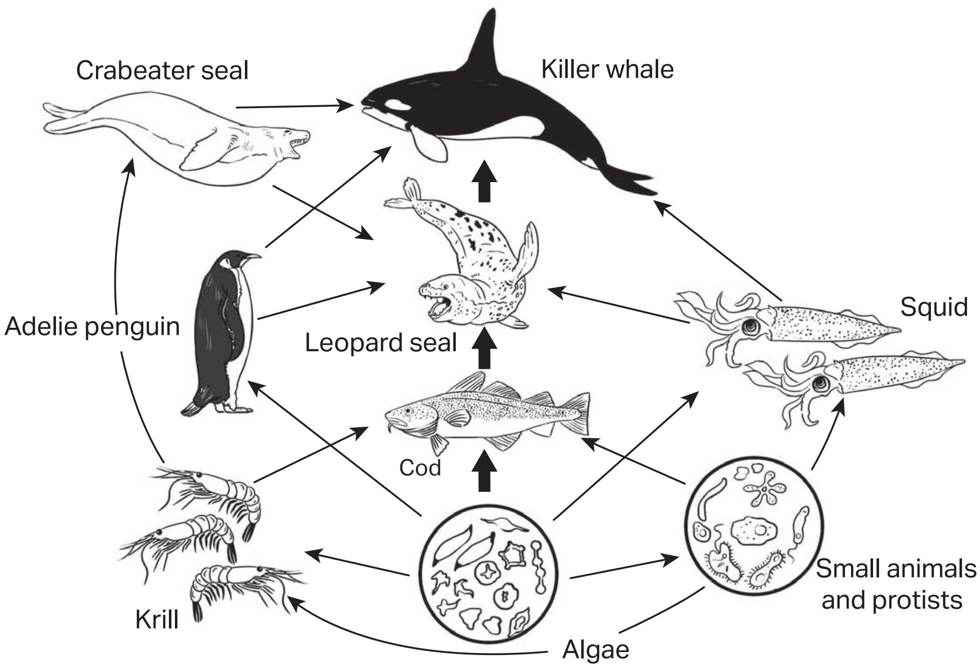
Learning Objective:

ECO 2.2(a) Use data to explain the growth of a population.

Area of Focus: Emphasis on Analytical Reading and Writing

USING A MODEL

The diagram represents a model of a typical food web from coastal waters in cool temperate and subpolar seas, such as those around Antarctica. Use the model to answer the following question.



3. If cod were overfished in this Antarctic region and were not an available food source, which of the following changes in the community is most likely to occur as a result?
   (A) The squid population will increase because there is reduced competition for food.
   (B) The killer whale population will increase because there are more leopard seals.
   (C) The crabeater seal population will decrease because there is a decrease in the krill population.
   (D) The squid population will decrease because there is a decrease in the algae population.

Assessment Focus

Question 3 assesses students' ability to use a model to make predictions about how the flow of energy through this food web would change if organisms are depleted. Students must also apply their understanding of ecological roles (e.g., primary consumers) and community dynamics (e.g., competition for food) at each trophic level in order to make this prediction.

Correct Answer: A

Learning Objectives:

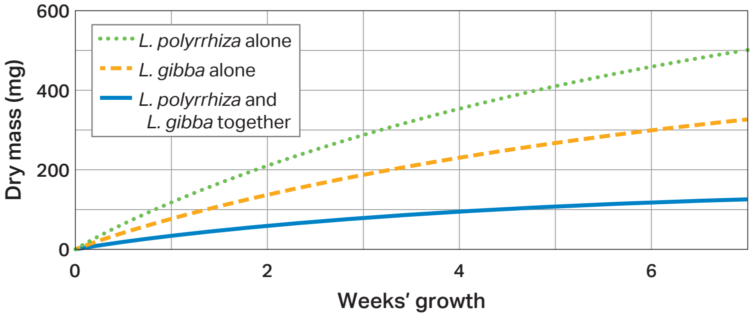
ECO 2.3(a) Create and/or use models to explain the transfer of energy through the food web of a community.

ECO 2.3(c) Make predictions about the energy distribution in an ecosystem based on the energy available to organisms.

Area of Focus: Attention to Modeling

DATA ANALYSIS

Duckweeds are small aquatic plants that live in freshwater ponds and streams throughout North America. Scientists conducted an experiment to determine how two different species of duckweed, *Lemna polyrrhiza* and *Lemna gibba,* affect each other's growth. They set up three containers: one with only *Lemna polyrrhiza,* one with only *Lemna gibba,* and one with both species together. The graph shows the results of all three experimental trials.



4. Which of the following claims is most consistent with the results of the experiment?

(A) The niches of the two organisms do not overlap; therefore, even when grown together, they are both able to continue to grow at their maximum growth rate.

(B) There is interspecific competition between the two species; therefore, the growth of the *L. polyrrhiza* population is stimulated.

(C) The niches of both organisms likely overlap; therefore, when they are grown together, interspecific competition reduces the growth of both populations.

(D) *L. polyrrhiza* has a wider niche than *L. gibba*; therefore, *L. polyrrhiza* experiences a greater population growth even when the species are grown together.

Assessment Focus

Question 4 assesses students' ability to use quantitative reasoning as they analyze data from a graph. In order to select the appropriate claim based on the data, they must apply their understanding of interspecific versus intraspecific competition and niche.

Correct Answer: C

Learning Objectives:

ECO 2.2(c) Explain how competition for resources shapes populations.

ECO 2.3(b) Analyze data about species distributions to make predictions about the availability of resources.

Area of Focus: Strategic Use of Mathematics

Pre-AP Biology Course Designation

Schools can earn an official Pre-AP Biology course designation by meeting the requirements summarized below. Pre-AP Course Audit Administrators and teachers will complete a Pre-AP Course Audit process to attest to these requirements. All schools offering courses that have received a Pre-AP Course Designation will be listed in the Pre-AP Course Ledger, in a process similar to that used for listing authorized AP courses.

PROGRAM REQUIREMENTS

- The school ensures that Pre-AP frameworks and assessments serve as the foundation for all sections of the course at the school. This means that the school must not establish any barriers (e.g., test scores, grades in prior coursework, teacher or counselor recommendation) to student access and participation in Pre-AP Biology coursework.
- Teachers have read the most recent *Pre-AP Biology Course Guide*.
- Teachers administer each performance task and at least one of two learning checkpoints per unit.
- Teachers and at least one administrator per site complete a Pre-AP Summer Institute or the Online Foundational Module Series. Teachers complete at least one Online Performance Task Scoring Module.
- Teachers align instruction to the Pre-AP Biology Course Framework and ensure their course meets the curricular requirements summarized below.
- The school ensures that the resource requirements summarized below are met.

CURRICULAR REQUIREMENTS

- The course provides opportunities for students to develop understanding of the Pre-AP Biology key concepts and skills articulated in the course framework through the four units of study.
- The course provides opportunities for students to engage in the Pre-AP shared instructional principles.
  - close observation and analysis
  - evidence-based writing
  - higher-order questioning
  - academic conversation

- The course provides opportunities for students to engage in the three Pre-AP science areas of focus. The areas of focus are:
  - emphasis on analytical reading and writing
  - strategic use of mathematics
  - attention to modeling
- The instructional plan for the course includes opportunities for students to continue to practice and develop disciplinary skills.
- The instructional plan reflects time and instructional methods for engaging students in reflection and feedback based on their progress.
- The instructional plan reflects making responsive adjustments to instruction based on student performance.

RESOURCE REQUIREMENTS

- The school ensures that participating teachers and students are provided computer and internet access for completion of course and assessment requirements.
- Teachers should have consistent access to a video projector for sharing web-based instructional content and short web videos.
- The school ensures teachers have access to laboratory equipment and consumable resources so that students can engage in the Pre-AP Biology inquiry-based model lessons.

Accessing the Digital Materials

Pre-AP Classroom is the online application through which teachers and students can access Pre-AP instructional resources and assessments. The digital platform is similar to AP Classroom, the online system used for AP courses.

Pre-AP coordinators receive access to Pre-AP Classroom via an access code delivered after orders are processed. Teachers receive access after the Pre-AP Course Audit process has been completed.

Once teachers have created course sections, student can enroll in them via access code. When both teachers and students have access, teachers can share instructional resources with students, assign and score assessments, and complete online learning modules; students can view resources shared by the teacher, take assessments, and receive feedback reports to understand progress and growth.

Unit 1

Unit 1
Ecological Systems

Overview

SUGGESTED TIMING: APPROXIMATELY 5 WEEKS

In this unit, students deepen and expand prior knowledge, gained in a middle school life science course, of how the cycling of matter and flow of energy regulate ecosystems. Students also apply proportional reasoning skills to examine data, especially bivariate data, in order to analyze and make scientific claims about patterns, relationships, and changes in the structure and distribution of ecological populations and communities. This unit provides students an opportunity to build on and deepen their understanding of the living and nonliving components that regulate the structure and function of ecological systems. Students should begin to gain an appreciation for the intricate and often fragile interdependent relationships that ecological communities rely on. Students also explore how communities change over time, both through naturally occurring processes and through human activities.

ENDURING UNDERSTANDINGS

This unit focuses on the following enduring understandings:

- Biological systems depend on the cycling of matter within and between Earth's systems.
- Most ecosystems rely on the conversion of solar energy into chemical energy for use in biological processes.
- The dependence on the availability of abiotic and biotic resources results in complex and dynamic interactions between organisms and populations.
- Changes to the environment can alter interactions between organisms.

KEY CONCEPTS

This unit addresses the following key concepts:

UNIT 1

- ECO 1: Cycling of Matter in the Biosphere
- ECO 2: Population Dynamics
- ECO 3: Defining Ecological Communities
- ECO 4: Ecological Community Dynamics
- ECO 5: Changes in Ecological Communities

UNIT RESOURCES

The tables below outline the resources provided by Pre-AP for this unit.

Lessons for Key Concept ECO 1: Cycling of Matter in the Biosphere				
Lesson Title	**Learning Objectives Addressed**	**Essential Knowledge Addressed**	**Suggested Timing**	**Areas of Focus**
1.1: Launch Lesson – Important Elements in Organisms			Less than 45 minutes	Emphasis on Analytical Reading and Writing, Strategic Use of Mathematics
1.2: Modeling the Water and Carbon Cycles	ECO 1.1(a), ECO 1.1(b), ECO 1.2(a), ECO 1.2(b)	ECO 1.1.1a, ECO 1.1.1b, ECO 1.1.1c, ECO 1.1.1d, ECO 1.2.1a	~90 minutes	Attention to Modeling
1.3: Analyzing Nitrogen Fertilizer Use on U.S. Corn Crops	ECO 1.2(c), ECO 1.2(d)	ECO 1.2.1b, ECO 1.2.1c	Less than 45 minutes	Strategic Use of Mathematics
1.4: Exploring and Modeling the Nitrogen Cycle	ECO 1.2(c), ECO 1.2(d)	ECO 1.2.1b, ECO 1.2.1c	~90 minutes	Emphasis on Analytical Reading and Writing, Attention to Modeling
All learning objectives and essential knowledge statements for this key concept are addressed with the provided materials.				

Practice Performance Task for Unit 1 (~45 minutes)
This practice performance task draws on learning objectives and essential knowledge statements addressed throughout Key Concept ECO 1: Cycling of Matter in the Biosphere.

Lessons for Key Concept ECO 2: Population Dynamics

Lesson Title	Learning Objectives Addressed	Essential Knowledge Addressed	Suggested Timing	Areas of Focus
1.5: Launch Lesson – Modeling Yellowstone's Food Web	ECO 2.3(a), ECO 2.3(c)	ECO 2.3.1a, ECO 2.3.1b, ECO 2.3.1c	~45–60 minutes	Attention to Modeling
1.6: Population Field Studies Simulations Lab – Quadrat and Mark–Recapture Sampling	ECO 2.1(b)	ECO 2.1.1a, ECO 2.1.1b, ECO 2.1.1c, ECO 2.1.1d	~135 minutes	Strategic Use of Mathematics

The following Key Concept ECO 2 learning objectives and essential knowledge statements are not addressed in Pre-AP lessons. Address these in teacher-developed materials.

- Learning Objectives: ECO 2.1(a), ECO 2.1(c), ECO 2.2(a), ECO 2.2(b), ECO 2.2(c), ECO 2.3(b)
- Essential Knowledge Statements: ECO 2.2.1a, ECO 2.2.1b, ECO 2.2.1c, ECO 2.2.1d, ECO 2.2.2a, ECO 2.2.2b

Learning Checkpoint 1: Key Concepts ECO 1 and ECO 2 (~45 minutes)
This learning checkpoint assesses learning objectives and essential knowledge statements from Key Concepts ECO 1 and ECO 2. For sample items and learning checkpoint details, visit Pre-AP Classroom.

Lessons for Key Concept ECO 3: Defining Ecological Communities				
Lesson Title	**Learning Objectives Addressed**	**Essential Knowledge Addressed**	**Suggested Timing**	**Areas of Focus**
1.7: Launch Lesson – Comparing Biomes Using HHMI's BiomeViewer	ECO 3.2(a)	ECO 3.2.1a, ECO 3.2.1b	Less than 45 minutes	Emphasis on Analytical Reading and Writing

The following Key Concept ECO 3 learning objectives and essential knowledge statements are not addressed in Pre-AP lessons. Address these in teacher-developed materials.

- Learning Objectives: ECO 3.1(a), ECO 3.1(b), ECO 3.2(b)
- Essential Knowledge Statements: ECO 3.1.1a, ECO 3.1.1b, ECO 3.1.1c, ECO 3.2.2a, ECO 3.2.2b, ECO 3.2.2c

Lessons for Key Concept ECO 4: Ecological Community Dynamics				
Lesson Title	**Learning Objectives Addressed**	**Essential Knowledge Addressed**	**Suggested Timing**	**Areas of Focus**
1.8: Launch Lesson – Examining Coral Bleaching Effects	ECO 4.2(a), ECO 4.2(b)	ECO 4.2.1a	Less than 45 minutes	Strategic Use of Mathematics
1.9: Modeling the Importance of Keystone Species	ECO 4.1(c)	ECO 4.1.1a, ECO 4.1.1b	~90 minutes	Attention to Modeling, Emphasis on Analytical Reading and Writing

The following Key Concept ECO 4 learning objectives and essential knowledge statements are not addressed in Pre-AP lessons. Address these in teacher-developed materials.

- Learning Objectives: ECO 4.1(a), ECO 4.1(b)
- Essential Knowledge Statements: ECO 4.1.1c, ECO 4.1.1d, ECO 4.2.1b, ECO 4.1.1c

Lessons for Key Concept ECO 5: Changes In Ecological Communities

Lesson Title	Learning Objectives Addressed	Essential Knowledge Addressed	Suggested Timing	Areas of Focus
1.10: Launch Lesson – Invasive Species—Brown Tree Snakes in Guam	ECO 5.2(a), ECO 5.2(b)	ECO 5.2.1a, ECO 5.2.1b	Less than 60 minutes	Emphasis on Analytical Reading and Writing, Strategic Use of Mathematics
1.11: Predicting Changes in Arctic Ecological Communities	ECO 5.2(a), ECO 5.2(b)	ECO 5.2.1a, ECO 5.2.1b	~60 minutes	Emphasis on Analytical Reading and Writing, Strategic Use of Mathematics
1.12: Understanding Beavers as Ecosystem Engineers	ECO 5.1(a), ECO 5.1(c)	ECO 5.1.1d	~60 minutes	Emphasis on Analytical Reading and Writing

The following Key Concept ECO 5 learning objectives and essential knowledge statements are not addressed in Pre-AP lessons. Address these in teacher-developed materials.

- Learning Objectives: ECO 5.1(b), ECO 5.2(c)
- Essential Knowledge Statements: ECO 5.1.1a, ECO 5.1.1b, ECO 5.1.1c

Learning Checkpoint 2: Key Concepts ECO 3–ECO 5 (~45 minutes)

This learning checkpoint assesses learning objectives and essential knowledge statements from Key Concepts ECO 3 through ECO 5. For sample items and learning checkpoint details, visit Pre-AP Classroom.

Performance Task for Unit 1 (~45 minutes)

This performance task assesses learning objectives and essential knowledge statements from the entire unit.

LESSON 1.1

UNIT 1

Launch Lesson – Important Elements in Organisms

OVERVIEW

LESSON DESCRIPTION

Students make predictions about the six most common elements in the human body. They then provide some scientific reasoning for their predictions.

AREAS OF FOCUS

- Emphasis on Analytical Reading and Writing
- Strategic Use of Mathematics

SUGGESTED TIMING

Less than 45 minutes

HANDOUT

- 1.1: Important Elements in Organisms

CONTENT FOCUS

This lesson focuses on the four classes of macromolecules and the common elements that make up those compounds, which students have had experience with in middle school life science. Although most students will not have learned the chemical structure of these macromolecules, they should have a solid understanding of the importance of the most common elements in living systems: oxygen, carbon, hydrogen, nitrogen, calcium, and phosphorus—the elements that make up the largest percentage of an organism's body weight. This lesson also primes student thinking in preparation for modeling biogeochemical cycles later in this unit.

COURSE FRAMEWORK CONNECTIONS

This first launch lesson connects to prior knowledge students gained in middle school life science about the importance of oxygen, carbon, hydrogen, nitrogen, calcium, and phosphorus in the development of macromolecules.

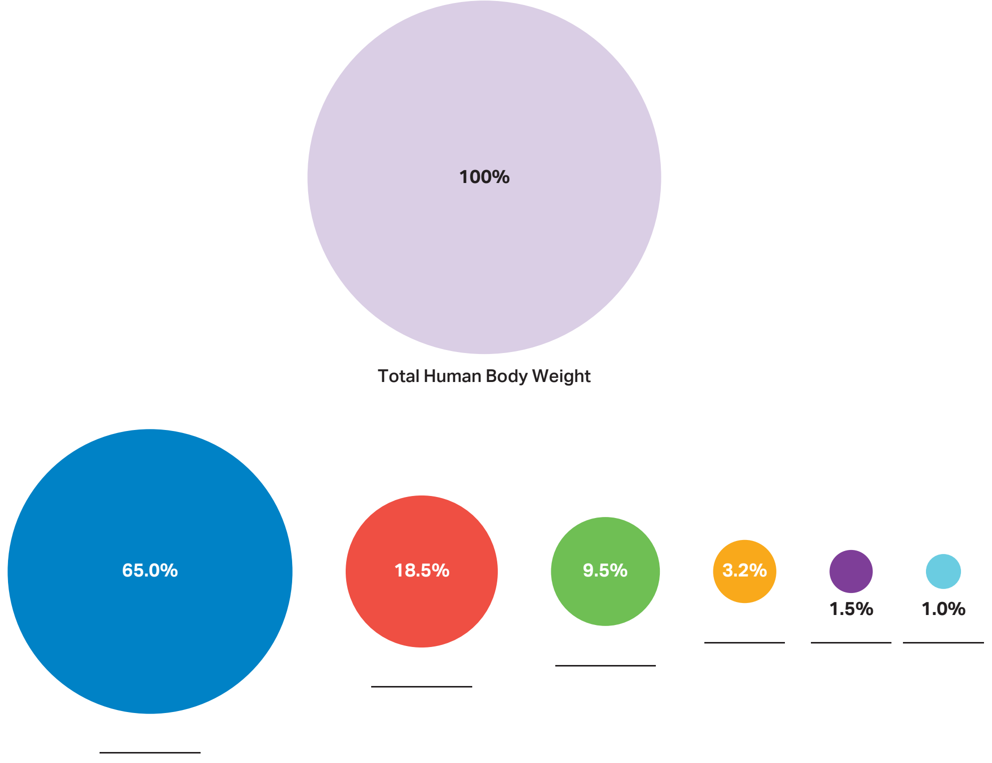
PREDICTING OUR MOST COMMON ELEMENTS

Before introducing lessons that demonstrate biogeochemical cycles such as the water, carbon, and nitrogen cycles, students should be motivated to explore *why* the cycling of matter is important for organisms. One way to spark inquiry is to have students make predictions about the most common elements found in their own bodies. This is also a great way to elicit prior knowledge about the importance of water, energy production (cellular respiration), and the stucture and function of human body systems. Students have likely already learned about these in middle school life science.

- To begin this lesson, have students look at the diagram on **Handout 1.1: Important Elements in Organisms**. Based on their prior knowledge, they will fill in the diagram with their predictions about the six most commonly occurring elements in the human body. The diagram and correct responses are shown below. (Do not reveal the correct answers to students until the end of the lesson.)

Meeting Learners' Needs

If students are struggling to think of evidence for their choices, suggest they think about a few things their body relies on, such as breathing or eating, to spark some ideas.



The top circle represents total human body weight. The circles in the bottom row represent the six most abundant elements in the human body.

Handout 1.1

- Next, as directed by the handout, students will provide scientific reasoning for their predictions. The following prompts may be helpful in getting students started reasoning like a scientist.
  - What type of molecules or compounds do you think your body relies on to function properly? What about for structural support?
  - Recall how the food you eat provides you with energy. What elements do you think that food is made of?
- Students should work with a partner or in a small group to share their answers to the first two questions on the handout. Encourage students to make revisions to their original predictions if a peer's reasoning is persuasive enough to warrant changes.
- Once students have discussed their answers in pairs or small groups, bring them back together for a whole-class discussion. Have students share their predictions about the six most commonly occurring elements in their bodies and note the reasoning they used to support their predictions. They may also note whether they made any modifications to their original predictions based on a peer's predictions and associated reasoning. During the discussion, generate a class list of predictions and reasoning for the six most common elements in the human body.
- At the end of the discussion, reveal to the class the correct answers.

  The six most abundant elements in the human body, in order from most to least abundant, are oxygen, carbon, hydrogen, nitrogen, calcium, and phosphorus.
- Finally, ask students to note which of their predictions were incorrect. Invite them to suggest revisions to their scientific reasoning to better support the correct answers.

Guiding Student Thinking

Student responses will likely identify respiration (use of O_2) and the presence of water as reasons to include **oxygen** and **hydrogen** in the list of the six most prevalent elements. Students may not immediately think of calcium as one of the six. To prompt this thinking, ask students what might be the building block for bones in our skeletal system. At this point it is okay for students to simply state that "all living things are made up of **carbon**" without being able to explain why. However, this is a good place to prompt students to think about how carbon serves as the backbone to the building blocks of life (macromolecules such as carbohydrates, proteins, lipids, etc.). Students should have at least been introduced to those molecules in middle school life science. They likely will not know how **nitrogen** and **phosphorus** contribute to their bodies, but this will be the focus of the next few lessons.

UNIT 1

LESSON 1.2

Modeling the Water and Carbon Cycles

OVERVIEW

LESSON DESCRIPTION

Part 1: The Importance of Water and Carbon
Students respond to a prompt and answer questions to elicit their prior knowledge from middle school about the importance of water and carbon in living systems.

Part 2: Modeling the Water and Carbon Cycles
Students utilize cycling cards to develop one model that illustrates the movement of water and carbon through the ecosystem. They focus on the beginning and ending forms of water and carbon for each main process in the cycles.

Part 3: Evaluating Models
Pairs of students swap models and evaluate the other pair's work. Students then participate in a whole-class discussion about the relationship between the carbon and water cycles.

AREA OF FOCUS

- Attention to Modeling

SUGGESTED TIMING

~90 minutes

HANDOUTS

- 1.2.A: Modeling the Water and Carbon Cycles
- 1.2.B: Water and Carbon Cycling Cards, with cards cut out

MATERIALS

- materials for creating a model, such as the following:
  - poster paper and markers
  - neon markers for lab tables
  - computer (laptop, tablet, etc.)

CONTENT FOCUS

This lesson elicits students' prior knowledge about the cycling of water and carbon through the ecosystem. Students focus on tracing oxygen through the ecosystem to build models of these cycles. This lesson also aims to deepen student understanding by focusing on the physical and chemical transformations that occur throughout these important biogeochemical cycles. Therefore, students identify the beginning and ending forms of water and carbon compounds as they move through the various processes in each cycles.

Students should understand why phosphorus is a crucial element in many important biomolecules (e.g., ATP, DNA), but the understanding of this cycle is covered in AP Biology. Also, students should be able to model the nitrogen cycle from a general standpoint of how biotic and abiotic components interact and depend on one another. However, an understanding of chemical conversions during this cycle is *beyond the scope* of this course.

COURSE FRAMEWORK CONNECTIONS

Enduring Understandings	
▪ Biological systems depend on the cycling of matter within and between Earth's systems. ▪ Most ecosystems rely on the conversion of solar energy into chemical energy for use in biological processes.	
Learning Objectives	**Essential Knowledge**
ECO 1.1(a) Explain how the unique properties and phase changes of water enable and regulate biological reactions and/or processes. **ECO 1.1(b)** Create and/or use a model to explain how biological systems function in the hydrologic cycle as water is transferred, transported, and/or stored.	**ECO 1.1.1** Water cycles between abiotic and biotic systems in a process known as the hydrologic cycle. **a.** The polar nature of water results in properties on which biological systems depend, such as dissolving organic and inorganic nutrients. **b.** The hydrologic cycle is driven by energy from the sun and gravity. **c.** The largest reservoir of water in the global hydrologic cycle is the world's oceans. **d.** A small portion of the water on Earth is fresh water, which is required for life by all terrestrial organisms, including humans.
ECO 1.2(a) Explain the importance of the cycling of carbon for biological systems. **ECO 1.2(b)** Create and/or use models to illustrate how organisms' capture and use of energy plays a role in the cycling of carbon in ecosystems.	**ECO 1.2.1** Elements that are building blocks of macromolecules are transported from abiotic to biotic systems through gaseous and sedimentary cycles. **a.** The carbon cycle is a series of molecular transformations that includes photosynthesis and cellular respiration.

UNIT 1

PART 1: THE IMPORTANCE OF WATER AND CARBON

Most middle school life and earth science courses require students to gain a basic understanding of both the water and carbon cycles. Therefore, certain facets of modeling these two cycles may be familiar to students. However, this lesson is designed to deepen and extend student understanding of these cycles by focusing on the physical and chemical transformations that occur as matter cycles through various ecosystem components, such as the atmosphere, ocean, and plants and animals.

The first part of this lesson is intended to elicit students' prior knowledge about the importance of water and carbon in living systems. See Part 1 of **Handout 1.2.A: Modeling the Water and Carbon Cycles**.

- Allow students time to carefully read the first paragraph of the handout, about the abundance of oxygen in the human body. Also have students examine the bar graph, which gives the percentage of total body weight by element. Then, as a whole class, have students share their prior knowledge by responding to the following prompt: *What important roles does water play in living systems?* Record students' responses on the board for the class to see.

  Student responses should address topics such as temperature regulation, photosynthesis, waste disposal in living systems, metabolism, and habitat. Prompt students to consider these topics as needed.

- Next, students explore the importance of carbon as the backbone of life's major macromolecules. They can work individually or in pairs as they read the second paragraph and table on the handout, and answer the Check Your Understanding questions.

Meeting Learners' Needs

Some of the information in the bar graph will be familiar to students from the launch lesson. For students who could use additional practice extracting information from a graph, you may want to discuss with them the pros and cons of these different ways of representing the information shown in the two lessons. Have students compare and contrast different types of data displays (e.g., bar graphs, line graphs, pie charts) and identify why the data displays used were appropriate. This is an important "just-in-time" refresher on the purpose of different type of graphs.

Guiding Student Thinking

While students may remember that carbon serves as the backbone to carbohydrates and proteins, which make up many of the foods they eat, they may not specifically recall the term *macromolecule*. Introduce this term in connection with the most common elements and the cycling of matter in ecosystems. Then, when the biochemistry of macromolecules is addressed in Unit 3: Cellular Systems, students will already have an understanding of how these elements are acquired by organisms as they cycle through the ecosystem.

PART 2: MODELING THE WATER AND CARBON CYCLES

Now that students have revisited the importance of water and carbon in the biosphere, it is time for them to explore how these substances cycle through ecosystems. Students work with a partner to create a single model that includes both the water and carbon cycles. See Part 2 of Handout 1.2.A and **Handout 1.2.B: Water and Carbon Cycling Cards**.

This part of the lesson has students connect their prior knowledge of the water and carbon cycles with a new understanding of how elements change chemical composition during these cycles. The focus here is on the beginning and ending forms of each molecule or compound as it undergoes various processes in each cycle.

Classroom Ideas

There are many tools/materials that students can use to create their models. A few include:

- Markers on a large poster paper
- Neon markers on dark lab tables
- Piktocharts (**http://piktochart.com**) or SageModeler (**http://concord.org/our-work/research-projects/building-models**) on a computer or tablet

- Prior to and during this part of the lesson, support students in understanding the following aspects of the task:
  - *Getting started*. Students should work with a partner to create the model. Indicate to students the materials you want them to use. Students should also have a set of cut-out Water and Carbon Cycling cards, in no particular order.
  - *Using the cards*. To develop the model, students will choose one card at a time. For each card chosen, students should add and revise their model accordingly. On the cards, carbon cycle processes are denoted by a diamond icon; water cycle processes are denoted by a water drop icon.

- *Following oxygen*. Since oxygen is the most common element, the model will follow the transformations of an oxygen atom.
- *Thinking creatively*. Emphasize to students that they will be developing and revising a concept/process model that shows both the water and carbon cycles. The modeling process will require creativity as students decide the best way to visually represent their ideas. They will also need to provide appropriate connections and explanations for those connections.

Meeting Learners' Needs

You may choose to scaffold this part of the lesson further by having students do the water cycle cards first. After reviewing student models and providing feedback, allow them to move on to the rest of the cards to complete the entire model, including carbon.

- Once student pairs have completed their model, they have the opportunity to test it out. Students should use the model, along with the cycling cards, to complete the Transformations and Processes table on the handout.
- As students work on the table, circulate around the room and provide support as needed. For your reference, the completed table is provided on the next page, with student responses in blue.

Instructional Rationale

Commonly, the concept of biogeochemical cycling, like carbon, is taught by simply having students fill in vocabulary words on a model of the cycle that is mostly developed for them. This type of memorization activity does not help students fully understand all the processes of the cycle and how they are connected. Having students construct, critique, and revise their own models allows them to develop a much deeper understanding of these concepts.

TRANSFORMATIONS AND PROCESSES IN THE WATER AND CARBON CYCLES

Cycles	Beginning Form(s)	Process	Ending Form(s)
Water	Liquid	Transpiration	Vapor (gas)
Water	Liquid	Evaporation	Vapor (gas)
Water	Liquid (rain) or solid (ice)	Surface runoff	Liquid with nutrients (N + P)
Water	Liquid (rain) or solid (ice)	Infiltration	Liquid
Water	Vapor	Condensation	Liquid (water drops) or solid (ice)
Water + Carbon	Liquid (rain) or solid (ice) + CO_2	Precipitation	H_2O liquid (rain) + carbonic acid (H_2CO_3)
Carbon + Water	$C_6H_{12}O_6 + O_2$	Respiration	$CO_2 + H_2O$
Carbon + Water	$CO_2 + H_2O$	Photosynthesis	$C_6H_{12}O_6 + O_2$
Carbon	Organic matter	Deposition	Fossils, fossil fuels
Carbon	$C_6H_{12}O_6$	Assimilation	Macromolecules
Carbon	$CaCO_3$	Sedimentation	Limestone
Carbon	Fossil fuels + organic matter	Combustion	CO_2

Handout 1.2.A

PART 3: EVALUATING MODELS

The final part of the lesson engages students in assessing and reflecting on their understanding of these two important cycles. Students evaluate each other's models using the Transformations and Processes table they completed in the handout, and engage in peer-to-peer critique in order to review and revise their models.

- Have each student pair exchange models with another pair and review the other pair's model.
- Students should use their Transformations and Processes table to guide feedback and suggested revisions to the other pair's model.
- The pairs should then work together to share feedback, examine both models, and make final revisions to their models and tables.

Instructional Rationale

As with all modeling lessons, the key to deeper understanding for students is in the process of evaluating other students' models and in revising their own models based on those. This process also makes student thinking visible in order to provide more actionable feedback as they make revisions.

- Finally, bring everyone together for a whole-class discussion. Have students share their solutions to the table and discuss how their models changed over the design process. Some guiding prompts for class discussion could be:
  - How are the water and carbon cycles connected to one another?
  - Describe how organisms directly acquire oxygen, hydrogen, and carbon.
  - How does the cycling of water and carbon support an organism's ability to make macromolecules?
  - In what ways do humans alter the carbon cycle? What about the water cycle?

LESSON 1.3

Analyzing Nitrogen Fertilizer Use on U.S. Corn Crops

OVERVIEW

LESSON DESCRIPTION

Students examine a graph from the USDA (United States Department of Agriculture) showing total macronutrient inputs and nitrogen inputs in comparison to corn yields.

CONTENT FOCUS

Nitrogen is a limiting factor in many ecosystems due to the major role it plays in supporting plant growth. This lesson highlights how nutrients such as nitrogen help regulate biological systems, and also starts to promote an understanding of how nitrogen can cycle between living systems. This is a necessary understanding in future activities involving the nitrogen cycle.

AREA OF FOCUS

- Strategic Use of Mathematics

SUGGESTED TIMING

Less than 45 minutes

HANDOUT

- 1.3: Analyzing Nitrogen Fertilizer Use on United States Corn Crops

MATERIALS

- calculators (optional)

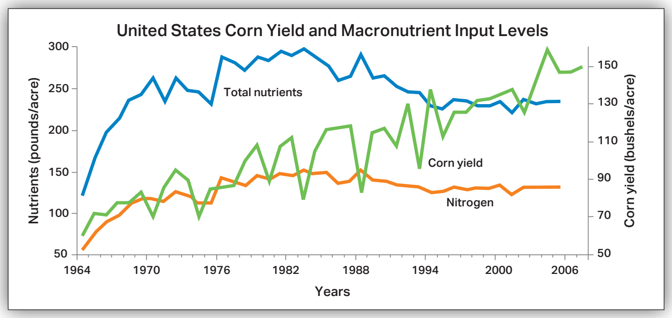
COURSE FRAMEWORK CONNECTIONS

Enduring Understandings	
▪ Biological systems depend on the cycling of matter within and between Earth's systems. ▪ The dependence on the availability of abiotic and biotic resources results in complex and dynamic interactions between organisms and populations.	
Learning Objectives	**Essential Knowledge**
ECO 1.2(c) Explain the importance of the cycling of nutrients for biological systems. **ECO 1.2(d)** Create and/or use models to describe the cycling of nitrogen between biotic and abiotic systems.	**ECO 1.2.1** Elements that are building blocks of macromolecules are transported from abiotic to biotic systems through gaseous and sedimentary cycles. **b.** The nitrogen cycle is a series of transformations that includes the conversion of nitrogen gas (the largest reservoir of nitrogen on Earth) into biologically available nitrogen-containing molecules (e.g., nitrates). **c.** Phosphorus is a critical element for organisms as it helps make up numerous biomolecules (e.g., ATP, DNA).

Through the previous lesson on modeling water and carbon cycles, students should have been able to see how the key elements oxygen, carbon, and hydrogen cycle through the ecosystem. In this lesson, students focus on the fourth most common element in living systems, nitrogen. This data analysis is intended to spark student curiosity and generate questions about the role of nitrogen and how organisms acquire this element.

EXPLORING THE ROLE OF NITROGEN

- Remind students that, as they saw in prior activities, nitrogen is the fourth most abundant element in the human body and is necessary for making key macromolecules, such as DNA and proteins. As with water and carbon, students need to understand how nitrogen cycles through ecosystems and how organisms acquire this key nutrient.
- Display the graph from **Handout 1.3: Analyzing Nitrogen Fertilizer Use on United States Corn Crops** (shown below) to the whole class.



Handout 1.3

> **Meeting Learners' Needs**
> Some students may need additional support unpacking the information in this graph since it measures three different variables and includes a double *y*-axis. Have them first focus on just one variable, such as nitrogen. Then help them connect what is being measured on each axis by asking questions such as:
> - How many pounds of nitrogen per acre were recorded in 2000?
> - How high was the corn yield in bushels per acre in 2000?

- Now engage students in a whole-class discussion to help orient them to the graph and promote close observation of the data. Prompts to encourage this include:
  - What two distinct variables are shown on the *y*-axis?
  - What can a given data point on this plot stand for or represent? (List all options.)
  - Nitrogen is shown separately from the total nutrients, even though it is also included in the total nutrient measurement. Why do you think this is the case?

- Next, have students work individually or in small groups on Handout 1.3. They should begin by examining the passage about nitrogen fertilizer use from the USDA, then move on to answering the Check Your Understanding questions. These questions require close observation and analysis of the data in the passage and the graph. For example:
    - The questions scaffold development of effective routines for data analysis, such as looking at major and minor trends found within the graph.
    - The last question engages students in sentence expansion to help them craft coherent evidence-based written claims. They should develop three unique sentences that begin with the same independent clause, "Nitrogen helps increase corn yield … ," using each of the following conjunctions: *because*, *but*, *so*.

WHOLE-CLASS DISCUSSION

- Once students have completed the handout, lead a whole-class discussion in which students share their answers to the Check Your Understanding questions. Sample responses are shown on the next page.
- Some additional prompts to promote critical thinking during the class discussion could include:
    - Another macronutrient found in fertilizer is phosphorus. Why would phosphorus be included in fertilizers?
    - Why is it important for farmers to continue to improve farming practices so that they can limit fertilizer use?

Instructional Rationale

Often students engage with the nitrogen cycle with very little real-world understanding about its importance. These whole-class discussion questions provide some context as to why nitrogen is important prior to the next lesson, where students model the nitrogen cycle.

CHECK YOUR UNDERSTANDING

1. Calculate the average rate of change in corn yield from 1964 to 2008. (Round to the nearest whole number.)

$$\frac{\text{change in corn yield}}{\text{change in years}}$$

$$\frac{\text{90 bushels per acre}}{\text{44 years}} = \frac{\text{2 bushels per acre}}{\text{1 year}}$$

2. Describe the overall trend in corn yield from 1988 to 2008. How does the trend in corn yield during that time compare to trends for total nutrients and nitrogen?

   Sample response: The overall trend is increasing for each of the variables measured. (Note: Students may want to draw a line of fit to help them analyze the overall trend.)

3. At the highest measurement for total nutrients, what percentage of the total nutrients is nitrogen?

   Sample response: The nutrient input was 300 lbs/acre and nitrogen accounted for 150 lbs of that—or roughly half. (Note: Students should be able to estimate this answer by quickly examining the year 1983.)

4. Complete the sentences below using evidence from the sources.

   Nitrogen helps increase corn yield because it is a key nutrient for plant growth.

   Nitrogen helps increase corn yield, but too much nitrogen-based fertilizer can harm the environment.

   Nitrogen helps increase corn yield, so farmers will continue to look for better farming practices that reduce nitrogen-based fertilizer use but keep corn yield high.

Handout 1.3

UNIT 1

LESSON 1.4

Exploring and Modeling the Nitrogen Cycle

OVERVIEW

LESSON DESCRIPTION

Part 1: Exploring the Nitrogen Cycle
Students read an excerpt from a *Nature Education* article and develop modeling cards from their reading notes.

Part 2: Modeling the Nitrogen Cycle
Student groups use the modeling cards developed by their classmates to develop a nitrogen cycle model. They then form larger groups to evaluate their models.

CONTENT FOCUS

In this lesson, students apply analytical reading and writing skills to a text about the nitrogen cycle and then use their notes to develop a model of the cycle. This is likely students' first introduction to the nitrogen cycle, so a deep understanding of chemical conversions during this cycle, as well as an understanding of the cycling of sulfur and phosphorus in the ecosystem are *beyond the scope* of this course and will be taught in AP Biology. However, students should develop a basic understanding of the transformations that occur during the nitrogen cycle (beginning and ending forms of nitrogen) and the processes that cause those transformations.

AREAS OF FOCUS

- Emphasis on Analytical Reading and Writing
- Attention to Modeling

SUGGESTED TIMING

~90 minutes

HANDOUTS

- 1.4.A: Exploring the Nitrogen Cycle
- 1.4.B: Nitrogen Card Template, with multiple cards cut out for each group
- 1.4.C: Modeling the Nitrogen Cycle, at least one per group

COURSE FRAMEWORK CONNECTIONS

Enduring Understandings	
▪ Biological systems depend on the cycling of matter within and between Earth's systems.	
Learning Objectives	**Essential Knowledge**
ECO 1.2(c) Explain the importance of the cycling of nitrogen for biological systems. **ECO 1.2(d)** Create and/or use models to describe the cycling of nitrogen between biotic and abiotic systems.	**ECO 1.2.1** Elements that are building blocks of macromolecules are transported from abiotic to biotic systems through gaseous and sedimentary cycles. **b.** The nitrogen cycle is a series of transformations that includes the conversion of nitrogen gas (the largest reservoir of nitrogen on Earth) into biologically available nitrogen-containing molecules (e.g., nitrates). **c.** Phosphorus is a critical element for organisms as it helps make up numerous biomolecules (e.g., ATP, DNA).

PART 1: EXPLORING THE NITROGEN CYCLE

In the first part of this lesson, students read an excerpt from a *Nature Education* article and develop modeling cards from their reading notes. The reading discusses the main ways that nitrogen cycles through ecosystems and how organisms acquire it.

- In the prior data analysis activity with corn, students were able to see that plants rely on nitrogen to grow. Remind students that nitrogen is the fourth most abundant element in living organisms and that it is necessary for making key macromolecules, such as DNA and proteins. Therefore, organisms must have a way to acquire this key nutrient.
- Next, have students work independently through the reading to identify key processes of the nitrogen cycle. Guide students to use metacognitive annotation strategies as they are reading, such as circling words they don't know, underlining key ideas, and summarizing in their own words in the margin to capture relevant information. Encourage students to also look for the beginning and ending forms of nitrogen during each process. See **Handout 1.4.A: Exploring the Nitrogen Cycle**. You may want to mention to students that they will be asked to use their notes from the reading to make modeling cards like those provided in the water and carbon cycling activity.
- After students have read independently, lead a whole-class debrief to ensure they were able to extract the key information from the text. You may want to include prompts such as:
  - Did anyone circle a word that was unfamiliar to them?
  - Describe an example that you underlined that represents nitrogen changing forms after a natural process.
  - Describe an example that you underlined that represents nitrogen changing forms after a human-induced process.

Meeting Learners' Needs

It is important for students to be able to extract information from these types of scientific texts. However, there are lots of scaffolding options so that all students can engage in this task. Some examples include:

- After students read and annotate the text, you can have them work with a partner to go over any words they didn't recognize and summarize their key ideas together.
- You can read the text aloud and have students make a list of words that are unfamiliar, then work in groups to define and summarize key ideas.

- Next, have students work in groups of three or four to develop cycling cards for the nitrogen cycle. See **Handout 1.4.B: Nitrogen Card Template**. These cards should mirror the cards used to develop their water and carbon cycles models.
- There is no set number of cards that students should produce. However, highlight for students that there should be enough cards to adequately model the nitrogen cycle.

PART 2: MODELING THE NITROGEN CYCLE

Now that students have read the excerpt and developed cards based on their notes, they can exchange cards and use the other group's cards to model the nitrogen cycle. They will then form larger groups to evaluate their models.

- First, have each group exchange their set of cycling cards with another group. Then, students should create a model using the other group's cards and a copy of the provided scene. See **Handout 1.4.C: Modeling the Nitrogen Cycle**.
- Once groups have constructed a model, ask them to highlight any key processes of the nitrogen cycle that they think were missing from the other group's cards.
- The groups should then engage in peer-to-peer discussion to collaboratively examine the two models they created. Write the following tasks on the board for students to address during their discussions:
  1. Compare and contrast the two models. How are they different? How are they the same?
  2. Discuss possible revisions to each model based on your comparisons. Be sure to cite evidence from the article to support your ideas.
  3. Make revisions to the models based on the group's discussion.
- Finally, lead a whole-class discussion by having students share the transformations and processes reflected in their models of the nitrogen cycle. Throughout the discussion, capture student responses in a table (projected or on the board) for students to see. By the end, ensure that the class identifies all the transformations and processes in the table provided on the next page.

NITROGEN CYCLE TRANSFORMATIONS AND PROCESSES

Location	Beginning Form(s)	Process	Ending Form(s)
Atmosphere	N_2	Nitrogen fixation by lightning	NO_3^- (nitrate)
Soil	Organic matter	Nitrogen fixation by decomposers	NO_3^- (nitrate) and/or ammonium (NH_4^+)
Soil	NO_3^- (nitrate)	Bacterial denitrification	N_2
Plants	N_2	Nitrogen fixation by symbiotic bacteria	NO_3^- (nitrate) or NH_4^+ (ammonium)
Plants	NO_3^- (nitrate) or NH_4^+ (ammonium)	Assimilation	Plant proteins, nucleic acids
Animals	Plant proteins, nucleic acids	Assimilation	Animal proteins, nucleic acids
Agriculture	Fertilizers	Assimilation	Plant (crop) proteins, nucleic acids
Oceans	Fertilizers	Assimilation/algal bloom	Algae proteins, nucleic acids
Industry	N_2	Industrial nitrogen fixation	NH_4^+ (ammonium)

UNIT 1

PRACTICE PERFORMANCE TASK

Termites, Guardians of the Soil

OVERVIEW

DESCRIPTION

Students read an excerpt from a *New York Times* article about the role of termites as soil engineers. Students must then use evidence from the article and from previous lessons to support claims about the cycling of matter.

CONTENT FOCUS

This practice performance task allows students an opportunity to transfer the knowledge they've developed in recent activities to a novel context, termites. This final task for Key Concept ECO 1: Cycling of Matter in the Biosphere is also a great transition to the next key concept of population dynamics.

AREA OF FOCUS

- Emphasis on Analytical Reading and Writing

SUGGESTED TIMING

~45 minutes

HANDOUT

- Practice Performance Task: Termites, Guardians of the Soil

MATERIALS

- copies of scoring guidelines for student use (optional)

COURSE FRAMEWORK CONNECTIONS

Enduring Understandings
▪ Biological systems depend on the cycling of matter within and between Earth's systems. ▪ Most ecosystems rely on the conversion of solar energy into chemical energy for use in biological processes. ▪ The dependence on the availability of abiotic and biotic resources results in complex and dynamic interactions between organisms and populations.
This practice performance task draws on learning objectives and essential knowledge statements addressed throughout Key Concept ECO 1: Cycling of Matter in the Biosphere.

SUPPORTING STUDENTS

BEFORE THE TASK

- **Question 1.** This question uses sentence-crafting to help students thoughtfully develop some initial claims about termites based on the text. Students practiced a similar technique in the data analysis lesson on nitrogen fertilizer use. This time, only the first word of each sentence is provided: *although, when,* and *if.* You may want to alert students to this difference prior to starting the performance task.
- **Question 2.** Prior to starting the task, you may want to remind students that while they should cite evidence from the text to support their claims, they should also use their knowledge of the water, carbon, and nitrogen cycles to elaborate on that evidence with scientific reasoning.
- **Question 3.** Encourage students to use their prior knowledge from the lessons to explain how humans affect the various cycles of matter.

DURING THE TASK

Since this is the first practice performance task in this course, the open-ended question type may initially seem difficult for students. To help build students' confidence with this question type, you may want to use one of the following strategies:

- Let them do this as a homework assignment and then do a whole-class evaluation using the Scoring Guidelines.
- Have students work in teams to answer the questions, and then switch with another group and use the Scoring Guidelines to provide written feedback.

SCORING GUIDELINES

There are 9 possible points for this practice performance task.

Question 1

Sample Solutions	Points Possible
Responses will vary. Some possible answers include: **Example 1:** **Although** some termites are considered pests, termites help plants get water. **When** termites dig into the soil, they allow more water to move down into the soil and reach the plants' roots. **If** termites were not in the ecosystem, more water would evaporate or run off instead of going into the soil. **Example 2:** **Although** termites are very small, they can be a big help to plants by providing nutrients. **When** bacteria in termites' guts convert nitrogen into usable fertilizer, plant communities benefit. **If** termites did not have these bacteria in their guts, the plant community might not grow as well.	**3 points maximum** 1 point for each appropriate sentence *Scoring note:* While it would be ideal if students used the three sentences together to form one idea, it is not necessary at this point. Each sentence could represent a different idea as this is just an opening question to get them into the text.

Targeted Feedback for Student Responses
Since this is just practice, it is okay for students to form three disconnected sentences, all focusing on unique ideas. However, if they do, provide feedback that it is better to form connected sentences to support one idea, and challenge them to write two connected sentences from one of their current ones.

TEACHER NOTES AND REFLECTIONS

Question 2

<table>
<tr><th colspan="2">Sample Solutions</th><th>Points Possible</th></tr>
<tr>
<td>Evidence from Text
Allowing the plants that surround them to persist on a fraction of the annual rainfall otherwise required to bounce back after a withering drought
Poking holes, or macropores, as they dig through the ground
Allow rain to soak deep into the soil rather than running off or evaporating
Artfully mix inorganic particles of sand, stone and clay with organic bits of leaf litter
Blending that helps the soil retain nutrients and resist erosion
Stickiness of a termite’s feces and other bodily excretions lend structure and coherence to the soil, which also prevents erosion
Bacteria in the termite’s gut are avid nitrogen fixaters, able to extract the vital element from the air and convert it into a usable sort of fertilizer</td>
<td>Scientific Reasoning
Each piece of evidence should be adequately paired with a reason as to why this is beneficial to a particular cycle. Some examples include:
Example 1:
Evidence: Allow rain to soak deep into the soil rather than running off or evaporating
Reasoning: This impacts the water cycle in a way that is beneficial to plants since more water will be available in the soil for them to use.
Example 2:
Evidence: Artfully mix inorganic particles of sand, stone and clay with organic bits of leaf litter
Reasoning: This impacts the carbon and nitrogen cycle since it speeds up deposition and helps the soil hold more nutrients such as nitrogen and phosphorus.</td>
<td>4 points maximum
1 point for each piece of evidence pulled from text that aligns to an impact in a cycle
1 point for each appropriate reasoning statement attached to the evidence</td>
</tr>
<tr><th colspan="3">Targeted Feedback for Student Responses</th></tr>
<tr><td colspan="3">If students don’t cite specific evidence from the reading, have them return to the text to find specific examples.</td></tr>
</table>

TEACHER NOTES AND REFLECTIONS

Question 3

Sample Solutions	Points Possible
▪ Removing water from storage for drinking impacts the water cycle. ▪ Farming practices increase evaporation from soil and runoff impacts the water and nitrogen cycles. ▪ Using fossil fuels for energy releases carbon dioxide and ammonia into the atmosphere, which impacts the carbon and nitrogen cycles. ▪ Using nitrogen-based fertilizers in farming impacts the nitrogen cycle.	**2 points maximum** 1 point for each correct description of a human activity that affects the cycling of matter 1 point for each appropriate sentence
Targeted Feedback for Student Responses	
Some students may use more vague language to describe the human activities. If they do, have them return to their carbon and nitrogen models from the prior lessons to find more specific language to include.	

TEACHER NOTES AND REFLECTIONS

UNIT 1

LESSON 1.5

Launch Lesson – Modeling Yellowstone's Food Web

OVERVIEW

LESSON DESCRIPTION

Part 1: Investigating Species in Yellowstone National Park

Students examine information about species in Yellowstone National Park to develop a table that identifies, describes, and provides examples of ecological roles of organisms in food webs.

Part 2: Modeling the Food Web in Yellowstone National Park

Students use the information they generated in their table and on the species cards to develop a model of the Yellowstone food web.

CONTENT FOCUS

To spark student curiosity about population dynamics, this lesson invites students to examine and model the food web of one of our most diverse and complex national parks—Yellowstone National Park in Wyoming. The lesson is designed to elicit students' prior knowledge of terrestrial food webs and species' ecological roles (e.g., primary consumer). As students extract information from species information cards to determine key species interactions, they will deepen and extend their understanding of how energy flows through ecosystems. Understanding these foundational concepts prepares students for a deeper exploration of population and community dynamics in subsequent lessons.

AREA OF FOCUS

- Attention to Modeling

SUGGESTED TIMING

~45–60 minutes

HANDOUT

- 1.5: Species Information Cards

MATERIALS

- internet access and a projector, computers, or other technology for students to view online images
- scissors
- rulers (optional, for making tables)
- one of the following sets of items for model development:
  - large poster or butcher block paper and markers
  - neon dry-erase markers for writing on lab tables
  - mini-whiteboard and dry-erase markers

COURSE FRAMEWORK CONNECTIONS

Enduring Understandings	
▪ Most ecosystems rely on the conversion of solar energy into chemical energy for use in biological processes. ▪ The dependence on the availability of abiotic and biotic resources results in complex and dynamic interactions between organisms and populations.	
Learning Objectives	**Essential Knowledge**
ECO 2.3(a) Create and/or use models to explain the transfer of energy through the food web of a community. **ECO 2.3(c)** Make predictions about the energy distribution in an ecosystem based on the energy available to the organisms in any trophic level.	**ECO 2.3.1** Energy availability helps shape ecological communities. **a.** Typically, only 10 percent of the total energy in a given trophic level is available to organisms in the next higher trophic level. **b.** The metabolic activity required to utilize the energy available in any given trophic level results in a loss of thermal energy to the environment, as heat. **c.** The energy available to organisms decreases from lower-order trophic levels (primary producers) to higher-order trophic levels (tertiary consumers).

PART 1: INVESTIGATING SPECIES IN YELLOWSTONE NATIONAL PARK

While the Yellowstone food web is abundant and complex, the model students develop includes only the following species: aspen trees, wheatgrass, wolves, beavers, coyotes, pronghorn, elk, and brown bears. In this part of the lesson, students examine information about these species in preparation for the modeling task.

- Have students spend a few minutes exploring the wildlife and plant image galleries found at Yellowstone's Nature webpage: **www.nps.gov/yell/learn/nature**. (Students can do this together as a class or on their own.) These images provide a sense of Yellowstone's diversity. As students are viewing the images, you could ask them to estimate how many species of mammals, birds, or plants are found in the park (67 mammal species, nearly 300 bird species, and more than 1,000 plant species).
- Next, group students into pairs and provide them with the handout containing the species information cards (**Handout 1.5: Species Information Cards**). Before having students cut out the cards, give them an opportunity to closely observe and analyze the information provided on each card. To help students navigate the cards' complex textual information, ask them to read each card and circle any word that seems to describe the species' ecological role or feeding habits (e.g., *herbivore, apex predator*). Also have them draw a box around any additional words they can define (e.g., *carrion*).
- Student pairs will now collaborate to develop working definitions for the terms they marked with a circle or box. Ask students to create and fill in a table like the one shown on the next page. Make a blank copy of this table (either on the board or large poster paper) so that all students can see it. Sample student responses are included on the next page for reference.
- Encourage students to fill in at least seven terms on their table, but note that more are possible. (By having students draw their own tables, rather than filling in a provided template, you can help signal that there is no fixed number of terms students should have.)

Meeting Learners' Needs

Students will likely have various levels of knowledge about the terms on the cards. This is a good opportunity for students to work together to share knowledge and develop a collective understanding of these terms. Some terms will be new to students—for example, *carrion*. Encourage students to use the context provided in the species information cards to help them define these new terms.

Ecological Role	Definition	Example(s)
Primary producers	Photosynthetic organisms that occupy the base of the food chain/web	Wheatgrass, aspen
Primary consumers	Organisms that obtain energy/nutrients by consuming primary producers; herbivores	Pronghorn, elk, beaver
Herbivores	Organisms that feed on primary producers (e.g., plants)	Pronghorn, elk, beaver
Secondary consumers	Organisms that obtain energy/nutrients by consuming other consumers, or by consuming both producers and consumers; carnivores and omnivores	Grizzly bear, coyote
Omnivores	Organisms that feed on both producers (e.g., plants) and consumers (e.g., animals)	Grizzly bear
Carnivores	Organisms that feed only on other consumers (e.g., animals)	Grey wolf, coyote
Apex predators	Organisms that have no known natural predators	Grey wolf

- Once students have had enough time to closely examine the cards and create their table, invite them to share terms, descriptions, and examples in a whole-class discussion. Let students know that their tables will contain a variety of different terms, based on which words they marked.
- While all responses should be shared and discussed, emphasize the terms about ecological roles: *primary producer*, *primary consumer*, *herbivore*, *secondary consumer*, *omnivore*, *carnivore*, and *apex predator*. All students should make sure to record these seven terms on their table; these will be important for the next part of the lesson.

PART 2: MODELING THE FOOD WEB IN YELLOWSTONE NATIONAL PARK

In this part of the lesson, students use the species cards along with the information in their table to develop a model of the Yellowstone food web.

- First, have students take a few minutes to cut out the species information cards. Then, they can begin to position the cards to make a model of Yellowstone's food web. Once students feel they are landing on their final model, ask them to label their model using the terms for ecological roles in their table.

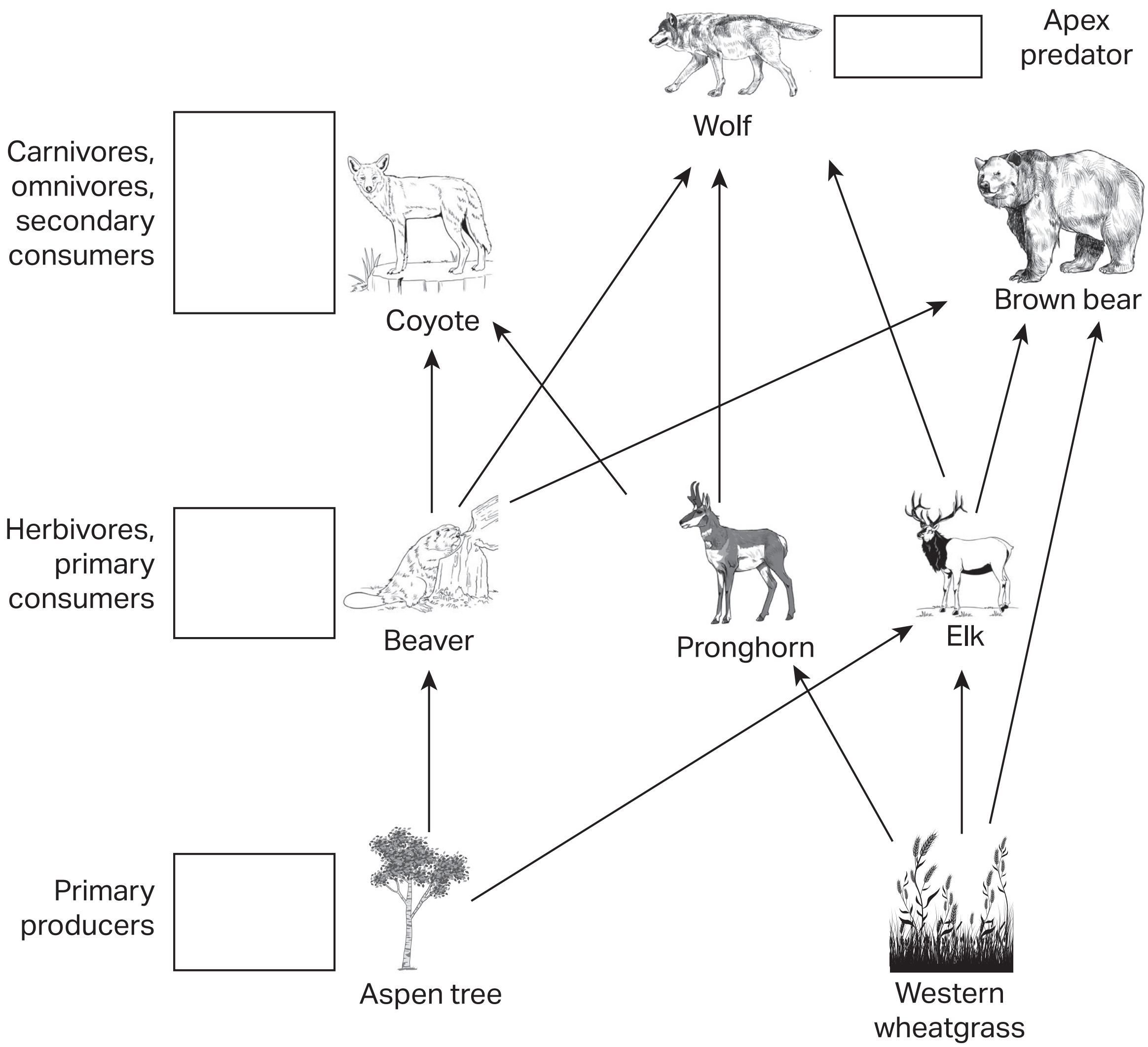
Instructional Rationale

The species information cards are written to challenge students as they engage in modeling. For example, the coyote card indicates that they eat pronghorn and rodents. Some students, though, may not recognize that a beaver is a rodent, and therefore will not include the connection between coyotes and beavers in their model. Or, they may struggle with prior perceptions of brown (grizzly) bears as apex predators, when in reality brown bears eat a lot of vegetation and scavenge on the kills of wolves (carrion). The cards are designed this way to allow productive thinking and peer-to-peer discussion to take place among the students as they create their models.

- As you monitor each pair's development and revision process, look for students placing the arrows in the appropriate direction of the energy flow and labeling ecological roles accurately. A sample student response is shown on the next page.

Classroom Ideas

While students could just write the plant and animal names on paper to sketch the model, it is better for them to be able to move the pieces around as they think through and revise their model based on peer and teacher feedback. Students could place cards on large poster paper, mini-whiteboards, or lab desks, and then use markers to draw energy arrows and add labels.



- To wrap up this part of the lesson, have students do a gallery walk to provide feedback on models developed by other student pairs. Finally, engage them in a whole-class discussion to build a shared understanding of Yellowstone's food web.

Guiding Student Thinking

It is important that students think about how energy transfer is represented in this system. You may have to explicitly prompt student thinking about both of these concepts with some questions such as, "How does the amount of energy in this ecosystem depend on how much sunlight western wheatgrass and aspen trees receive?" Students should know that plants need sunlight to grow and that producers make up the largest biomass of available energy in most ecosystems.

UNIT 1

LESSON 1.6

Population Field Studies Simulations Lab – Quadrat and Mark–Recapture Sampling

OVERVIEW

LESSON DESCRIPTION

Part 1: Quadrat Sampling
Students watch an HHMI video about the Great Elephant Census to spark thinking about the need for population sampling methods. They then carry out a simulated field study in which they apply the quadrat sampling method.

Part 2: Mark–Recapture Sampling
Students are introduced to the mark–recapture sampling method. They think critically about necessary assumptions in this method and perform a simulated field study using mark and recapture. Then, they evaluate this method by analyzing and interpreting data.

Part 3: Comparing Sampling Methods
Students compare the quadrat and mark–recapture sampling methods, drawing on their experiences running the two simulations. They also revisit applications of population sampling.

CONTENT FOCUS

Prior to performing this lab, students should have a basic understanding of a population, a community, and an ecosystem, and be able to distinguish between the three. Through the topic of the Great Elephant Census, students explore various survey methods and mathematical models for estimating population density and distribution, community structure, and how species diversity impacts environmental quality.

AREA OF FOCUS

- Strategic Use of Mathematics

SUGGESTED TIMING

~135 minutes

HANDOUT

- 1.6: Population Field Studies Simulations Lab

MATERIALS

- red kidney beans
- white navy beans
- tape
- metersticks
- paper bags
- straws
- LCD projector, electronic whiteboard, or other technology to show an online video
- internet access to the HHMI BioInteractive video “The Great Elephant Census” (8:23), available at **www.hhmi.org/biointeractive/great-elephant-census**

This allows students to apply and reinforce their proportional reasoning skills as they analyze and predict population density and size. Biologists require this kind of information to make informed decisions about wildlife and habitat management; this understanding provides the lens through which students explore population sampling.

Once students have an understanding of sampling methods, this lab should be conducted in the field, if possible. Students later connect concepts from this lab lesson to Unit 2 concepts such as coevolution, the importance of variation and diverse gene pools, and how changes in the ecosystem can lead to extinction and/or speciation.

COURSE FRAMEWORK CONNECTIONS

Enduring Understandings	
▪ The dependence on the availability of abiotic and biotic resources results in complex and dynamic interactions between organisms and populations.	
Learning Objectives	**Essential Knowledge**
ECO 2.1(b) Collect and/or use data to predict population size, density, and/or distribution.	**ECO 2.1.1** Species live in a defined range of abiotic and biotic conditions, or niche. **a.** Sunlight serves as the primary energy input for most ecosystems. **b.** Species have a range of tolerance for abiotic resources and conditions (e.g., sunlight, nutrients, pH, temperature). **c.** Biotic conditions, such as the behavior of social groups or intraspecific competition for mates and food, also influence population structure. **d.** Environmental changes can alter the availability of abiotic and biotic resources and conditions (e.g., climate changes, drought, fire, floods).

PART 1: QUADRAT SAMPLING

Students watch a video about the Great Elephant Census project to spark thinking about the need for population sampling methods. Students then carry out a simulated field study in which they apply the quadrat sampling method.

INTRODUCTION TO POPULATION SAMPLING

The video that kicks off this lesson illustrates for students the importance of collecting data about populations. Over the past few years, biologists have been conducting, for the first time, a survey of elephant populations across the entire African continent. This survey is being called the Great Elephant Census. Elephants are rapidly disappearing from the African landscape, primarily due to habitat loss and poaching for ivory. Officials have limited budgets, resources, and staff to help protect the elephants. Knowing how many elephants there actually are and where these populations are located may help officials make better decisions about where to invest their money, resources, and workers more efficiently.

- Have students watch "The Great Elephant Census" from HHMI BioInteractive (**https://www.biointeractive.org/classroom-resources/great-elephant-census**). In the video, students learn about one technique being used to track and estimate the size of Africa's elephant populations. As students watch, have them answer the following questions:
  - Why must scientists use sample counts for elephants instead of counting them directly?

    For large moving populations, like elephants, it is often too difficult to count them directly.

  - What is the purpose of defining a specific quadrat transect for counting the elephants?

    Having specific area parameters allows the scientists to make predictions about the total population of elephants in a much larger area based on their sample counts collected.

  - Why is it important to get an accurate count of the elephant population?

    This information is extremely valuable in guiding management and policy decisions regarding elephant protection, especially since these animals are at risk from poaching.

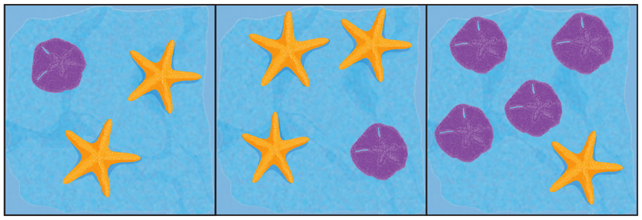
Classroom Ideas

If instructional time is an issue, you can have students watch the HHMI BioInteractive video at home and answer the associated questions prior to starting this lesson.

THE QUADRAT SAMPLING METHOD AND DENSITY

Prior to starting the simulation, students should consider how population sampling leads to population estimates. This exploration will introduce students to vital concepts in population sampling techniques: density and average density.

- First, have students read the introductory text about quadrat sampling and density on the handout. They should then examine the quadrat diagram of the sea stars and sand dollars. See Part 1 of **Handout 1.6: Population Field Studies Simulations Lab**.



$$\text{Density} = \frac{\text{Number of organisms}}{\text{Area}}$$

Handout 1.6

- Next, lead a whole-class discussion to promote student thinking about density. The following guiding questions may be helpful:
  - Ask students to craft a ratio of sand dollars to sea stars for just the **first** quadrat on the left.
    Ratio = 1 : 2
  - Next, have them write a ratio for each echinoderm that represents the **density** for that same quadrat. You may want to remind students that ratios can be also be expressed as fractions.
    $\frac{\text{1 sand dollar}}{4\ m^2}$; $\frac{\text{2 sea stars}}{4\ m^2}$ or $\frac{\text{1 sea star}}{2\ m^2}$
  - Finally, have them predict what the population of sand dollars would be if they sampled 8 m^2 of the reef. What would the population of the sea stars be if they sampled 12 m^2 of the reef?

Meeting Learners' Needs

It is likely that students may need some additional "just-in-time" refreshment of these skills. For practice, you could ask students to first think about a context they are more familiar with, such as:

There are 27 students and 9 teachers eating in a cafeteria that measures 9 m × 9 m.

- What is the density of people eating in the cafeteria?
  36 people/81 m^2
  = 4 people/9 m^2
- What is the ratio of students to teachers?
  27 teachers: 9 students or 3:1 ratio

Students should be able to do these calculations quickly in their head. For the sand dollars, they should see that 8 m^2 of the reef is two times larger than the first quadrat, and therefore predict a population of two sand dollars, based on the original density sampling ratio. For the sea stars, 12 m^2 is three times larger than the first quadrat; therefore, they should predict a population of six sea stars, based on the original density sampling ratio.

Instructional Rationale

Biologists rely on mathematics in order to analyze their data. This lesson allows students to engage in the type of thinking scientists would do to estimate population sizes. The lesson asks students to think about the sample population as one part of a whole (or true population). This type of proportional thinking should not be new to students as they begin developing these type of ideas in third- and fourth-grade mathematics, but this is a good way to continue to strategically reinforce these concepts so students become more proficient with them.

- Students should also understand the value of multiple trials. Ask students to think about why using only one quadrat to draw conclusions about a larger area would be problematic. Invite students to share and discuss their responses.
- Now that students understand why the marine ecologist would use multiple trials, ask them to find the **average density** of the echinoderm populations. You may need to explain to students that to find the average density, we need to know the density across all three quadrats.

$$\text{Average density of sand dollars} = \frac{6}{12\ m^2} \text{ or } \frac{1}{2\ m^2}$$

$$\text{Average density of sea stars} = \frac{6}{12\ m^2} \text{ or } \frac{1}{2\ m^2}$$

- Finally, to reinforce student understanding of how to use density and average density to make population predictions, ask the following questions:
  - What is the predicted sand dollar population in a 30 m^2 area of the reef?

    15 sand dollars
  - What is the predicted sea star population in a 90 m^2 area of the reef?

    45 sea stars
  - What are the predicted sea star and sand dollar populations in the entire reef (3,600 m^2)?

    1,800 for each species

SIMULATING THE QUADRAT SAMPLING METHOD

Now that students have been introduced to how population density, patterns, and distribution are studied, they will simulate a quadrat study using two different colors of beans. See Part 1 of **Handout 1.6: Population Field Studies Simulations Lab**. (It is always best to have students conduct studies in the field when time allows. The simulations in this lab lesson provide effective ways for students to engage with the sampling methods and the type of ratio calculations used to estimate population density, prior to conducting field studies. See the extension section at the end of this lab for ideas about follow-up laboratory work in sampling.)

- In the simulation, students will perform the following general steps (described in greater detail on the student handout):
  - **Define the sampling plot.** Students mark a boundary area for sampling on their lab desks or on the floor if there is not enough desk space. Next, they should spread ample handfuls of both color beans across this marked area, ensuring that they are randomly spread and not stacked on top of each other.
  - **Make a quadrat.** Students will make a quadrat out of two flexible straws, as shown in the diagram on the student handout. They are guided to produce rectangular quadrats with sides between 6 and 10 cm in length. Working with rectangular quadrats is a way to deepen students' use of mathematical reasoning about density. To reduce the degree of difficulty, you could have students produce square quadrats (e.g., 10 cm by 10 cm).
  - **Collect data.** Students should complete three separate quadrat sampling events and record their data in the table provided on the handout.

Classroom Ideas

Students could also make quadrats out of card stock or thick construction paper instead of straws. To do so, they would make a frame (quadrat) by cutting a measured square or rectangle out of the center of the card.

Meeting Learners' Needs

If students are having trouble predicting population density using the area of all three quadrats, first have them do this using just one quadrat. Guide students students in setting up the following example:

$$\frac{5 \text{ beans}}{72 \text{ cm}^2} = \frac{x}{7200 \text{ cm}^2}$$

$$x = 500 \text{ beans.}$$

Using one quadrat in this case reduces the number of calculations involved and makes the numbers easier to work with. Students are likely to notice that the total plot area in this example is 100 times one sample quadrat. Help students recognize that when they move on to working with three quadrats, the ratio of plot area to quadrat area will be different.

UNIT 1

- **Analyze.** Students will use the data to calculate the average density across all three quadrats and the estimated populations, based on the average density. They will then do an actual count of the beans, and calculate percent error using the formula shown here:

$$\text{Percent Error} = \frac{|\text{Experimental} - \text{Actual}|}{\text{Actual}} \times 100.$$

It is important to highlight for students why we are calculating percent error: to get a sense of how accurate the sampling method was during this experiment. It can help students identify potential sources of error in this simulation. In an actual study, it would not be possible to count the individuals, which is why field biologists use population sampling. Calculating percent error is also used here to develop a general conclusion about the overall accuracy of the method.

- To conclude this part of the lab, students will apply their understanding of the average density of a population to make predictions about population size in larger areas. Students will also consider what types of species this particular sampling method would be best suited for and how the size of the quadrat may impact their sampling accuracy. See the sample responses to Handout 1.6 shown here.

APPLICATION OF THE QUADRAT METHOD

1. Scientists use the average density found in quadrat sampling of smaller areas to make predictions about population sizes in areas too large to sample. Use the average density you found for your beans to calculate predicted population sizes for the following areas:

   (a) What do you predict the red bean population to be in a 3,600 cm^2 area?

   Student answers will vary based on their respective average density calculations. Some students may see that this area is half the size of their original plot and simply divide the original predicted population by two. Other students may set up the calculation as:

$$\frac{(N)\text{ beans}}{7{,}200\text{ cm}^2} = \frac{x}{3{,}600\text{ cm}^2} = x\text{ beans}$$

Handout 1.6

(b) What do you predict the white bean population to be in a 14,400 cm^2 area?

Student answers will vary based on their respective average density calculations. Some students may see that this area is twice the size of their original plot and simply multiply the original predicted population by two. Other students may set up the calculation as:

$$\frac{(N)\text{ beans}}{7{,}200\text{ cm}^2} = \frac{x}{14{,}400\text{ cm}^2} = x\text{ beans}$$

2. List two additional populations for which this technique would work well. Justify why this technique is an appropriate choice for the populations you identified.

Students could list a wide variety of species to be sampled. They should highlight that quadrat sampling really works best with organisms that have limited movement or are sessile—e.g., corals, sea stars, trees, and wildflowers (plant species in general).

3. Describe how the size of the quadrat would impact population estimates. What limitations do you think exist for selecting quadrat size for field biologists?

In general, having a larger sampling area would improve accuracy of population size and density estimates since you are sampling a larger area on which the predictions are based. However, quadrats must be manageable and easy to move around in the field in order to do the sample counts, and therefore cannot be too large.

Handout 1.6

PART 2: MARK–RECAPTURE

In Part 2 of this laboratory lesson, students are introduced to the mark–recapture method. They think critically about necessary assumptions in this model and carry out a simulation. Then they evaluate this method by analyzing and interpreting data.

INTRODUCTION TO MARK–RECAPTURE SAMPLING

- To begin, have students individually read introductory material about mark–recapture sampling and the formula for estimating population size using this method. Students should continue to use their reading strategies, such as underlining key ideas or circling words they need help defining, in order to annotate the text as they go. See Part 2 of Handout 1.6.

UNIT 1

- Explain to students that this sampling method involves some assumptions that help ensure the validity of the population estimates. For example, an assumption of mark–recapture is that individuals with marks/tags have the same probability of survival as other members of the population. Have students work in small groups to brainstorm some other assumptions and the rationales for each assumption. Students should record these on the table provided on the handout.
- Once students have had ample time to brainstorm important assumptions, have student groups share their list. Ensure that the class identifies and defines the assumptions and rationales shown in the handout.

Assumptions	Rationales
Individuals with marks have the same probability of survival as other members of the population.	It is important to choose a marking method that does not harm your animal. If a predator used your tagging marks to locate and capture marked organisms at a higher rate than other organisms, your number of recaptures would be lower, and the estimate would therefore be too high.
Births and deaths do not occur in significant numbers between the time of release and the time of recapture.	If marked individuals die and are replaced with newborns, then you will recapture few or no marked individuals, and your estimate will be too high. This is not a large concern in studies of organisms that breed slowly, but can significantly affect estimates for rapidly breeding organisms.
Immigration and emigration do not occur in significant numbers between the time of release and the time of recapture.	If marked individuals leave the study area and new, unmarked individuals come in to replace them, you will get fewer recaptures than the equilibrium population size would lead you to expect. To think about this another way, the real population covers a much larger area than the habitat you thought you were studying.
Marked individuals mix randomly with the population at large.	If marked organisms do not move among unmarked organisms, and you recapture them near the place you released them, the recaptured organisms may be overrepresented in your second sample, driving down your population estimate.
Marked organisms are neither easier nor harder to capture a second time.	If marking an animal frightens it so that it hides from you a second time, then recaptures will be underrepresented in a second sample. If organisms become tame and are easier to recapture, then the opposite error is introduced.

Handout 1.6

Meeting Learners' Needs

There are several ways you can scaffold this reading. Some options are:

- Students can work with a partner after they finish reading to share any words that were not familiar and synthesize their notes.
- Students could read the text aloud as a whole-group discussion, stopping to define words together using the context of the text.

Assumptions	Rationales
Marks do not come off your marked organisms.	Invertebrates molt and shed marks, mammals can wriggle out of their collars, and many other things can happen to obscure your marks. If this happens, recaptures will be undercounted, and your estimate will be too high.
Recapture rates are high enough to support an accurate estimate.	The Lincoln–Peterson calculation tends to overestimate the population size, especially if the number of recaptures is small.

Handout 1.6

- Finally, have students work on the two practice problems for estimating population size based on mark–recapture data. Students are asked to find the estimated population for the box turtle and leopard frog, given the data in the problems. See student solutions shown.

PRACTICING CALCULATIONS FOR MARK–RECAPTURE SAMPLING

Problem 1: Box Turtles. Suppose you want to know how many box turtles there are in a wooded park. On the first day, you hunt through the woods and capture 18 turtles. You place a spot of paint on each turtle's shell and release all turtles back where you found them. A week later you return, and with hard work and effort, catch 50 turtles. Of these, 10 are marked and 40 are unmarked. Since you know how many turtles you marked, sampled, and recaptured, you can estimate the size of the whole population. By the definitions above, $M = 18$ marked and released; $S = 50$ in the second sample; and $R = 10$ recaptures.

Credit: Phil Degginger / Alamy Stock Photo

Handout 1.6

UNIT 1

Assuming the second sample is representative of the whole population, use the Lincoln–Peterson index to find the estimated total population.

$$\frac{10}{50} = \frac{18}{N}$$
$$10N = 900$$
$$N = 90$$

Problem 2: Leopard Frogs. A biologist nets 40 leopard frogs from a local pond, tags them with a microchip, and releases them unharmed. A week later, she nets 65 frogs from the same pond, including 26 with tags.

Based on the Lincoln–Peterson index, estimate the number of leopard frogs in the pond.

$$\frac{26}{65} = \frac{40}{N}$$
$$26N = 2{,}600$$
$$N = 100$$

SIMULATING THE MARK–RECAPTURE METHOD

During this section of the lab, you and your lab partners will use the mark–recapture method to estimate a population. Whereas a fisheries biologist might use this method to estimate the population of largemouth bass in a pond, you will be using the method to estimate the number of beans in a container.

Handout 1.6, *continued*

Meeting Learners' Needs

If students struggle with these problems, it's a good idea to debrief together as a whole class to highlight the purpose of the setup and each calculation. You can provide a few additional practice problems at this point in the class if students need some more skill-building prior to engaging in the data collection and analysis portion of the lesson.

Guiding Student Thinking

Students can typically memorize or follow a formula to find predicted population sizes. However, they often have trouble connecting what those variables represent and how they may be inaccurate based on the assumptions they listed in their group. Encourage students to think about which variable(s) would change if these assumptions were not met. For example: "If marked organisms are easier to find, *R* would not be accurate and would likely cause *N* to be higher than it actually is."

MARK–RECAPTURE SIMULATION

Now that students have been introduced to the mark–recapture sampling method, they will simulate a mark–recapture study, again using two different colors of beans. See Part 2 of Handout 1.6.

- In the simulation, students will perform the following general steps (described in greater detail on the student handout):
    - **Represent the population.** Students will use red beans to represent the total population. To begin, they should place at least three large handfuls of red beans in a container.

- **Capture and mark.** Next, they will capture their first sample (a handful of beans) from the container and record this as the marked individuals in this investigation (*M*). These red beans should be replaced with white beans and then returned to the supply table.
- **Recapture.** Students should complete 10 sampling trials and record data for the size of each sample (*S*) as well as the number of marked individuals recaptured (*R*). For each trial, they should calculate the population size estimate (*N*).
- **Analyze.** Finally, they will calculate the average estimated population after all the trials and the percent error.

- To conclude this part of the lab, students will consider what types of species this particular sampling method would be best suited for, and how the time between recaptures may impact sampling accuracy. Student questions and sample responses are shown here.

1. List two additional populations (other than those listed in the lab) for which mark and recapture would work well. Justify why this technique is an appropriate choice for the populations you identified.

   Students may list a wide variety of organisms. However, they should highlight organisms that have high mobility, for which a quadrat sampling method would be more difficult.

2. Explain how the time between recaptures, in actual field experiments, might influence the sampling results.

   If the organisms being sampled do not have enough time to adequately mix back into the larger population, then the recapture sampling could inflate the population estimates.

Handout 1.6

Guiding Student Thinking

At this point, students may be confused about why scientists used the quadrat method to estimate the elephant population in the HHMI video, instead of mark and recapture. This may be a valuable conversation to have as you discuss the application questions with your students. They should see that elephants in the wild would be dangerous to mark, and therefore each elephant marked would need to be sedated. This made an alternative method such as aerial quadrat sampling a better choice.

PART 3: COMPARING SAMPLING METHODS

To conclude this lab, students compare the quadrat and mark–recapture sampling methods, drawing on their experiences running the two simulations. Students also revisit applications of population sampling.

- Have students work with their lab groups to respond to the questions in Part 3 of the handout. Conclude with a whole-class discussion in which student groups share and compare their responses.

Part 3: Comparing Sampling Methods

1. In field studies, population sampling methods are used to estimate population size because counting the actual population is not possible. However, in this experiment, it is useful to see how accurate these sampling methods can be by counting the actual populations and calculating the percent error.

   (a) Discuss which method yielded the lowest percent error.

   Answers will vary for each lab group.

   (b) For each method, identify potential sources of error that may have occurred during your sampling methods.

   Students should identify sources of error such as counting inaccuracy, beans being stacked on one another (quadrat), or not shaking the container fully (mark and recapture).

   (c) Knowing that there were sources of error in your sampling methods, describe how field biologists could reduce these sources of error as they conduct their field sampling.

   Students should think of how sources of error in their own data collection could be analogous to situations in the field: field biologists should count twice or have two counters; for organisms that live in clusters (e.g., corals), biologists must ensure that all individuals are counted; and the recapture of a mobile organism should occur after there has been enough time for the organism to mix back into the original population.

Handout 1.6

2. Compare and contrast the two different methods, giving specific examples of when and why you would use one method over another to assess and predict the population size of a species.

   Students should see that, in general, quadrat studies are best for organisms with limited or no movement or for mobile animals where it would be too dangerous or difficult to mark individuals. Mark and recapture is an appropriate survey method for organisms that have high mobility and are therefore difficult to assess using traditional quadrat field count sampling.

3. Name and describe *at least* two applications for population estimates.

   Population estimates are used by wildlife management agencies and policymakers to make informed decisions about protecting wildlife, especially species that are threatened or endangered.

Handout 1.6, *continued*

NEXT STEPS

- **Field study**: Students should now be given the opportunity to practice the sampling methods learned in this lab in the field. They should design their own experiment based on techniques learned during this lab. It may be more feasible to conduct a quadrat survey on school grounds, using PVC pipes or metersticks, than a mark–recapture survey.

EXTENDING THE LESSON

If students would like to learn more about survey methods for estimating the size of populations, there is a resource from HHMI BioInteractive called Survey Methods that allows students to explore other methods being used in Africa to track and study elephant populations. These methods include aerial surveys, dung transects, acoustic surveys, and individual registration. This is a self-paced online interactive activity that can be done either in class or out of class, with a student worksheet already created to supplement it. Both resources are available at **www.hhmi.org/biointeractive/survey-methods**.

UNIT 1

LESSON 1.7

Launch Lesson – Comparing Biomes Using HHMI's BiomeViewer

OVERVIEW

LESSON DESCRIPTION

This introductory lesson stimulates students to begin thinking of biomes in terms of abiotic and biotic characteristics. Students explore Earth's ecosystems by comparing two biomes, the one where they live and one of their choosing.

CONTENT FOCUS

This launch lesson is designed to elicit students' prior knowledge about biomes and spark their interest in the importance of biodiversity. As students explore the characteristics of different biomes using HHMI's BiomeViewer, they begin to develop an understanding of how abiotic and biotic characteristics are used to define ecosystems.

AREA OF FOCUS

- Emphasis on Analytical Reading and Writing

SUGGESTED TIMING

Less than 45 minutes

HANDOUT

- 1.7: Comparing Biomes with HHMI's BiomeViewer

MATERIALS

- computers with internet access, for individual students or groups

COURSE FRAMEWORK CONNECTIONS

Enduring Understandings

- The dependence on the availability of abiotic and biotic resources results in complex and dynamic interactions between organisms and populations.

Learning Objectives	Essential Knowledge
ECO 3.2(a) Describe differences in the abiotic and/or biotic factors that shape aquatic and terrestrial communities.	**ECO 3.2.1** Terrestrial biomes are classified by geographic locations and the abiotic factors that shape the unique ecological communities. **a.** Two major abiotic factors that help define terrestrial biomes include climate (temperature, precipitation) and soil type. **b.** Ecological communities in terrestrial biomes are shaped by the availability and abundance of the abiotic factors in that region.

This launch lesson is designed to spark student curiosity and appreciation for Earth's diverse ecosystems and biodiversity. A great way to do this is using HHMI's BiomeViewer application. In this lesson, students use the application to learn a little about both the biome where they live and another biome they are interested in. This also elicits prior knowledge from middle school life science about topics such as species diversity and regional temperature and precipitation.

Meeting Learners' Needs
If students struggle to recall characteristics about biomes, encourage them to reflect on what they have observed about their own biome—for example, types of trees or annual rainfall. Then have students extend this type of thinking to other areas of the world.

- To begin, students should work independently to make predictions about the characteristics of different biomes and how those characteristics could be used to define unique biomes. See **Handout 1.7: Comparing Biomes with HHMI's BiomeViewer**. To make these predictions, students will likely draw on prior knowledge from middle school life science.
- Invite students to share their various predictions about biome characteristics in a whole-class discussion. Encourage students to provide examples for abiotic or biotic features of specific biomes they are familiar with.
- For the next steps, which students can follow by referencing their handout, students will navigate to the HHMI BiomeViewer website (**www.hhmi.org/biointeractive/biomeviewer**) and launch the application. From here, students first explore their own biome and then explore a different biome of their choosing. They will be asked to record data for each of the two biomes in the data table provided. Note: The HHMI BioInteractive Biome Viewer works best on a laptop or desktop computer.
- Once students have finished collecting their data, have them form groups of three or four to compare their findings. Ideally, each student in the group will have investigated a different biome. Have student groups consider the questions from the handout shown on the next page.

Classroom Ideas
It is best to have as many biomes explored as possible for the final share-out and discussion. One idea is to assign students a type of biome for their second location and challenge them to find a city in that type of biome. There are 12 unique biome types that the class can explore.

Instructional Rationale

Often biome lessons have students utilize maps of different biomes across the world that have little to no connection to actual data about precipitation and temperatures or images of the flora and fauna. Therefore, this lesson is designed to engage students in using and analyzing authentic data about different global biomes and to help them make explicit connections about how abiotic features influence biotic features.

4. After you have completed your data collection, discuss the following questions in a small group:
   - How did your original thoughts about biomes compare with data collected during your investigation?

     Students should discuss how their original predictions and descriptions compare with the information collected during the investigation.

   - What abiotic and biotic features help scientists define biomes?

     Sample response: Abiotic: Precipitation and climate; Biotic: Vegetation and animal species diversity

   - Use the data to describe any trends you see between abiotic features and biotic features. Give specific evidence from your data.

     Student answers will vary but should describe how precipitation and climate influence the type and abundance of animal species.

   - Explain how human activities may have led to species being threatened or endangered.

     Examples could include, but are not limited to, habitat destruction, climate change, and air and water pollution.

Handout 1.7

- After students have had time for small-group discussion, engage them in a whole-class debrief. Invite students to share their responses and reasoning to the group discussion questions.
- As students share their ideas, generate a class list of abiotic and biotic features for each unique biome. Work together to identify how abiotic features may help regulate and determine the biotic features for each biome.

Guiding Student Thinking

Students likely have a baseline idea about the type of plants and animals that live in certain biomes (e.g., rain forest and deserts). However, they may struggle to see how abiotic factors, such as climate and precipitation, influence what vegetation can live in these regions and, consequently, what animal species can live in these regions. It might be helpful to remind students about the influence of abiotic factors on species niche (from Key Concept ECO 2: Population Dynamics) to make this idea clearer.

UNIT 1

LESSON 1.8

Launch Lesson – Examining Coral Bleaching Effects

OVERVIEW

LESSON DESCRIPTION

Students apply proportional reasoning skills and use information drawn from text and graphs to analyze changes in a coral reef ecosystem.

AREA OF FOCUS

- Strategic Use of Mathematics

SUGGESTED TIMING

Less than 45 minutes

HANDOUT

- 1.8: Examining Coral Bleaching Effects

CONTENT FOCUS

In this lesson, students apply proportional reasoning skills to analyze changes in a coral reef ecosystem, and use sentence expansion strategies to draw conclusions from data and support or refute a claim. The lesson serves to introduce or reinforce the concept of complex community interactions, such as the symbiotic relationship between coral and the algae in their cells.

This task is ideally used after students have been introduced to the quadrat sampling method, one of the most common methods of sampling used in ecological studies to assess species distribution and abundance.

COURSE FRAMEWORK CONNECTIONS

Enduring Understandings	
▪ Most ecosystems rely on the conversion of solar energy into chemical energy for use in biological processes. ▪ The dependence on the availability of abiotic and biotic resources results in complex and dynamic interactions between organisms and populations. ▪ Changes to the environment can alter interactions between organisms.	
Learning Objectives	**Essential Knowledge**
ECO 4.2(a) Describe what type of symbiotic relationship exists between two organisms. **ECO 4.2(b)** Explain how a symbiotic relationship provides an advantage for an organism by reducing one or more environmental pressures.	**ECO 4.2.1** Competition in ecosystems has led to symbiotic relationships where two or more species live closely together. **a.** Mutualistic relationships often form to provide food or protection for both of the organisms involved.

To begin this lesson, engage students in a whole-class guided reading and discussion of a short passage about coral bleaching adapted from NOAA (see the top of **Handout 1.8: Examining Coral Bleaching**). This passage helps establish context for the subsequent passage from a research article. Discussion may also unearth student questions or unfamiliar terms that should be clarified prior to data analysis.

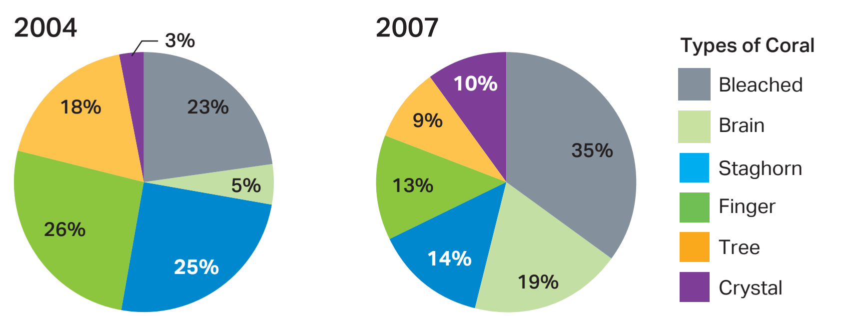
- Next, have students independently read the Coral Bleaching Study summary on the handout and closely observe and analyze the data in the graphs.

Meeting Learners' Needs

Some students may struggle with some of the words in the opening text, such as *symbiotic* or *zooxanthellae*. It will be necessary to help students define these words prior to examining the data.

Instructional Rationale

This lesson is designed to have students think like scientists, as they must extract and synthesize information both from a reading and from a data display. It is important to give students plenty of time to really sit with the data and make observations prior to moving into making analytical inferences.



Adapted from Zaki (student researcher), "*Resilience of a Red Sea Fringing Coral Reef Under Extreme Environmental Conditions: A Four Year Study*." © 2008 by the American Museum of Natural History. **www.amnh.org.**

Handout 1.8

- Engage students in a whole-class discussion of their initial observations about the data. Prompts to promote student thinking may include:
  - What similarities and differences do you notice first between the two data collections?
  - What does a recorded percentage for a species in the data set actually mean?

- Why would scientists want to record the percentage of bleached corals in their samples?
- Why was it important to collect data from the same 18 m^2 of the reef in both 2004 and 2007?

- Next, have students work in pairs to answer the Check Your Understanding questions about changes in species composition in the reef.

  Question 6 asks students to use the sentence expansion routine to "craft three separate sentences to support or refute this scientist's claim" using evidence from the data. Students may need help crafting their initial independent clause and expanding their sentences to incorporate evidence from the data.

- Once pairs have finished answering the questions, have them get together in larger groups to share and revise their sentence expansions. Groups should collaborate to develop final sentences to refute or support the scientist's claim.

Guiding Student Thinking

Sometimes students have difficulty crafting strong scientific claims based on evidence from data. Therefore they will use the sentence expansion approach to focus on writing one sentence at a time to help scaffold their thinking. If students struggle getting started with their sentences, have them return to the initial observations and inferences made about the data together as a class to help guide their writing.

- To close the lesson, engage students in a whole-class discussion of evidence-based claims. Invite student pairs/groups to share their sentences, and encourage peer-to-peer feedback on statements.

Check Your Understanding

1. Describe the ecological relationship between the coral and the zooxanthellae algae.

   Coral and the algae zooxanthellae are symbiotic with each other. The algae provide the coral with nutrients to grow. (Note: At this point students are being introduced to the idea of symbiosis, so it is not important for them to identify mutualism or what the algae is gaining in return. However, you could extend this question during discussion.)

2. How many quadrats were needed to examine the percent coverage of the coral species across the 18 m^2 covered during the transect of the reef?

   $1.5\ m(1.5\ m) = 2.25\ m^2$; $18\ m^2/2.25\ m^2 = 8$ quadrats

Handout 1.8

3. How many square meters does the crystal coral cover in the experimental sample ($18\ m^2$) in 2007?

   $10\% = 0.1; 0.1(18\ m^2) = 1.8\ m^2$

4. If the percent of crystal coral coverage in 2007 remained constant for the entire reef, how many square meters of crystal coral coverage would you expect for an area of reef totaling $100\ m^2$?

   $10\% = 0.1;\ 0.1(100\ m^2) = 10\ m^2$

5. What percentage of the entire reef did the scientists sample?

   $18\ m^2/360\ m^2 = 0.05(100) = 5\%$

6. When asked about the shift in biodiversity of coral in the reef system from 2004 to 2007, a marine ecologist stated, "The shift in biodiversity really isn't too surprising given that brain coral is a hardier species, whereas staghorn is much more vulnerable to stressful environmental conditions. I believe staghorn will continue to decline in percent coverage."

   Craft three separate sentences to support or refute this scientist's claim. Use the following sentence expansion routine:

   - Start with a short statement that you generate from the data.
   - Expand that statement into three different sentences, using the conjunctions *because*, *but*, and *so*.
   - Each sentence should use available data to support or refute the scientist's claim.

   Sample response:

   Initial statement: Staghorn is not as hardy as brain coral.

   - Staghorn is not as hardy as brain coral *because* when stressful conditions increased, it decreased in percent coverage by 44%.
   - Staghorn is not as hardy as brain coral, *but* it is still the second-most abundant species in the reef.
   - Staghorn is not as hardy as brain coral, *so* I think brain coral will continue to have more percent coverage than staghorn while the reef is under stressful conditions.

7. Predict what changes in the reef ecosystem might occur if coral continue to decline.

   Student answers will vary, but students should lean on prior knowledge of food webs to explain that the coral is a food source for organisms and therefore there would be a disruption in the food web. Also, it serves as a habitat to many organisms who may not survive without the coral.

Handout 1.8

UNIT 1

LESSON 1.9

Modeling the Importance of Keystone Species

OVERVIEW

LESSON DESCRIPTION

Part 1: Developing a Model of the Badlands National Park Food Web

The first part of this lesson introduces students to the idea of a keystone species. It also revisits concepts of food webs by having students develop a model of a food web for specific organisms in Badlands National Park.

Part 2: Using the Model to Make Predictions

Students revise the models they created in Part 1 of this lesson to predict what changes could occur if the prairie dog were removed from the ecosystem. Students then evaluate each other's models.

CONTENT FOCUS

This lesson builds on and extends student understanding of the flow of energy through predator–prey interactions in an ecosystem. Students read an article and develop a model of the food web in South Dakota's Badlands National Park by interpreting information on provided species cards. As they develop their models, students reinforce concepts about the ecological roles of organisms and interspecific competition in ecological communities. By using their models to predict what disruptions could occur in this community if the prairie dog were removed, students develop an authentic understanding of what a keystone species is and its importance in maintaining ecosystem dynamics.

AREA OF FOCUS

- Attention to Modeling
- Emphasis on Analytical Reading and Writing

SUGGESTED TIMING

~90 minutes

HANDOUTS

- 1.9.A: Modeling the Importance of Keystone Species
- 1.9.B: Species Cards for Modeling the Importance of Keystone Species

MATERIALS

One of the following sets of items for model development:

- poster paper, markers, scissors, and tape
- mini-whiteboards, markers, scissors, and tape
- computer modeling tool (e.g., SageModeler)

COURSE FRAMEWORK CONNECTIONS

Enduring Understandings	
▪ The dependence on the availability of abiotic and biotic resources results in complex and dynamic interactions between organisms and populations. ▪ Changes to the environment can alter interactions between organisms.	
Learning Objectives	**Essential Knowledge**
ECO 4.1(c) Create and/or use models to explain predictions about the possible effects of changes in the availability of resources on the interactions between species.	**ECO 4.1.1** Competition between species drives complex interactions in ecosystems. **a.** Predator and prey populations respond dynamically to each other. **b.** Keystone species have a dramatic impact on the structure and diversity of ecological communities (e.g., trophic cascade).

UNIT 1

PART 1: DEVELOPING A MODEL OF THE BADLANDS NATIONAL PARK FOOD WEB

The first part of this lesson introduces students to the idea of a keystone species. It also revisits the concept of food webs by having students develop a model of a food web for specific organisms in Badlands National Park.

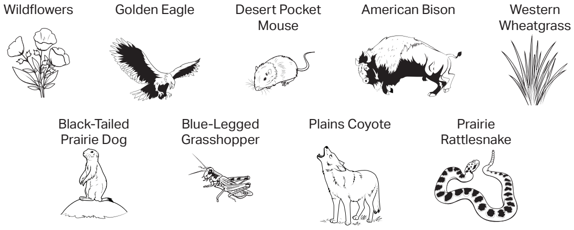
- First, have students read a short passage about the importance of the prairie dog in the Badlands National Park ecosystem (see **Handout 1.9.A: Modeling the Importance of Keystone Species**).

"Look at that landscape out there," said Dr. Glenn E. Plumb, the wildlife biologist for Badlands National Park, as he gazed out across the prairie-dog town. "That's a real concentration of biological activity, a lot of complex nature."

Its verdant carpet produces more new growth in a given year than is produced in similarly sized patches of the surrounding plains, attracting a crowd of plant and seed eaters from insects to mice to birds to bison. Predators like hawks, coyotes, and bug-eating birds follow.

The prairie dogs, as architects and custodians of their immediate environment, are largely responsible for this concentration of life. Their constant cropping of vegetation stimulates faster and more nutritious growth, while their burrows provide homes and hunting grounds for many organisms, large and small. The resulting patches of habitat make the Plains ecosystem more complex, diverse and biologically active than it would otherwise be.

Adapted from William Stevens, "Prairie Colonies Bolster Life in the Plains."



Common organisms in the Badlands National Park ecosystem

Handout 1.9.A

Classroom Ideas

It may be helpful to show students some images of the Badlands National Park in South Dakota. Most students are not aware that this park contains one of the richest mammal fossil beds in the world, with fossils of saber-toothed tigers and rhinos. The Badlands National Park website (**www.nps.gov/badl**) features photo galleries and virtual field trip resources to share with students.

- Once students have read the passage, engage the whole class in a discussion of it and the accompanying figure to elicit students' prior knowledge about the flow of energy in terrestrial food webs. This discussion will also help prepare students for the upcoming modeling handout. Some prompts to promote discussion and student thinking are:

- What images come to mind when you think of a prairie?

  Responses will vary, but students may indicate that these ecosystems are dominated by small or tall grasses and shrubs rather than trees. Students often describe grasslands as "open" due to the scarcity of trees.

- What evidence from the opening text supports the author's description of prairie dogs as "architects and custodians" of their environment?

  Look for student responses that point to how prairie dogs serve as "architects" by constructing tunnels. These tunnels provide both homes and "hunting grounds" for a multitude of organisms. Similarly, students should point out that prairie dogs serve as "custodians," helping to maintain their environment, through "constant cropping of vegetation," which stimulates plant growth. Students might thread in supporting information from earlier in the excerpt, including the descriptions of the national park as a "prairie-dog town" and of the grass as a "verdant carpet."

- Next, students will work in pairs to develop a model of the food web in this prairie ecosystem, using the provided species cards from **Handout 1.9.B: Species Cards for Modeling the Importance of Keystone Species**. Students can use classroom reference materials, including their textbooks, as well as online resources for additional support in developing their models.

  Models can be built in various ways, including with large poster paper, on mini-whiteboards, or using technology. Students should provide evidence from their resources to support each organism's role as shown in their model. Students should also use appropriate terminology to label each organism's ecological role (e.g., apex predator, primary producer).

Instructional Rationale

The species cards are designed to allow for some student choice in creating the model. For example, the species card for the prairie rattlesnake indicates it does eat small mammals and uses the prairie dog's den for hunting, but doesn't specifically reference preying on the prairie dog. This ambiguity requires students to make some assumptions based on the available information, just as scientists also make assumptions when modeling a natural phenomenon. These assumptions help facilitate productive peer-to-peer discussions when students evaluate each other's models. This type of development and revision process leads to much deeper conceptual understanding than more traditional rote memorization and filling in models that are already populated for them.

- After student pairs have completed their models, lead another whole-class discussion to assess student thinking about some basic components of the food web model. Some possible questions to ask are:
  - What organism(s) serve as the base for this prairie food web?

    wildflowers, wheatgrasses
  - Which organisms in the food web have more than one consumer feeding upon them?

    desert pocket mouse, prairie dog, wheatgrasses, wildflowers
  - What are the benefits to being able to feed on more than one type of prey?

    Being able to consume a wider range of prey typically increases an organism's chance for survival since it is not dependent on the survival of a single prey species.
  - When an organism eats prey, why doesn't the organism gain all the energy stored in the prey's body?

    As energy flows through the food web, from one trophic level to the next, only about 10% of the energy from consuming prey is stored as body tissue. The remaining energy is primarily "lost" as heat given off during metabolic processes.

PART 2: USING THE MODEL TO MAKE PREDICTIONS

In this part of the lesson, students use their models to consider what changes would occur in this ecosystem if the prairie dog were removed.

- To begin, student pairs create a list of disruptions that may occur to the food web if the prairie dog is no longer in the ecosystem. See Part 2 of Handout 1.9.A.

Guiding Student Thinking

Students may easily see some direct impacts of the removal of the prairie dog, such as top predators (e.g., plains coyote, golden eagle, and prairie rattlesnake) not having a main prey source. However, they should be pushed to think about indirect disruptions as well. For example, if prairie dogs are not there to stimulate growth of the grasses, as students learned in the excerpt, then species that depend on grasses (e.g., American bison, blue-legged grasshopper) will suffer. Also, the rattlesnakes use the prairie dogs' dens for hunting other small prey; without these dens, the snakes would be less effective at hunting. It's important that students recognize the wide variety of disruptions to the community that could be caused by the removal of the prairie dog. This recognition helps solidify the concept of a keystone species' impact on its ecosystem.

- Next, have each student pair work with another group to evaluate each other's models and compare and contrast lists of food web disruptions. The peer-to-peer dialogue should lead to students critiquing each other's models and prompt groups to consider revisions. Monitor student discussions to provide appropriate feedback and guidance on their predictions, explanations, and connections.
- Finally, facilitate a whole-class discussion on the possible ecosystem changes that could take place if the prairie dog were removed from the Badlands National Park ecosystem. A class list of disruptions should be generated using student models and predictions. Have students develop their own definition of a keystone species based on how their models illustrate the changes that could occur in an ecosystem when a keystone species is removed.

Meeting Learners' Needs

Some students may struggle to give critical feedback on their peers' models. If students need support, you can have them use some sentence frames that help with giving feedback, such as:

Can you explain why there is a relationship between ________ and ________ .

UNIT 1

LESSON 1.10

Launch Lesson – Invasive Species—Brown Tree Snakes in Guam

OVERVIEW

LESSON DESCRIPTION

Students work in small groups to draw conclusions about the brown tree snake—an invasive species in Guam—based on information in clue cards. Then, students share answers in a whole-group discussion and make connections to invasive species in their local environment.

CONTENT FOCUS

This lesson engages students in thinking about how even small changes in the natural processes of ecological communities can result in major consequences. Students explore this idea through the phenomenon of an invasive species, the brown tree snake in Guam, and analyze text and data in order to make claims and predictions about this invasive species.

AREAS OF FOCUS

- Emphasis on Analytical Reading and Writing
- Strategic Use of Mathematics

SUGGESTED TIMING

Less than 60 minutes

HANDOUTS

- 1.10.A: Brown Tree Snake Clue Cards
- 1.10.B: Drawing Conclusions About Brown Tree Snakes

COURSE FRAMEWORK CONNECTIONS

Enduring Understandings	
▪ Changes to the environment can alter interactions between organisms.	
Learning Objectives	**Essential Knowledge**
ECO 5.2(a) Use evidence to support the claim that changes in ecosystems have resulted from human activities. **ECO 5.2(b)** Given a human activity, predict the potential biological consequences for an ecosystem's biodiversity.	**ECO 5.2.1** Human activities (e.g., urbanization, farming, tree harvesting) also alter availability of nutrients, food, and niches for species and therefore affect population and community dynamics. **a.** Human activities include anthropogenic climate change, the introduction of invasive species, habitat destruction, and air/water pollution. **b.** The effects of human-induced environmental changes and their impact on species are the subject of a significant amount of current scientific research.

Students may be familiar with invasive species that live in their area or with invasive species that are more common, or “famous,” across the globe. This lesson is designed to have students apply Key Concept ECO 4: Ecological Community Dynamics to a common ecological problem, the introduction of invasive species, to explore how ecological processes may be altered through human activity. Students use textual and graphical evidence from clue cards to form inferences about the ecological impact of the invasive brown tree snake.

EXPLORING IMPACTS OF AN INVASIVE SPECIES

- Show students a picture of an invasive brown tree snake in Guam, such as the one below. Engage students in a brief discussion about invasive species. To help promote thinking about invasive species, the following prompts may be helpful:
  - Why do you think the term *invasive* is used for these species?
  - How do these species get to new ecosystems?

Classroom Ideas

It may be helpful to show a map of where Guam is located in relation to the native regions of the brown tree snake (northeastern Australia, eastern Indonesia, and Melanesia).

Credit: Photo of Brown Tree Snake. © 2012 by Pavil Kirillov. CC BY 2.0. **https://flic.kr/p/dMbxtN**.

Guiding Student Thinking

Some students may not realize that invasive species are species that have been introduced into a new environment where they are not native organisms. In this new environment, invasive species may have few if any natural predators and their populations can increase rapidly. Sometimes, this rapid population increase can cause ecological damage as well as economic problems. Students may not fully understand that these same species in their native ecosystems are not invasive. Therefore, it may be helpful to remind them that invasive species are also referred to as *nonnative* species.

- For this investigation of how invasive species impact their new ecosystems, have students work in pairs or small groups. To begin, give students time to read an excerpt from an NBC News article about Guam's efforts to eradicate the brown tree snake. See **Clue Card 1: Mice Dropped on Guam by Parachute** from **Handout 1.10.A: Brown Tree Snake Clue Cards**.

Classroom Ideas
You may want to cut out the clue cards and laminate them or glue them on to stiff paper, particularly if you plan to reuse the cards for multiple class sections.

- The excerpt tells us that Guam is on a mission to kill off the brown tree snake, but why? Have groups brainstorm how an invasive species, such as the brown tree snake, may cause severe disruption to natural ecological systems. As groups are working, you may need to circulate around the room and promote critical thinking with the following prompts:
    - How could the introduction of a new species affect the local food web?
    - What species would be most likely to cause a disruption? Explain your response.
    - Do you think native species would only decline or would some flourish? Why?
- Next, have students closely observe and analyze the graphs of data on bird populations on Guam, from **Clue Card 2: Data on Bird Populations on Guam from 1976 to 2000**. Ask students to consider the following questions as they examine the graphs:
    - Do all bird species seem equally at risk for decline?
    - What characteristics might the birds have that help protect them or place them more at risk?
    - During what years do you see most species start to decline?
    - What overall trend statement could you make about the impact of the brown tree snake on bird populations in Guam?

Meeting Learners' Needs
To ensure that all students feel they can engage with this text, you may want to read the first clue card together and discuss some of the challenging vocabulary together before moving on.

Guiding Student Thinking

Students should predict that some birds are more prone to decline than others. Students may need help identifying characteristics that affect populations' risk of decline. Some characteristics to discuss with the class include the following:

Characteristics of Birds *Most* at Risk	Characteristics of Birds *Least* at Risk
▪ Live in forests ▪ Smaller size (may be easier to prey upon) ▪ Produce few offspring per clutch (the group of eggs in each nest)	▪ Live in cities ▪ Larger size (may be more difficult to prey on) ▪ Produce more offspring per clutch

- Finally, have students read about recent research on indirect impacts of Guam's brown tree snakes. See **Clue Card 3: Guam Could Lose More Than Its Birds**. Students should then work together on a question set that will help them synthesize their thoughts across all three clue cards. See **Handout 1.10.B: Drawing Conclusions About Brown Tree Snakes**.

WHOLE-CLASS DISCUSSION

- Once students have completed the clue card handout in their groups, engage them in a whole-class discussion about invasive species in your area, as well as famous examples in the world (e.g., zebra mollusks, cane toads, Asian carp, lionfish, kudzu, Africanized bees, and fire ants). If you are not familiar with local invasive species, you can go to **www.iucngisd.org/gisd/** to find an extensive list.
- As a class, debrief on the groups' answers to the question set on the handout. Sample answers are provided on the next page for reference.

Drawing Conclusions About Brown Tree Snakes

1. The brown tree snake is native in areas such as Australia and eastern Indonesia. In those ecosystems, the brown tree snake is not causing the decline of bird or tree populations. So what makes this same species damaging in Guam? Identify some characteristics a species may possess that would fuel its ability to cause ecological damage, as the brown tree snake has in Guam. Provide some reasoning for why you chose these characteristics.

    - Outcompete native species.
    - Have no natural predators.
    - Are generalists that can eat many things and live in many different habitats.

2. Make a list of ecological consequences that you can infer have occurred on Guam due to the introduction of the invasive (nonnative) brown tree snake.

    - Overall decline in bird populations.
    - Birds scatter seeds after they eat them, so fewer birds means fewer seeds are dispersed.
    - Birds eat insects, so fewer birds mean more insects; more insects may lead to increased insect-borne diseases in humans and animals.

Handout 1.10.B

3. On the first clue card, you learned how scientists are trying to control the snakes by dropping acetaminophen-laced mice into Guam to kill the snakes. Do you think we should get involved in cases like this to try to fix problems that we started? Can you think of any problems that might happen because of humans trying to fix the original problems?

   - Nonnative species being brought in by humans to stop another invasive species may also damage the ecosystem.
   - Other animals getting harmed in the process of removing the targeted animal.

4. According to the article, there are 3,000 brown tree snakes in Guam per square mile (mi^2). The average high school in the United States is approximately 121,000 square feet or 0.004 square miles (mi^2). According to these numbers, how many brown tree snakes would be found in an area the size of a typical U.S. high school?

$$\frac{3{,}000 \text{ snakes}}{\text{mi}^2} \times \frac{0.004 \text{ mi}^2}{\text{school}} = \frac{12 \text{ snakes}}{\text{school}}$$

Handout 1.10.B

Guiding Student Thinking

This part of the lesson is an excellent opportunity for students to practice the critical skill of working with multiple units to solve a problem (dimensional analysis). However, students may struggle with starting the problem. Encourage students to identify the units needed in the answer (“snakes per school”). Then have them work backward and set up the problem to compare the right units in order to end with what they need.

LESSON 1.11

Predicting Changes in Arctic Ecological Communities

OVERVIEW

LESSON DESCRIPTION

Part 1: Examining Data on Arctic Sea Ice Extent
Students use data from a graph to observe and analyze changes in Arctic sea ice extent.

Part 2: Making Predictions and Asking Scientific Questions
Students use information about Arctic species to make predictions about changes in this Arctic community and to ask scientific questions.

Part 3: Summary
Students share their predictions and scientific questions in a whole-class discussion. Students also consider how small changes in their daily activities could curb contributions of carbon dioxide.

CONTENT FOCUS

Ecological communities face both natural and unnatural (human-induced) changes that alter ecological processes. Students make connections to Key Concept ECO 1: Cycling of Matter in the Biosphere and other key concepts as they examine how changes to the climate affect Arctic sea ice extent and, consequently, the local ecological community that depends on the sea ice.

AREAS OF FOCUS

- Emphasis on Analytical Reading and Writing
- Strategic Use of Mathematics

SUGGESTED TIMING

~60 minutes

HANDOUTS

- 1.11.A: Predicting Changes in Arctic Ecological Communities
- 1.11.B: Arctic Species Information Cards, one set of cards cut out per student pair

MATERIALS

- internet access and LCD projector, electronic whiteboard, or other technology for displaying images showing Arctic sea ice extent (optional)
- rulers

COURSE FRAMEWORK CONNECTIONS

Enduring Understandings	
▪ Changes to the environment can alter interactions between organisms.	
Learning Objectives	**Essential Knowledge**
ECO 5.2(a) Use evidence to support the claim that changes in ecosystems have resulted from human activities. **ECO 5.2(b)** Given a human activity, predict the potential biological consequences for an ecosystem's biodiversity.	**ECO 5.2.1** Human activities (e.g., urbanization, farming, tree harvesting) also alter availability of nutrients, food, and niches for species and therefore affect population and community dynamics. **a.** Human activities include anthropogenic climate change, the introduction of invasive species, habitat destruction, and air/water pollution. **b.** The effects of human-induced environmental changes and their impact on species are the subject of a significant amount of current scientific research.

UNIT 1

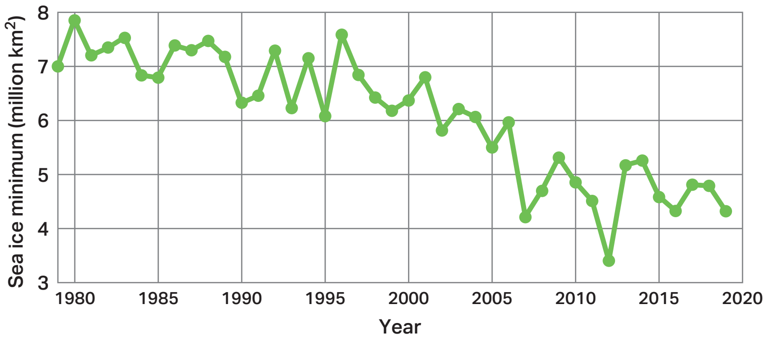
PART 1: EXAMINING DATA ON ARCTIC SEA ICE EXTENT

In this first part of the lesson, students read an excerpt about changes in Arctic sea ice. They then analyze and interpret data from a graph to make predictions.

- First, have students closely observe and analyze an introductory paragraph and graph about changes in Arctic sea ice extent. See Part 1 of **Handout 1.11.A: Predicting Changes in Arctic Ecological Communities**. The graph, included here, shows the annual minimum Arctic sea ice extent, measured each year in September. Students may want to use rulers in order to make better estimates of data points on the graph.

Part 1: Examining Data on Arctic Sea Ice Extent

Arctic sea ice, the layer of frozen seawater covering much of the Arctic Ocean and neighboring seas, is often referred to as Earth's air conditioner: its white surface bounces solar energy back to space, cooling the globe. The sea ice cap changes with the season, growing in the autumn and winter and shrinking in the spring and summer. Its minimum summertime extent (how much surface area it covers), which typically occurs in September, has been decreasing, overall, at a rapid pace since the late 1970s due to warming temperatures.



Arctic sea ice minimum extent in September (1979–2019). (Text and graph adapted from "End-of-Summer Arctic Sea Ice Extent Is Eighth Lowest on Record." © 2019 by NASA.)

Handout 1.11.A

- After students have analyzed the paragraph and graph on their own, lead a whole-class discussion to orient students to the graph, using questions such as the following:
    - Based on the introductory text, what does extent mean?

      The surface area (coverage) of sea ice over the Arctic.
    - What measurement on the graph provides evidence that surface area is being measured?

      The *y*-axis is in millions of square kilometers (km^2) and square kilometers is a measure of area ($km \times km$).
    - What does one data point on this graph represent?

      Each data point represents the total surface area (million km^2) of Arctic sea ice, recorded in September of each year.
- Next, to prompt students to think about the overall trend in Arctic sea ice extent and its importance to organisms in the Arctic ecosystem, have each student work with a partner to answer the data analysis questions on the handout.

Classroom Ideas

It may be helpful to have students see a visual representation of the changing surface area of sea ice in the Arctic. NASA's Climate Change website (**https://climate.nasa.gov/**) provides a digital interactive that you can explore with students. By expanding the Arctic Ice Minimum tab, you can play a time-lapse video or drag the slider to see changes in Arctic sea ice extent from 1979 to 2018.

Meeting Learners' Needs

Some students may need additional support in working through this math. If so, it might be best to do an example as a class prior to them getting started. For example, analyze the percent change in the area from 1978 to 1995.

$$\frac{6 \text{ million km}^2 - 7 \text{ million km}^2}{6 \text{ million km}^2} \times 100 = -16.7\%$$

1. Calculate the percent change in the area of September Arctic sea ice extent between 1980 and 2019.

   $$\frac{(4.2 \text{ million km}^2 - 8 \text{ million km}^2)}{8} \times 100 = -47.5\%$$

2. Determine the average change in Arctic sea ice extent per decade.

   $$2019 - 1980 = 39 \text{ years} \times \frac{1 \text{ decade}}{10 \text{ years}} = 3.9 \text{ decades} \therefore \frac{-47.5\%}{3.9 \text{ decades}} = \frac{-12.2\%}{\text{decade}}$$

3. Predict which organisms may depend on Arctic sea ice.

   Sample response: Polar bears, orcas, or walruses. (*Note: Penguins do not live in the Arctic; furthermore, they are found in the Southern Hemisphere*.)

Handout 1.11.A

- When students have finished, have volunteers share and explain their answers to the class. It would also be helpful to show the worked problems on the board so students can see the steps of the calculations for each answer.

Guiding Student Thinking

The ability to calculate percent change is a necessary skill for data analysis. While students should have prior experience, from middle school, using percentages to solve problems, they may need a bit of help getting started. As you monitor students working on their calculations, some helpful hints and examples for students may include:

- A percent change represents the change that has occurred in a quantity over time, normalized as a percentage (out of 100).
- Percent change is calculated by finding the difference between the final and initial quantities, dividing the difference by the initial quantity, and multiplying by 100.
- A negative value indicates that the quantity decreased, while a positive value indicates that the quantity increased. For example:
  - If \$1,000 is deposited in a bank account and after one year the balance is \$1,050, the percent change is calculated as follows:

    $$\frac{(1{,}050 - 1{,}000)}{1{,}000} \times 100 = 5\%, \text{ or a } 5\% \text{ increase.}$$

  - If the population of snails in a garden was 350 five years ago and is 50 today, the percent change is calculated as follows:

    $$\frac{(50 - 350)}{50} \times 100 = -600\%, \text{ or a } 600\% \text{ decrease.}$$

PART 2: MAKING PREDICTIONS AND ASKING SCIENTIFIC QUESTIONS

In this part of this lesson, students begin with a brief reading about the relationship between sea ice and some predator species in the Arctic food web. Then they practice making predictions and asking questions using information about Arctic species and ecosystems.

- To begin, have students pair up and read the initial text about the importance of Arctic sea ice in Part 2 of **Handout 1.11.A: Predicting Changes in Arctic Ecological Communities**.
- Once students have completed the reading, provide each pair with a set of the cards from **Handout 1.11.B: Arctic Species Information Cards**. Students should organize the cards in such a way that it will be easy for them to quickly find information about different species.
- For the upcoming portion of this lesson, students need to understand the information and vocabulary (e.g., *ice-obligate*, *ice-associated*, and *seasonally migrant*) used on the cards. To build this understanding, give students time to arrange the cards, and then randomly call on different students to answer some preliminary questions, such as the following:
  - What term can we use to describe the relationship between a bearded seal and ice? (If they don't understand the question, ask if bearded seals are ice-obligate, ice-associated, or seasonally migrant species.)

    Bearded seals are ice-obligate.
  - What would happen to the bearded seal population if the area of sea ice decreased?

    Their populations would likely decrease if the area of sea ice decreased.
  - What term can we use to describe the relationship between a humpback whale and ice?

    Humpback whales are seasonally migrant.
  - What would happen to the humpback whale population if the area of sea ice decreased?

    Their populations would likely increase if the area of sea ice decreased.
- Now that students have familiarized themselves with the cards, have student pairs work together to complete both the Species Predictions Table and the Asking Scientific Questions question set. The question set requires students to apply and build on some of the predictions they have made.

- As pairs are working, circulate around the room and provide support as needed. Sample responses to the table and question set are provided here for your use in supporting students. However, allow pairs to work through the table and questions without stopping to check answers as a class. Students will share responses as a whole class in the final part of this lesson.

Species	Sea Ice Requirement	Change in Sea Ice	Predicted Effect and Reasoning
Walrus	Ice-obligate	Decrease	Walrus populations will likely decline if the area of sea ice decreases, due to the loss of critical habitat.
Gray Whale	Seasonally migrant	Decrease	Gray whale populations will likely increase if the area of sea ice decreases, due to the opening of new feeding grounds.
Ringed Seal	Ice-obligate	Increase	Ringed seal populations will likely increase if the area of sea ice increases, due to the availability of additional habitat.
Narwhal	Ice-associated	No change	Narwhal populations are likely to not be affected if there is no change in the area of sea ice in the Arctic.
Killer Whale	Seasonally migrant	Decrease	Killer whale populations will likely increase if the area of sea ice decreases, due to the opening of new feeding grounds.
Polar Bear	Ice-obligate	Increase	Polar bear populations will likely increase if the area of sea ice increases, due to the availability of additional habitat.
Polar Bear	Ice-obligate	Decrease	Polar bear populations will likely decline if the area of sea ice decreases, due to the loss of critical habitat.
Spotted Seal	Ice-associated	Decrease	Spotted seal populations will likely decline if the area of sea ice decreases, due to the loss of habitat.

Handout 1.11.A

ASKING SCIENTIFIC QUESTIONS

1. Based on the change in sea ice area since 1980, make **three** predictions about how the sea ice change has affected specific Arctic species.

   Answers will vary but should include information similar to those in the table students previously completed. For example, "Ringed seal populations are likely to have declined since 1980 due to the decrease in sea ice extent."

2. Use data from the graph in Part 1 to predict the year in which ice-obligate species were impacted the most?

   Sample response: In 2012, Arctic sea ice extent was at its lowest and therefore ice-obligate species would have been greatly impacted that year.

3. State a scientific question, based on one of your predictions.

   This is a critical component of the lesson. A related scientific question might read like one of the following: "Are ringed seal populations declining as a result of the decrease in the area of sea ice?" or "Will killer whale populations increase due to the decrease in Arctic sea ice?"

4. Identify the data that scientists would need to collect to answer your scientific question.

   Sample response: The population of ringed seals (or killer whales) over time, and the area of sea ice over time.

5. What methods could scientists use to collect the data required to answer your scientific question? Be specific.

   Sample response: They could use population biology methods to determine the number of ringed seals: mark–recapture, quadrat sampling, aerial photography, feeding signs, vocalization, or visual observation of breathing. They could use satellite data to measure sea ice extent.

6. Think about the city or state in which you live. If the area of your city or state was substantially decreased, predict what would happen to you and your fellow residents.

   Student answers will vary but should include some thinking about how the loss of habitat and/or resources could impact their local ecological community.

Handout 1.11.A

PART 3: SUMMARY

In the final part of this lesson, students share some of their predictions and scientific research questions from Part 2 in a whole-class discussion. Students are also prompted to reflect on and discuss their own role in the local ecosystem.

- Lead a whole-class discussion in which student pairs share their predictions about the scenarios in the Species Predictions Table. Then, ask pairs to share their suggested scientific questions (question 3). Record student ideas for the whole class to see.
- To prompt further discussion, consider asking these follow-up questions:
  - When looking at your table, what organisms will suffer most if sea ice extent continues to decline by approximately 12% each decade?
  - In what ways could we easily modify some of our daily activities to decrease our contribution of carbon dioxide to the atmosphere?

UNIT 1

LESSON 1.12

Understanding Beavers as Ecosystem Engineers

OVERVIEW

LESSON DESCRIPTION

Part 1: Close Reading
Students read a science text about the role of beavers as ecosystem engineers and practice close reading strategies to extract information and evidence from this text.

Part 2: Writing to Think About the Text
Students use writing strategies, such as working with sentence frames and outlining, to organize and refine their thoughts and evaluate the reading.

AREA OF FOCUS

- Emphasis on Analytical Reading and Writing

SUGGESTED TIMING

~60 minutes

HANDOUT

- 1.12: Understanding Beavers as Ecosystem Engineers

CONTENT FOCUS

This lesson requires students to apply analytical reading and writing skills to an extended science text, and builds on key ideas from prior lessons: food webs, an organism's role in the ecosystem, and biological responses to changes in the ecosystem. Students apply and transfer knowledge of these ideas to a novel situation (i.e., the beaver as an ecosystem engineer). This lesson also serves as a primer for subsequent instruction on community changes over time (e.g., primary and secondary succession events).

COURSE FRAMEWORK CONNECTIONS

Enduring Understandings	
▪ The dependence on the availability of abiotic and biotic resources results in complex and dynamic interactions between organisms and populations. ▪ Changes to the environment can alter interactions between organisms.	
Learning Objectives	**Essential Knowledge**
ECO 5.1(a) Explain how natural changes in the ecosystem affect ecosystem dynamics. **ECO 5.1(c)** Analyze data to make predictions about the effects on biodiversity in response to environmental changes.	**ECO 5.1.1** Ecosystem biodiversity is influenced by several naturally occurring factors that alter the environment. **d.** Keystone species and ecosystem engineers (e.g., elephants, beavers) dramatically affect biodiversity in the ecosystem.

UNIT 1

PART 1: CLOSE READING

In the first part of the lesson, students read an extended science text about the role of beavers as ecosystem engineers (**Handout 1.12: Understanding Beavers as Ecosystem Engineers**) and practice close reading strategies to extract information and evidence from this text.

- To begin, read the text aloud, pausing at key moments to gather student feedback about important ideas from it. Some guiding prompts for class discussion could include:
  - What does the term *engineer* mean? (after paragraph 2)
  - Why are humans and beavers compared with one another?
  - How are humans and beavers similar and different, according to the text?
  - What activities of the beaver support the common expression "eager beaver"? (after paragraph 3)
  - Why do you think MIT adopted the beaver as the university mascot?
  - What characteristics of the beaver surprised you? (after paragraph 5)
- Students should reread the text independently and practice close reading strategies, such as highlighting and summarizing. Students should also identify key terms and concepts and examine the figures in the text.

Classroom Ideas
As this is a longer text, you may want to use a jigsaw arrangement for the independent reading task. Arrange students in groups and have each group member closely read a different portion of the text; then, each group member shares their notes about the reading with the group.

Meeting Learners' Needs
This is an extended reading that requires students to extract important information from the text. It is critical that students practice these analytical reading skills; however, it may be beneficial for students who need extra support to only read 2–3 paragraphs at a time. Then regroup to discuss key ideas and challenging words as a class.

PART 2: WRITING TO THINK ABOUT THE TEXT

In this part of the lesson students use writing strategies, such as sentence frames and outlines, to help organize and refine their thoughts and evaluate the reading. These strategies help students craft more coherent evidence-based written claims.

- Instruct students to fill in the sentence frames in the handout to help them articulate the key concepts from the text. As students are working, circulate through the classroom and provide guidance as needed. Some sample responses to the sentence frames are shown below.

- The formation of dams happens as a result of beavers gnawing down trees and stacking them in rivers or creeks.
- I know that beavers are adapted to swimming because they have webbed feet and strong hind legs.
- I predict that the ecosystem in a river would change if beaver dam construction occurs.

- After students have completed their sentence frames, have them form groups of three or four to share the key concepts they have articulated. Encourage students to engage in peer-to-peer discussion about these concepts, challenging each other's statements and asking for clarification as appropriate. As needed, monitor and guide these conversations to model effective peer-to-peer discussion.
- Once students have discussed the concepts in their small groups, lead a whole-class discussion to summarize the key concepts students identified. Some guiding prompts for class discussion could include:
  - What words in this reading were new to you?
  - What ecological role do you think the beaver plays?
  - What evidence from the text signals the beaver's ecological role?
  - What images come to mind now when you think of a beaver dam?
- Next, students should work individually to collect evidence from the text, supporting or refuting the following prompts from the handout:
  - Claim 1: Both humans and beavers are skilled ecosystem engineers.
  - Claim 2: Beavers are not well adapted to living in aquatic ecosystems.

  Guide students to record their responses in the paragraph outline structure provided on the handout.
- After students have had time to record their evidence individually, have them discuss and share their responses. Try to elicit responses from students who developed opposing arguments or who used different pieces of evidence.
- To complete the lesson, ask students to work individually to write out or sketch a hypothetical food web for the beaver pond on Red River. As indicated on the handout, students should then write a prediction of how this food web might change once the beaver dam is gone (breached) and the ecosystem returns to a river.

Unit 1

Performance Task

UNIT 1

PERFORMANCE TASK

Exploring Species Interactions in the Great Barrier Reef

OVERVIEW

DESCRIPTION

This performance task engages students in all the areas of focus. They use their analytical reading skills to extract important information from a dive in order to journal to develop a model of a coral reef ecosystem and describe community interactions. They also use mathematics to describe population density of the coral.

CONTENT FOCUS

This performance task assesses student understanding across many of the key concepts from this unit. Students demonstrate their knowledge of energy transfer and aquatic community dynamics as they create a model of a coral reef food web and use data to describe the coral population density. They also demonstrate their understanding of symbiotic relationships and make predictions about what can happen to coral reef ecosystems when human-induced changes occur.

AREAS OF FOCUS

- Emphasis on Analytical Reading and Writing
- Attention to Modeling
- Strategic Use of Mathematics

SUGGESTED TIMING

~30–45 minutes

HANDOUT

Unit 1 Performance Task: Exploring Species Interactions in the Great Barrier Reef

MATERIALS

- calculator (optional)

COURSE FRAMEWORK CONNECTIONS

Enduring Understandings
▪ Most ecosystems rely on the conversion of solar energy into chemical energy for use in biological processes. ▪ The dependence on the availability of abiotic and biotic resources results in complex and dynamic interactions between organisms and populations. ▪ Changes to the environment can alter interactions between organisms.

Learning Objectives	Essential Knowledge
ECO 2.2(a) Use data to explain the growth of a population.	**ECO 2.2.1** Population growth patterns are influenced by the availability of resources and the interactions that occur within and between populations of species. **b.** Both density-dependent (e.g., nutrients and food) and density-independent (e.g., weather, natural disasters) factors regulate population growth.
ECO 2.3(a) Create and/or use models to explain the transfer of energy through the food web of a community.	**ECO 2.3.1** Energy availability helps shape ecological communities. **a.** Typically, only 10 percent of the total energy in a given trophic level is available to organisms in the next higher trophic level. **b.** The metabolic activity required to utilize the energy available in any given trophic level results in a loss of thermal energy to the environment, as heat. **c.** The energy available to organisms decreases from lower-order trophic levels (primary producers) to higher-order trophic levels (tertiary consumers).
ECO 3.2(a) Describe differences in the abiotic and/or biotic factors that shape aquatic and terrestrial communities.	**ECO 3.2.2** Aquatic biomes can generally be classified according to their salt concentrations: oceanic, brackish, and freshwater. **a.** Two major abiotic factors that help define terrestrial biomes are climate (temperature, precipitation) and soil type.

ECO 4.2(a) Describe what symbiotic relationship exists between two organisms. **ECO 4.2(b)** Explain how a symbiotic relationship provides an advantage for an organism by reducing one or more environmental pressures.	**ECO 4.2.1** Competition in ecosystems has led to symbiotic relationships where two or more species live closely together. **a.** Mutualistic relationships often form to provide food or protection for both of the organisms involved. **b.** Parasitic relationships benefit only one organism in the relationship (the symbiont) and harm the host. **c.** Commensalism is a kind of relationship that benefits only one organism in the relationship (the symbiont); the host is neither harmed nor helped.
ECO 5.1(a) Explain how natural changes in the ecosystem affect ecosystem dynamics. **ECO 5.1(b)** Create and/or use models to make predictions about how changes in biodiversity affect local ecosystems.	**ECO 5.1.1** Ecosystem biodiversity is influenced by several naturally occurring factors that alter the environment. **a.** Changes in energy, nutrient, and niche availability influence an ecosystem's biodiversity.
ECO 5.2(b) Given a human activity, predict the potential biological consequences for an ecosystem's biodiversity.	**ECO 5.2.1** Human activities (e.g., urbanization, farming, tree harvesting) also alter availability of nutrients, food, and niches for species and therefore affect population and community dynamics. **a.** Human activities include anthropogenic climate change, the introduction of invasive species, habitat destruction, and air/water pollution. **b.** The effects of human-induced environmental changes and their impact on species are the subject of a significant amount of current scientific research.

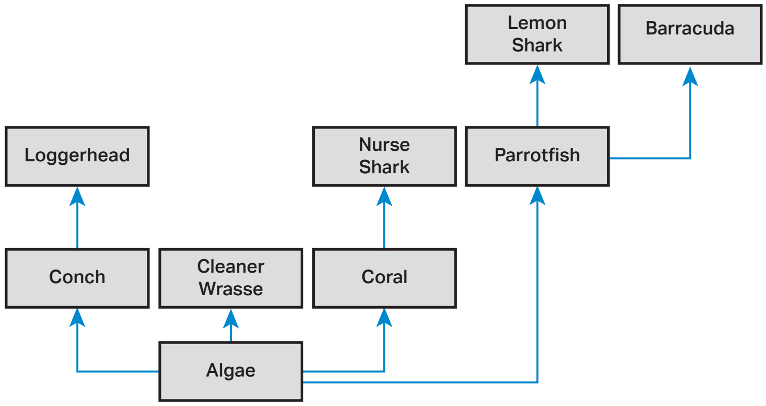
UNIT 1

Exploring Species Interactions in the Great Barrier Reef

SCORING GUIDELINES

There are 17 points possible for this performance task.

Question 1(a)

Sample Solutions	Points Possible
	**3 points maximum** 1 point: All arrows point in the direction of the flow of energy 2 points: Sketch includes at least four accurate relationships. Two or three should earn 1 point. *Scoring note:* Some students may choose to include the fungus on the food web, which is absolutely fine but not necessary to earn all the points on this question.

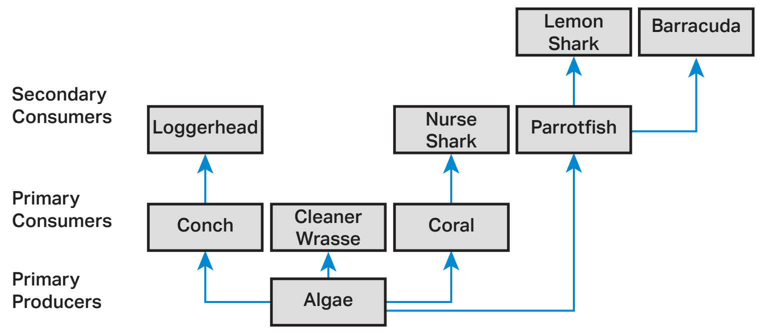
Targeted Feedback for Student Responses

Since students must extract information directly from the dive journal texts, they may fail to include all the organisms in their model. Encourage them to go back to the dive journals, underline each mention of an organism, and ensure they are placed appropriately in the food web model.

TEACHER NOTES AND REFLECTIONS

Question 1(b)

Sample Solutions



Points Possible

1 point maximum

1 point for labeling at least one organism with the correct ecological role for each of the three roles asked for (e.g., primary producers)

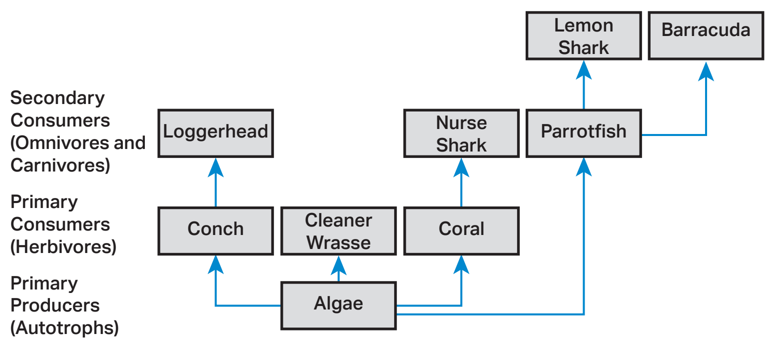
Targeted Feedback for Student Responses

If students struggle to find appropriate pairings for these ecological roles, have them return to the dive journal to find evidence of how the organism is acquiring energy, so they can provide an appropriate label (e.g., since cleaner wrasse eat algae, which is a primary producer, they should be labeled as primary consumers).

TEACHER NOTES AND REFLECTIONS

Question 1(c)

Sample Solutions



Points Possible

1 point maximum

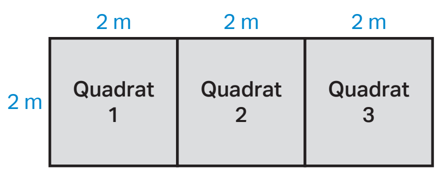
1 point for labeling at least one organism with the correct ecological role for each of the three roles asked for (e.g., autotrophs)

UNIT 1

Targeted Feedback for Student Responses
If students struggle to find appropriate pairings for these ecological roles, have them return to the dive journal to find evidence of how the organism is acquiring energy, in order to provide an appropriate label (e.g., since the algae acquire energy from sunlight, they should be labeled as autotrophs).

TEACHER NOTES AND REFLECTIONS

Question 2(a)

Sample Solutions	Points Possible
Area = Length × width  Sample Plot $= 6 \text{ m} \times 2 \text{ m} = 12 \text{ m}^2$	**1 point maximum** 1 point for correctly calculating surface area

Targeted Feedback for Student Responses
Some students may struggle in setting up their calculations. Encourage them to use the diagram of the quadrats and label the total length and width (as shown in the student sample).

TEACHER NOTES AND REFLECTIONS

Question 2(b)

Sample Solutions	Points Possible
$\frac{4}{12\text{ m}^2} = \frac{x}{120\text{ m}^2}$ $480\text{ m}^2 = (12\text{ m}^2)x$ $\frac{480\text{ m}^2}{12\text{ m}^2} = x$ $40 = x$	**1 point maximum** 1 point for correctly calculating expected population size *Scoring notes:* ▪ Some students may see that the area given, 120 m^2, is 10 times larger than the original experimental plot. So, they may jump to simply multiplying 10 by the original population to get 40. This strategy demonstrates the use of structure in numbers and should also receive full credit. ▪ If students use an incorrect value for surface area, due to errors in part (a), but do the calculations in part (b) correctly, they should be awarded full credit for part (b).

Targeted Feedback for Student Responses

If students have an incorrect setup, provide them with a partially developed setup and have them return to the data to complete it. For example, you could provide:

$$\frac{\#\text{ of coral on dive 1}}{\text{area of all 3 quadrats }(\text{m}^2)} \times \frac{x}{\text{total reef area }(\text{m}^2)}$$

TEACHER NOTES AND REFLECTIONS

Question 2(c)

Sample Solutions	Points Possible
Students could identify any of the following species: lemon shark, barracuda, parrotfish, nurse shark, loggerhead. Mark and recapture is a useful sampling method for mobile animals.	**1 point maximum** 1 point for listing at least two correct species and providing an appropriate explanation
Targeted Feedback for Student Responses	
If students do not recall why mark–recapture would be more appropriate for moving organisms, have them return to Lesson 1.6 and review the data collection methods.	

TEACHER NOTES AND REFLECTIONS

Question 2(d)

Sample Solutions	Points Possible
Since coral are sessile (do not move), the mark–recapture method would not be appropriate. Quadrat sampling is best for organisms with limited mobility.	**1 point maximum** 1 point for providing an appropriate explanation
Targeted Feedback for Student Responses	
If students do not recall why the quadrat method would be more appropriate for nonmobile organisms, have them review the quadrat data collection methods used in Lesson 1.6.	

TEACHER NOTES AND REFLECTIONS

Question 3

Sample Solutions	Points Possible
(see table below)	**4 points maximum** Award 0.5 points for each correct example of a type of species interaction Award 0.5 points for each correct reasoning that is paired with a type of species interaction

Type of Interaction	Example(s)	Reasoning
Mutualism	*Zooxanthellae algae and coral*	*It's a benefit to both since zooxanthellae provide coral with nutrients and they receive protection from predation.*
	Cleaner wrasse and turtle	The cleaner wrasses get nutrients from the algae and the turtle benefits from the removal of the algae from its shell.
Parasitism	Cleaner wrasse and fungus	The fungus benefits by feeding on the cleaner wrasse. The cleaner wrasse is harmed by the fungus.
Interspecific Competition	Barracuda and lemon shark	They are two different species, both after the same prey (parrotfish).
Intraspecific Competition	Parrotfish	Several were competing for the algae on the coral.
	Cleaner wrasse	Many were competing for algae found on the turtle's shell.
	Nurse sharks	Two were competing for coral.

Targeted Feedback for Student Responses
If students do not find appropriate pairings for each type of interaction, have them return to the text of the dive journal and underline each relationship they find between organisms.

TEACHER NOTES AND REFLECTIONS

Question 4(a)

Sample Solutions	Points Possible
Primary consumers such as the conchs and parrotfish would decline due to lack of their food source; secondary consumers such as loggerhead turtles would decline since their food sources, such as conchs, are also declining.	**2 points maximum** 1 point for each correct prediction based on an appropriate ecological relationship
Targeted Feedback for Student Responses	
If students do not make reasonable predictions, encourage them to return to their model and add arrows to show what would happen to each organism in the food web if the coral was to decline.	

TEACHER NOTES AND REFLECTIONS

Question 4(b)

Sample Solutions	Points Possible
Algae are primary producers. Therefore, their decline can cause a decline in both primary consumers who depend on them directly as a food source and secondary consumers who depend on the primary consumers.	**2 points maximum** 1 point for the ecological role of the algae 1 point for food web importance

Targeted Feedback for Student Responses
If students struggle with appropriate answers, have them return to their labeled models in order to analyze the ecological role algae play and the impact it would have on the reef as a system if they were to decline.

TEACHER NOTES AND REFLECTIONS

PERFORMANCE TASK

Exploring Species Interactions in the Great Barrier Reef

> To say that the Great Barrier Reef is the world's largest coral reef may be understating things; the Australian government notes that it is "the only living organic collective visible from Earth's orbit." Certainly, it is vast—a conglomeration of some 3,000 reefs and 600 islands stretching more than 1,250 miles along Australia's northeast coast. Sea turtles, dolphins and whales live there, along with 200 species of birds, 1,500 species of fish, 4,000 species of mollusks and, yes, an abundance of corals.
>
> Excerpt from T.A. Frail, "Diving Into the Great Barrier Reef." © 2008 Smithsonian Institution. Reprinted with permission from Smithsonian Enterprises. All rights reserved. Reproduction in any medium is strictly prohibited without permission from Smithsonian magazine. **https://www.smithsonianmag.com/travel/diving-into-the-great-barrier-reef-11923941**.

In 2008, a marine biologist and her research team were interested in the complex relationships that exist among the many organisms found within the Great Barrier Reef. They made several dives over the course of a few months and recorded their observations. Below are journal entries from two of their dives:

Dive 1 Journal (January 21, 2008): This area of the reef seems to have a healthy population of algae growing on and in the coral which supports a diverse reef ecosystem. There is a healthy diversity of vibrant colors of the coral species due to the presence of zooxanthellae algae that live in the tissue of the coral polyps. These algae provide not only color to the coral but also energy, while safely protected in the tissue of the coral. There were four nurse sharks present on this dive. Two of them were actively feeding on the coral, alongside several parrotfish eating algae growing on the coral.

Dive 2 Journal (March 11, 2008): Today we recorded one female loggerhead turtle on the reef. She successfully preyed upon a large conch mollusk that was grazing on the algae on the coral. She was surrounded by dozens of small cleaner wrasse fish that were feeding on the algae covering her shell. We also noticed that one of the cleaner wrasses appears to have a puffy white fungus that is feeding on its dorsal fin tissue. We encountered one large barracuda and a lemon shark, both chasing a juvenile parrotfish.

1. Based on the marine biologist's research journal entries:
   (a) Sketch a food web for the portion of the Great Barrier Reef that was being observed.
   (b) Label the primary producer(s), primary consumer(s), and secondary consumer(s) in your food web.
   (c) Label one autotroph, one herbivore, and one carnivore in your food web.

2. The research team also conducted a population study on brain coral during their dives. They used three quadrats in a line (transect). Each quadrat measured $2\ \text{m} \times 2\ \text{m}$.

Quadrat 1	Quadrat 2	Quadrat 3

After each dive, they recorded the total number of brain coral for all three quadrats:

Dive	Total Number of Brain Coral
1	4
2	3

   (a) Calculate the total surface area (m^2) of the entire sampling plot (all three quadrats). Show your work.

   (b) If researchers use only the number of coral found in dive 1, calculate the predicted population of brain coral in a reef that covers $120\ \text{m}^2$. Show your work.

PERFORMANCE TASK

(c) Identify two organisms in the food web you sketched (see question 1) that you could sample using the mark–recapture method. Explain why the mark–recapture method is appropriate for the organisms you identified.

(d) Explain why the researcher chose to use the quadrat method rather than mark and recapture to sample the coral population.

3. Based on the marine biologist's observations, find one example of each type of species interaction listed in the table below. For each example, also include your reasoning as to why it illustrates this type of interaction (see example provided).

Type of Interaction	Example(s)	Reasoning
Mutualism	*Zooxanthellae algae and coral*	*It's a benefit to both since zooxanthellae provide coral with nutrients and coral receive protection from predation.*
Parasitism		
Interspecific Competition		
Intraspecific Competition		

4. In 2018, the marine biologist's team returned to the Great Barrier Reef. They noticed sizable areas of coral bleaching due to reductions of the symbiotic photosynthetic algae population. They are concerned that warming ocean temperatures may be causing a decline of important algae populations.

   (a) If algae populations continue to decline, predict how this might impact the Great Barrier Reef food web.

   (b) Describe why the algae population is so vital to this ecosystem.

Unit 2

Unit 2
Evolution

Overview

SUGGESTED TIMING: APPROXIMATELY 4 WEEKS

In this unit, students explore the diverse types of data and multiple lines of evidence that have informed our understanding of the theory of evolution over time. Students should have a general familiarity with concepts associated with evolution from middle school life science. This course is designed to build on that general understanding to provide a foundation in the mechanisms of evolution. This includes both small-scale evolution (changes in the relative frequency of a gene in a population from one generation to the next) and large-scale evolution (speciation events over many generations).

ENDURING UNDERSTANDINGS

This unit focuses on the following enduring understandings:

- The theory of evolution states that all organisms descend from a common ancestor and share some characteristics.
- Biological evolution is observable as phenotypic changes in a population over multiple successive generations.
- Speciation, extinction, and the abundance and distribution of organisms occur in response to environmental conditions.

KEY CONCEPTS

This unit addresses the following key concepts:

- EVO 1: Patterns of Evolution
- EVO 2: Mechanisms of Evolution
- EVO 3: Speciation

UNIT 2

UNIT RESOURCES

The tables below outline the resources provided by Pre-AP for this unit.

Lessons for Key Concept EVO 1: Patterns of Evolution				
Lesson Title	**Learning Objectives Addressed**	**Essential Knowledge Addressed**	**Suggested Timing**	**Areas of Focus**
2.1: Launch Lesson – Examining Evidence of Evolution	EVO 1.1(a), EVO 1.1(b)	EVO 1.1.2a, EVO 1.1.2b	~45 minutes	Attention to Modeling
2.2: Examining Anatomical Evidence from Fossils – *Spinosaurus*	EVO 1.1(a)	EVO 1.1.2a	~60 minutes	Emphasis on Analytical Reading and Writing

The following Key Concept EVO 1 learning objectives and essential knowledge statements are not addressed in Pre-AP lessons. Address these in teacher-developed materials.

- Learning Objectives: EVO 1.2(a), EVO 1.2(b)
- Essential Knowledge Statements: EVO 1.1.1, 1–2 for EVO 1.1.2b, EVO 1.2.1a, EVO 1.2.1b

Lessons for Key Concept EVO 2: Mechanisms of Evolution				
Lesson Title	**Learning Objectives Addressed**	**Essential Knowledge Addressed**	**Suggested Timing**	**Areas of Focus**
2.3: Launch Lesson – Variation in Asian Ladybugs	EVO 2.2(a)	EVO 2.2.1a	Less than 45 minutes	Emphasis on Analytical Reading and Writing

2.4: Modeling Natural Selection Lab	EVO 2.2(a), EVO 2.2(b), EVO 2.2(c), EVO 2.2(d)	EVO 2.2.1a, EVO 2.2.1b, EVO 2.2.1c, EVO 2.2.1d, EVO 2.2.1e, EVO 2.2.2a	~180 minutes	Attention to Modeling

The following Key Concept EVO 2 learning objectives and essential knowledge statements are not addressed in Pre-AP lessons. Address them in teacher-developed materials.

- Learning Objectives: EVO 2.1(a)
- Essential Knowledge Statements: EVO 2.1.1a, EVO 2.1.1b

Practice Performance Task for Unit 2 (~45 minutes)

This practice performance task draws on learning objectives and essential knowledge statements addressed throughout Key Concept EVO 2: Mechanisms of Evolution.

Learning Checkpoint 1: Key Concepts EVO 1 and EVO 2 (~45 minutes)

This learning checkpoint assesses learning objectives and essential knowledge statements from Key Concepts EVO 1 and EVO 2. For sample items and learning checkpoint details, visit Pre-AP Classroom.

Lessons for Key Concept EVO 3: Speciation

Lesson Title	Learning Objectives Addressed	Essential Knowledge Addressed	Suggested Timing	Areas of Focus
2.5: Launch Lesson – Introduction to the Process of Speciation—Salamander Evolution	EVO 3.1(a), EVO 3.1(b)	EVO 3.1.1a, EVO 3.1.1b, EVO 3.1.1c, EVO 3.1.1d	~45 minutes	Emphasis on Analytical Reading and Writing

The following Key Concept EVO 3 learning objectives and essential knowledge statements are not addressed in Pre-AP lessons. Address these in teacher-developed materials.

- Learning Objectives: EVO 3.2(a), EVO 3.2(b), EVO 3.2(c)
- Essential Knowledge Statements: EVO 3.2.1a, EVO 3.2.1b, EVO 3.2.1c, EVO 3.2.1d

Learning Checkpoint 2: Key Concept EVO 3 (~45 minutes)

This learning checkpoint assesses learning objectives and essential knowledge statements from Key Concept EVO 3. For sample items and learning checkpoint details, visit Pre-AP Classroom.

Performance Task for Unit 2 (~45 minutes)

This performance task assesses learning objectives and essential knowledge statements from the entire unit.

LESSON 2.1

Launch Lesson – Examining Evidence of Evolution

OVERVIEW

LESSON DESCRIPTION

Part 1: Examining *Archaeopteryx*
The first part of the launch lesson has students closely observe a picture of *Archaeopteryx*. Together the class generates a list of *Archaeopteryx*'s observable characteristics and inferences about the roles of those characteristics.

Part 2: Evolution of Birds
Students first examine a variety of sources about fossil evidence for the evolution of birds from theropods. Then, they examine data, based on fossil record evidence, to draw conclusions about how *Archaeopteryx* serves as an intermediate link between dinosaurs and birds.

CONTENT FOCUS

This lesson is an introduction to the idea of examining anatomical features of fossils to establish lines of evidence for evolutionary relationships. It also introduces students to how scientists model these relationships using tools such as phylogenetic trees.

AREA OF FOCUS

- Attention to Modeling

SUGGESTED TIMING

~45 minutes

HANDOUT

- 2.1: Examining Evidence of Evolution

MATERIALS

- LCD projector, electronic whiteboard, or other technology for showing students a detailed image and an online video
- internet access to the National Geographic video "The Feathered Dinosaur" (3:39), available at **https://www.youtube.com/watch?v=LQcoLWJmsp0**

COURSE FRAMEWORK CONNECTIONS

Enduring Understandings	
▪ The theory of evolution states that all organisms descend from a common ancestor and share some characteristics. ▪ Biological evolution is observable as phenotypic changes in a population over multiple successive generations.	
Learning Objectives	**Essential Knowledge**
EVO 1.1(a) Use scientific evidence to justify a claim of an evolutionary relationship between species. **EVO 1.1(b)** Describe shared characteristics (homologies) among organisms that provide evidence for common ancestry.	**EVO 1.1.2** Scientists use various sources of evidence to establish evolutionary relationships between organisms. **a.** Fossil evidence, in conjunction with relative and radiometric dating, provides insight into the geographic and temporal distribution of species throughout Earth's history. **b.** Comparisons of anatomical and molecular homologies are used to determine the degree of divergence from a common ancestor.

PART 1: EXAMINING ARCHAEOPTERYX

In the first part of the launch lesson, students get a sense of how scientists engage with fossil evidence to develop and refine claims about the evolution of organisms over time from a common ancestor. Students focus on anatomical features of a fossil of *Archaeopteryx* to gain insight into the organism's characteristics and possible ecological role. The discovery of *Archaeopteryx* in the 1860s was important in paleontologists' understanding of the evolution of birds as it was the first dinosaur fossil found with feathers.

- To begin, have students closely observe a detailed image of an *Archaeopteryx lithographica* fossil such as the one shown. Students should be able to see details such as wing and tail feather imprints, ribs, teeth, claws, and distinct digits. You could display the image using an LCD projector or electronic whiteboard or have students view it on individual devices.

Archaeopteryx lithographica (45 cm fossil size = ~1.5 ft). Credit: James L. Amos, National Geographic Society. CC BY 1.0. **https://commons.wikimedia.org/wiki/File:Archaeopteryx_fossil.jpg**.

- As students examine the image, have them record any observations about *Archaeopteryx*'s anatomy. Next, have them use those observations to draw some inferences about this organism's characteristics and behaviors. It will be helpful to generate a list of student responses on the board for the class to see.

UNIT 2

Instructional Rationale

The purpose of this part of the lesson is for students to take their time to make observations about the fossil, as scientists would do, before they consider any inferences.

Some possible student answers may include:

Anatomical Characteristics	Inferences
Feathers	*Archaeopteryx* may have been able to fly and likely was a terrestrial organism. Feathers may have provided insulation, coloration for mating, or camouflage.
Claws on wing	Claws may have been used for protection and/or predation.
Backbone that extends into tailbone	Backbone allowed for greater range of movement and protection of spinal cord.
Feet bones (phalanges) have 3 distinct digits	*Archaeopteryx* could walk, run, and climb.
Rib cage	The rib cage provided protection for internal organs.
Teeth	*Archaeopteryx* possibly was a carnivorous predator.

PART 2: EVOLUTION OF BIRDS

To begin the second part of the lesson, students explore additional discoveries involving feathered dinosaurs that have fueled our understanding of dinosaurs and the evolution that led to birds. This part of the lesson is intended to help students gain an appreciation for how new scientific evidence that emerges from discovering new fossils continues to strengthen our understanding of evolutionary processes.

Classroom Ideas

If you have time, you could also show students a video on the importance of the discovery of *Archaeopteryx*: "Great Transitions: The Origin of Birds" (**https://www.biointeractive.org/classroom-resources/great-transitions-origin-birds**).

- First, remind students that *Archaeopteryx* was an important discovery in our understanding of the evolution of birds, since it was the first dinosaur fossil found with feathers. Then, show the National Geographic video, "The Feathered Dinosaur" (**https://www.youtube.com/watch?v=LQcoLWJmsp0**), about the 1996 discovery of *Sinosauropteryx*.
- Next, have students read the excerpt from a *Nature* article on feather color in dinosaurs (see "Fossil Feather Colors" on **Handout 2.1: Examining Evidence for Evolution**).
- Once students have completed the reading, ask them to draft one or two sentences summarizing the article. Invite volunteers to share their sentences with the class. From the article, students should be aware that scientists found color-producing organelles in fossil dinosaur feathers. These organelles have also been found in fossilized bird feathers and are present in modern-day animals.

Now that students have a better understanding of how scientists use fossil evidence to support their claims about the characteristics of species over time, they will use two figures provided on the handout to support the inferences they made in Part 1 of this lesson about *Archaeopteryx*. The first figure shows stratigraphic ranges and origins of some major animal groups to help students gain a better sense of the scale of time and to place the evolution of birds in relationship to the evolution of other organisms. The second figure, called an evogram, includes a phylogenetic tree combined with species timeline information.

- To first orient students to the two figures on their handout, you may want to pose the following questions:
    - Why do you think some organisms become fossils and others do not?
    - According to the first figure, how many millions of years before birds are found in the fossil record is there evidence of the presence of reptiles?
    - What do the branches on the phylogenetic tree in the second figure represent?
    - What type of evidence would cause scientists to create a new branch on the phylogenetic tree?

UNIT 2

Guiding Student Thinking

Students often struggle with understanding why relatively few organisms are fossilized in Earth's rock layers. They tend to think that fewer fossils points to weaknesses in evolutionary theory since they don't fully appreciate how rare the events are that result in fossilization of organisms. You can remind students that in order to be fossilized, organisms must be covered quickly by sediments, such as gravel, mud, or sand (or sometimes volcanic ash). Emphasize that this typically occurs *only* if organisms die or are involved in events near lakes, rivers, or oceans where they can be quickly covered by sediments, which preserves skeletal structures. Over time, the layers of sediments are compacted by the weight of overlying sediments and cemented together to become the sedimentary rocks called limestone, shale, sandstone, and conglomerate. The buried plant and animal remains become fossils within the sedimentary layers and are only discovered as these layers erode away or are purposefully excavated by paleontologists.

- Once students have analyzed the two figures, have them work in pairs to use the phylogeny to determine in which group(s) each of the characteristics listed in the data table on the handout occur. Then students should identify the evidence that supports their conclusions. Sample responses are shown on the next page.
- Finally, lead a whole-class discussion on the following prompts:
  - What characteristics of dinosaurs do modern birds still exhibit?
  - Defend the following scientific claim, using evidence from the table:

    ***Archaeopteryx* represents an intermediate link between birds and dinosaurs.**

Meeting Learners' Needs

If students need support in how to craft statements of evidence to defend a scientific claim, you may want to have them work with a partner and write down their evidence prior to engaging in a whole-class discussion. Having students write before they discuss will give them time to reflect more deeply on the evidence.

Guiding Student Thinking

In response to the prompt defending the scientific claim, the specific evidence students mention will vary but they should highlight the evidence that points to some characteristics of only dinosaurs and only birds. For example, they can highlight that *Archaeopteryx* had teeth and a bony tail like dinosaurs but had a fused wishbone and longer arm bones like modern birds.

DATA ANALYSIS

Use the data in Figure 2 to complete the table.

Characteristics	Theropods	*Archaeopteryx*	Modern-Day Birds	Evidence from Phylogenetic Tree
Teeth	✓	✓		Seen in all theropods but not birds
Vertebrae extend into tail	✓	✓		Seen in all theropods but not birds
Four digits	✓			First seen in *Eoraptor* around 230 mya
Claws on wings	✓	✓		Seen in *Archaeopteryx* 150 mya
Hollow bones	✓	✓	✓	First seen in coelophysoids between 230 and 220 mya
Hollow and tufted feathers	✓	✓	✓	Both first seen in tyrannosauroids between 170 and 160 mya
Three digits	✓	✓	✓	First seen in allosaurids and tyrannosauroids between 170 and 160 mya
Fused furcula (wishbone)		✓	✓	Seen in *Archaeopteryx* 150 mya
Longer arm bones		✓	✓	Seen in *Archaeopteryx* 150 mya
Feathered (boneless) tail			✓	Seen in modern birds only between 130 and 120 mya
Toothless beak			✓	Seen in modern birds only between 130 and 120 mya

Handout 2.1

UNIT 2

LESSON 2.2

Examining Anatomical Evidence from Fossils – *Spinosaurus*

OVERVIEW

LESSON DESCRIPTION

Part 1: Finding *Spinosaurus*

Students analyze the first part of the *National Geographic* article on *Spinosaurus* to gain background information on the Kem Kem fossil beds and the type of anatomical evidence the paleontologists are examining.

Part 2: Unearthing Anatomical Evidence from *Spinosaurus*

In this next part of the lesson, students extract crucial information from the article to analyze key anatomical features of *Spinosaurus* that provide insight into its ecological role and environment.

CONTENT FOCUS

In the launch lesson for this key concept, students were introduced to the idea that anatomical features provide scientists with lines of evidence to establish evolutionary relationships. Now students have an opportunity to examine the anatomical features of *Spinosaurus,* make claims about the function of those features, and draw inferences about *Spinosaurus*'s ecological role and surrounding environment. Students will need to recall concepts from Unit 1 that are associated with ecological roles (e.g., carnivore versus herbivore) to draw inferences about *Spinosaurus*.

AREA OF FOCUS

- Emphasis on Analytical Reading and Writing

SUGGESTED TIMING

~60 minutes

HANDOUTS

- 2.2.A: Searching for *Spinosaurus*
- 2.2.B: Unearthing Anatomical Evidence from *Spinosaurus*

MATERIALS

- LCD projector, electronic whiteboard, or other technology for displaying a text document and an online video
- internet access to the National Geographic video "Nizar Ibrahim: Lost Giant of the Sahara" (15:12), available at **https://www.youtube.com/watch?v=NaWERiPJagk**
- highlighters or markers for text annotation (optional)

COURSE FRAMEWORK CONNECTIONS

Enduring Understandings	
▪ The theory of evolution states that all organisms descend from a common ancestor and share some characteristics. ▪ Biological evolution is observable as phenotypic changes in a population over multiple successive generations.	
Learning Objectives	**Essential Knowledge**
EVO 1.1(a) Use scientific evidence to justify a claim of an evolutionary relationship between species.	**EVO 1.1.2** Scientists use various sources of evidence to establish evolutionary relationships between organisms. **a.** Fossil evidence, in conjunction with relative and radiometric dating, provides insight into the geographic and temporal distribution of species throughout Earth's history.

PART 1: FINDING *SPINOSAURUS*

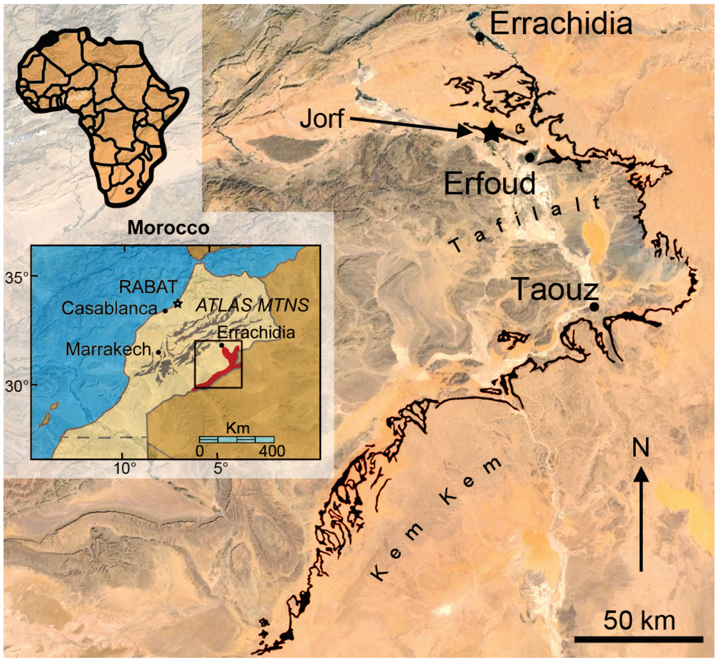
In Part 1 of the lesson, students learn about the exciting discovery of *Spinosaurus* by reading the first part of the *National Geographic* article "Mister Big." In this part of the reading, students are introduced to the main scientist in the article, a paleontologist named Nizar Ibrahim, and the field study site in Morocco where the *Spinosaurus* fossils were discovered—the Kem Kem fossil beds.

- To begin, students should read approximately half of the *National Geographic* article "Mister Big," found on **Handout 2.2.A: Searching for *Spinosaurus***. You can have students work independently through the reading or work in pairs. Tell students to stop at the end of paragraph 11. They should use text-analysis strategies, such as highlighting and summarizing, to capture key concepts from the reading. Remind students to record annotations and summaries in the notes section of the handout.
- Some students may run across a few words that are unfamiliar to them. Have students circle these words and encourage them to discuss the meaning of these terms with their reading partner or during the whole-class discussion.

Meeting Learners' Needs

Some students may find it challenging to apply some of the text-analysis strategies. To help students engage with the article, it could be helpful to first model for students how to use these strategies. You may choose to display the text for the whole class or lead a guided discussion to remind students of these strategies, which have been used in prior lessons.

- Once students have finished reading the first half of the article, it is important to stop and unpack some of the important information they should have extracted from it. Use the following questions to guide a whole-class discussion about the article:
  - What images come to mind when you read about the Kem Kem fossil beds?
  - What evidence from the article indicates this area is rich in fossils from many species?
  - What type of conditions do you think must have existed during the Cretaceous period to produce an area with such diverse fossil evidence of life?
- To help students further contextualize information in this article, you may want to locate and display some online images and other visual information about the Kem Kem fossil beds, located in northern Africa along the border of Algeria and Morocco. A map is provided on the next page.

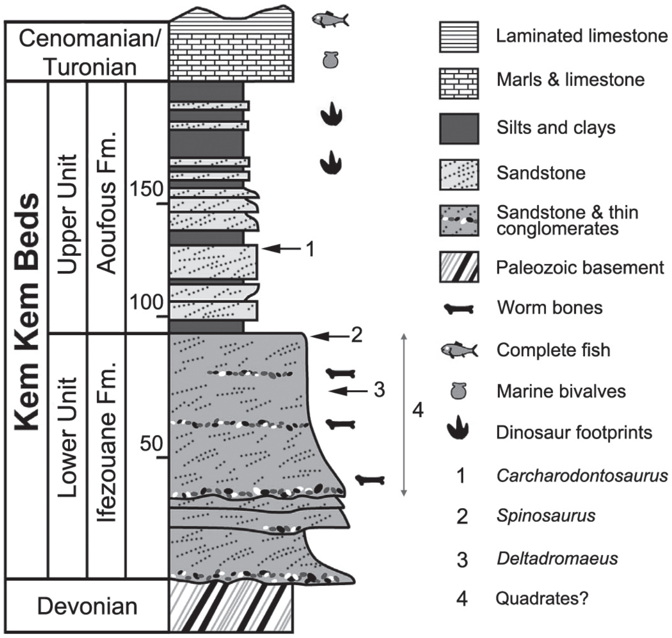


Map of the Kem Kem fossil beds. Credit: © 2016 Hendrickx et al. CC BY 4.0. **http://journals.plos.org/plosone/article?id=10.1371/journal.pone.0144695.**

Instructional Rationale

This lesson is designed to engage students in analyzing an extended reading. It is important for students to practice this skill as they will have science-based extended reading passages on the SAT. This also helps students practice for the type of analytical reading they will utilize in higher-level science courses.

- You may also want to deepen this discussion by showing students the figure on the next page, which models the stratigraphy of the Kem Kem beds.



Stratigraphy of the Kem Kem fossil beds. Credit: © 2016 Hendrickx et al. CC BY 4.0. **http://journals.plos.org/plosone/article?id=10.1371/journal.pone.0144695**.

Classroom Ideas

Students may have some idea of how rock layers form from middle school science courses. But if students haven't been introduced to relative and radiometric dating yet, you may want to provide a brief overview prior to showing the rock layers of the Kem Kem fossil beds. *Nature* provides a summary of these processes at **https://www.nature.com/scitable/knowledge/library/dating-rocks-and-fossils-using-geologic-methods-107924044.**

Guiding Student Thinking

The launch lesson explained that unique conditions are needed to preserve remains as fossils. You may need to prompt students to recall what they know about desert biomes from Unit 1 to look for key characteristics of the environment mentioned in the article. For example, "great meandering rivers had flowed there a hundred million years ago" (paragraph 11) is evidence that that environment was primed for fossil formation. The map of the Kem Kem fossil beds will help students identify a hot, dry desert environment with high cliffs and exposed layers of rock. Descriptions in the text, such as "Stromer found some 45 different taxa of dinosaurs, crocodiles, turtles, and fish" (paragraph 2), provide evidence of species diversity. Encourage students to cite specific evidence from the text to support their answers.

PART 2: UNEARTHING ANATOMICAL EVIDENCE FROM *SPINOSAURUS*

In Part 2 of the lesson, students finish reading the rest of the article, which can be done individually or with a partner. Students should continue using their text-analysis strategies to extract important information. In the second half of the article, students focus on how anatomical evidence can provide clues to the ecological role of *Spinosaurus*.

- Before students begin reading the second half of the article, use the following question to help focus their analysis:
  - What anatomical evidence provides clues about the ecological role *Spinosaurus* played in its environment?
- Once students are finished reading the remaining part of the article, provide them with **Handout 2.2.B: Unearthing Anatomical Evidence from *Spinosaurus***. Students should work in pairs to populate the table and draw inferences about *Spinosaurus* using information from the article.
- After student pairs have completed the table and inference questions, show the following 15-minute video about *Spinosaurus* from National Geographic, available at the following link: **https://www.youtube.com/watch?v=NaWERiPJagk**. Prompt students to evaluate their claims about *Spinosaurus*'s ecological role and its environment as they watch the video, and revise their claims as needed.
- Next, have student pairs merge with another group (forming groups of four, if possible). Have groups compare and contrast their tables and inferences. Students should make any needed revisions to their own work based on their peer-to-peer critique and dialogue.
- After student groups have had ample time to work, have each group share their table with the whole class in order to generate one collective data table that you can display. The portion of the student handout on the next page shows an example of how students might complete the table using information from the text.

Anatomical Structure	Description	Probable Function in *Spinosaurus*
Nostrils	Nostrils set very high on the skull toward the eyes	Nostrils may have allowed breathing while the rest of the head was still submerged in water.
Openings in skull at end of snout	Pits similar to the pressure sensors that crocodiles and alligators have	These may help detect prey in murky water.
Jaw and teeth	Slender and elongated jaw; smooth and cone-shaped (conical) teeth	This type of jaw and smooth, cone-shaped teeth are well suited for snaring fish in the water.
Forelimbs	Bulky	Bulky forelimbs may have allowed for walking on all four limbs (functional quadruped).
Hind limbs	Disproportionately short and slender	Hind limbs are perfectly proportioned for paddling in water.
Bones	Long, with bone density similar to that of aquatic mammals	The bone density would have allowed for more buoyancy in the water.
Feet and claws	Flat claws that may have also allowed for webbing on the feet	Webbing would allow for better swimming capabilities.
Sail (dorsal spines)	Smooth bones that protrude from the back/ spinal column	They may have supported a dorsal sail like those seen in modern lizards and chameleons.

Handout 2.2.B

- Then, invite student groups to share and discuss their claims about *Spinosaurus* from the set of inference questions. Encourage students to identify evidence to support their claims using the table. The portion of the handout on the next page provides sample student responses.
- Finally, lead a whole-class discussion to collectively answer the following questions:
  - Why is it important to understand the functions of *Spinosaurus*'s anatomical characteristics?
  - How does anatomical fossil evidence help scientists connect lines of evidence for evolutionary relationships between species?

Drawing Inferences About *Spinosaurus*

1. Why did Ibrahim conclude that the dorsal spines were not used to support a hump or to regulate body temperature?

   The bones were smooth and not capable of supporting the soft tissue of a hump, like those seen in bison. Also, the spines had "few channels for blood vessels, so it seemed unlikely that they were used to regulate body temperature."

2. How was Ibrahim able to confirm that *Spinosaurus* was the largest carnivore to ever walk the Earth?

   He used digital computer modeling to reconstruct the spacing of the vertebrae of *Spinosaurus*. This confirmed that the dinosaur was 50 feet "from nose to tail," whereas *T. rex* was approximately 41 feet tall.

3. (a) Based on the evidence in the table, make a claim as to what kind of environment *Spinosaurus* lived in.

   Answers will vary.

   (b) Select the three most compelling pieces of evidence that support your claim.

   Answers will vary.

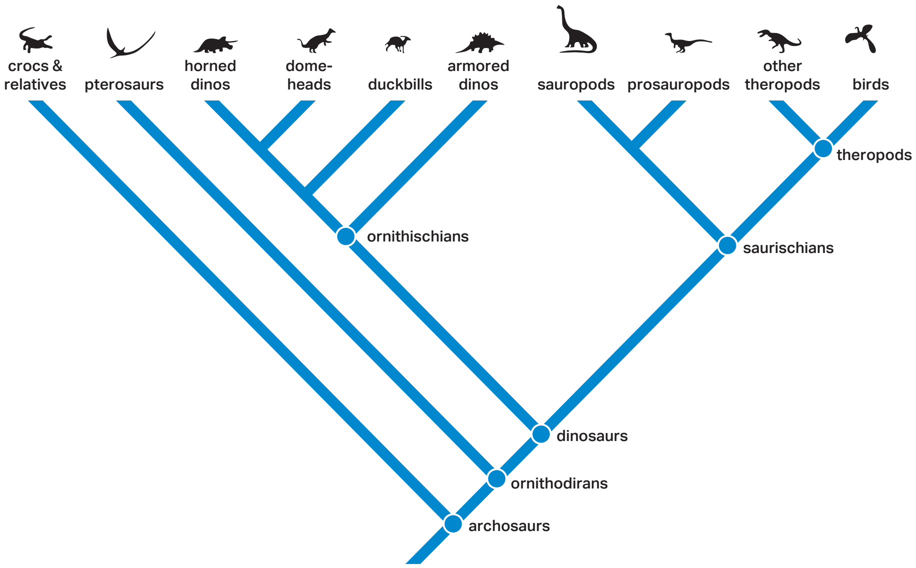
   (c) Explain how this evidence supports your claim.

   Student answers to the questions above will vary. However, they should indicate that *Spinosaurus* was a large carnivore that spent much of its time in aquatic environments. They could highlight anatomical evidence such as webbed feet, hind-limb-to-body ratios that are useful for swimming, nostrils located high on the head to allow breathing while submerged in water, or pits in its snout that sense prey in murky water.

Handout 2.2.B

UNIT 2

4. The theropod *Spinosaurus* seems to share several characteristics with other aquatic predators, like the crocodile. Based on the phylogenetic tree, describe how closely related they actually are to one another. What modern-day organism are they more closely related to?



Adapted from "Meet the Relatives: A Dinosaur Family Tree." © 2005 by the University of California Museum of Paleontology, Berkeley. **www.ucmp.berkeley.edu/museum/events/bigdinos2005/turkey.html**.

Theropods are not closely related to the crocodile. Their last common ancestor is the archosaurs group. Theropods are more closely related to modern-day birds.

Handout 2.2.B

LESSON 2.3

Launch Lesson – Variation in Asian Ladybugs

OVERVIEW

LESSON DESCRIPTION

Part 1: Making Connections to the Hierarchy of Life

In the first part of the lesson, students closely observe the phenotypic variances of the Asian ladybug. They then use this context and prior knowledge to describe the levels in the hierarchy of life and provide examples of each.

Part 2: Using Observations to Make Inferences About Ladybugs

Students work in pairs to think about how phenotypic variations in an Asian ladybug population may influence survival and reproduction. They are also asked to predict what may change if the environment changes.

CONTENT FOCUS

The focus of this lesson is to provide students with an opportunity to observe and define phenotype variance and identify pressures in the environment that may influence the variation we see. They will not be formally introduced to the ideas of selective pressures, differential reproduction, fitness, or adaptation in this lesson. However, understanding the big picture of how the environment influences the traits we see in populations will prepare them to dive into those ideas in the next lesson for Key Concept EVO 2 (Lesson 2.4: Modeling Natural Selection Lab).

AREA OF FOCUS

- Emphasis on Analytical Reading and Writing

SUGGESTED TIMING

Less than 45 minutes

HANDOUTS

- 2.3.A: Ladybugs and the Environment
- 2.3.B: Hierarchy of Life Cards

MATERIALS

- LCD projector, electronic whiteboard, or other technology for displaying a photo
- digital image of Asian ladybug phenotype variation
- scissors

COURSE FRAMEWORK CONNECTIONS

<table>
<tr><th colspan="2">Enduring Understandings</th></tr>
<tr><td colspan="2">

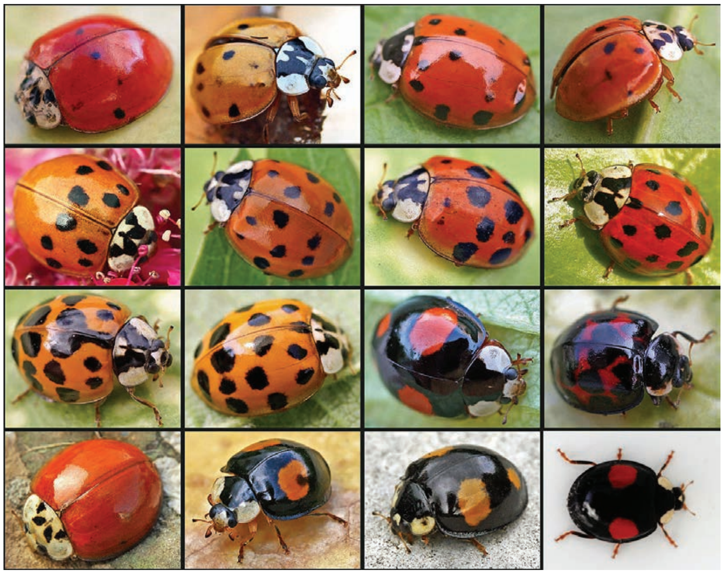
- Biological evolution is observable as phenotypic changes in a population over multiple successive generations.
- Speciation, extinction, and the abundance and distribution of organisms occur in response to environmental conditions.

</td></tr>
<tr><th>Learning Objectives</th><th>Essential Knowledge</th></tr>
<tr><td>EVO 2.2(a) Describe how selective pressures in the environment can affect an organism's fitness.</td><td>EVO 2.2.1 Darwin's theory of natural selection is that a selective mechanism in biological evolution may lead to adaptations.
a. Abiotic ecosystem components (e.g., nutrients) and biotic ecosystem components (e.g., predators) act as selective pressures.</td></tr>
</table>

PART 1: MAKING CONNECTIONS TO THE HIERARCHY OF LIFE

The goal of this part of the lesson is to have students make direct connections to concepts from Unit 1: Ecological Systems and to elicit their prior knowledge about the levels of organization found within ecological systems.

- Show students the collection of photos of the Asian lady beetle (or ladybug), *Harmonia axyridis*. Before you explain to students that these images are all one species, ask them to closely observe the photo and record all their observations.



Photos of *Harmonia axyridis.* Credit: © Entomart. **https://commons.wikimedia.org/wiki/File:Harmonia_axyridis01.jpg**.

- Lead a whole-class discussion by asking the following questions:
  - What do you notice about the beetles?
  - Do you think this is a picture of one species or more than one species? Why?
  - What information would you need to know in order to determine if it is just one species?

Guiding Student Thinking

During the discussion, students should point out the variations in color and spot patterns. The physical diversity may lead some students to think that this image shows many different beetle species. However, students should remember that members of a species must be able to breed and produce fertile offspring with one another. Students can conclude that in order to determine if the beetles are the same species, they need to know if the beetles can produce viable offspring.

You can now confirm for students that the photos do show members of one species: the Asian ladybug, *Harmonia axyridis*. Have students examine the background information about this species provided at the top of **Handout 2.3.A: Ladybugs and the Environment**.

- Have students work in pairs to complete Part 1 of the handout. Students should fill in a description and an example on each of the provided cards about the hierarchy of life (see **Handout 2.3.B: Hierarchy of Life Cards**). To do this, students should draw on their prior knowledge about the structure and hierarchy of life as well as the background information about the Asian ladybug. Finally, have students number the cards to construct a hierarchy, starting with the first level of organization—organism.

Classroom Ideas
You can have students cut out the cards either before or after they have completed filling in their information. They can then arrange them in the hierarchy. This provides a great visual diagram for students.

1) Organism ⟶ 2) Population ⟶ 3) Community ⟶ 4) Ecosystem ⟶ 5) Biome ⟶ 6) Biosphere

- Allow students to share their descriptions and examples with the entire class. Then, revisit the image of the ladybugs.

PART 2: USING OBSERVATIONS TO MAKE INFERENCES ABOUT LADYBUGS

In this part of the lesson, students work in pairs to think about how phenotypic variations in an Asian ladybug population may influence survival and reproduction. They are also asked to predict what may change if the environment changes.

- Have students continue to work in pairs to answer the questions in Part 2 of Handout 2.3.A, which explore the effects of the phenotypic differences shared among the population of ladybugs.
- Students should begin to formulate ideas about how different traits may be beneficial or detrimental under various environmental conditions. While student answers will vary, the portion of the student handout included at the end

Meeting Learners' Needs
If students have difficulty answering the questions in Part 2 of Handout 2.3.A, you can provide them with a modified sentence expansion technique. For example, the first two questions ask students to think about how ladybug traits influence their ability to survive and mate. Students could use sentence expansions as supportive prompts to their thinking, such as: "The ladybug traits are beneficial to survival, because ________________" or "The ladybug traits are beneficial to survival, so ________________."

of this lesson provides insight into what type of answers they should generate. It's important that students can simply list as many ideas about benefits or detriments to organisms as they can think of.

Instructional Rationale

The point of this part of the lesson is simply for students to start thinking about what type of traits may or may not be beneficial to organisms in the environment and how these traits may lead to differences in organisms' chances for reproduction. This helps scaffold students' understanding of the idea of *differential reproduction*, which is critical in the next lesson on natural selection. It's also key to introduce the term *phenotype* here to describe difference in traits. Students are more likely to remember these terms when they can attach them to an authentic context, such as variations in ladybug coloration.

- After students have had ample time to work on these questions, lead a whole-class discussion in which you invite student groups to share their ideas with the entire class.
- By the end of the class discussion, the following important ideas should emerge from the conversation. It would be helpful for you to record them on the board for students to see:
  - Even though populations are made up of one species, individuals in the population may demonstrate different physical traits (phenotypes).
  - The differences in traits may influence the survival and/or the reproductive success of the individual.
  - If the individual survives, they can pass along those genes to the next generation.

PART 2: USING OBSERVATIONS TO MAKE INFERENCES ABOUT LADYBUGS

Think about a population of ladybugs that has all the phenotypic differences you observed. Consider how those differences impact the species.

1. How might the variety of traits affect the survival of the ladybugs?

   Benefits include: 1) warning coloration to decrease predation and 2) darker colors that absorb more sunlight, allowing ladybugs to stay warmer in colder climates. Note: It is still productive if students think about camouflage as a possible benefit. However, they should see that in this case the ladybug coloration actually makes them stand out in their environment.

2. How might the variety of traits affect the reproduction of individuals?

   Traits that allow organisms to survive by decreasing predation increase their chances of reproduction. Also, certain coloration variances may be more helpful in attracting mates, thereby increasing chances of reproduction.

3. Describe how traits (phenotypes) and reproduction of ladybugs are connected to one another.

   If a trait (phenotype) helps an organism survive or attract mates, then the organism will likely have more opportunities to reproduce than organisms who do not have that trait.

4. Explain why survival and reproductive success may not be equal for all individuals in this population.

   Since the ladybugs have different coloration, they may experience different abilities in escaping predators or attracting mates.

5. Describe how changes in the ladybugs' environment may influence their survival or reproduction.

   If the environment changes, then the coloration (or trait) they have may not be as beneficial for them. For example, if the climate warms in a given area, then darker coloration in ladybugs may not be as beneficial as it was in colder environments.

Handout 2.3.A

LESSON 2.4

Modeling Natural Selection Lab

OVERVIEW

LESSON DESCRIPTION

Part 1: Data Collection for Natural Selection Simulation

Students are first introduced to the context that they will be modeling: survival rate of brown-lipped snails. They then collect data using the protocol for the model.

Part 2: Data Analysis for Natural Selection Simulation

After students have collected data, they analyze their results by graphing the frequencies of brown-lipped snails for each generation. They then work in small groups to make evidence-based claims about the characteristics necessary in a population to allow change over time. Finally, students participate in a whole-class discussion to summarize their ideas about the process of natural selection.

Part 3: Modification of the Natural Selection Model

Students return to the snail model and modify some of the parameters. They then make predictions about what they may see and model their predictions. Finally, students engage in some peer-to-peer review and discussion of each other's modifications and analysis.

CONTENT FOCUS

During this exploratory laboratory lesson, students model the changes in phenotype frequencies in a prey population over three generations. They should begin to develop an understanding of what is required for a population to change over time through natural

AREA OF FOCUS

- Attention to Modeling

SUGGESTED TIMING

~180 minutes

HANDOUT

- 2.4: Modeling Natural Selection

MATERIALS

- three colors of beans (e.g., black beans, kidney beans, and navy beans)
- electronic whiteboard, LCD projector, or other technology for displaying images and showing online videos (optional)
- internet access to one of the following videos (optional): **http://statedclearly.com/videos/what-is-natural-selection** (9:18) or **https://ed.ted.com/lessons/myths-and-misconceptions-about-evolution-alex-gendler** (4:22)

selection by analyzing data through guided small-group discussions and whole-class discussions. Later in the lesson, students return to the model and investigate what happens to the same population when they modify the parameters of the model and run the investigation again.

The practice performance task that follows this lesson provides an opportunity for students to practice writing evidence-based claims and applying their knowledge of natural selection to real data sets. The task can also be used before Part 3 of this lesson.

COURSE FRAMEWORK CONNECTIONS

Enduring Understandings	
▪ Biological evolution is observable as phenotypic changes in a population over multiple successive generations. ▪ Speciation, extinction, and the abundance and distribution of organisms occur in response to environmental conditions.	
Learning Objectives	**Essential Knowledge**
EVO 2.2(a) Describe how selective pressures in the environment can affect an organism's fitness. **EVO 2.2(b)** Explain how selective pressures in the environment could cause shifts in phenotypic and/or allele frequencies. **EVO 2.2(c)** Use data to describe how changes in the environment affect phenotypes in a population. **EVO 2.2(d)** Predict how allelic frequencies in a population shift in response to a change in the environment.	**EVO 2.2.1** Darwin's theory of natural selection is that a selective mechanism in biological evolution may lead to adaptations. **a.** Abiotic ecosystem components (e.g., nutrients) and biotic ecosystem components (e.g., predators) act as selective pressures. **b.** Favorable traits in a given environment lead to differential reproductive success, or fitness, and over time can produce changes in phenotypic and/or allele frequencies. **c.** Heritable traits that increase an organism's fitness are called adaptations. **d.** Over time, the relative frequency of adaptations in a population's gene pool can increase. **e.** Patterns of natural selection can include phenomena such as coevolution, artificial selection, and sexual selection.

	EVO 2.2.2 Favorable traits are relative to their environment and subject to change. **a.** Changes in the environment happen both naturally (e.g., floods, fires, climate change) and through human-induced activities (e.g., pollution, habitat destruction, climate change).

SETUP AND PREPARATION NOTES

- The three colors of beans represent dark, intermediate, and light-colored snails. (As an alternative to beans, other materials such as different colors of hole-punched paper can be used.)
- There are several ways to simulate the "environment" for this lab. The most common are to use a colorful or patterned fabric to place the bean on, or to use colored poster paper to place different colored hole-punches (including the color of the background). Keep in mind that the goal is for at least one phenotype of the snail (beans or hole-punch) to have a survival advantage in that given environment (fabric or poster paper) so that they are chosen less often by the predatory birds (students).
- For each lab group, prepare a bag with 25 beans of each color (i.e., dark, intermediate, and light). This will represent the initial population of snails.
- Prepare additional bags with 50 beans of each color for each lab group to speed up the transition between generations of the simulated populations.
- If you have a large enough area outside to conduct this lab, then students can "hunt" for beans in a grassy area. You should pre-mark a plot of grass for this ahead of time. You may use one large plot with your students or several smaller plots for individual lab groups.
- If using large fabric or poster paper for your background, it should be pre-cut for each student group.

Additional Lab Materials

- containers for sorting beans
- plastic spoons
- small paper or plastic cups
- graph paper
- stopwatch or timer
- clipboard for student recorders when outside (optional)

INTRODUCTION: STUDENT MISCONCEPTIONS ABOUT NATURAL SELECTION

In this laboratory lesson, students have an opportunity to model natural selection and then evaluate what characteristics must exist in a population for it to evolve. During this in-depth lesson, students collect and analyze data to draw conclusions about natural selection.

Guiding Student Thinking

There are many common misconceptions about natural selection that can make it harder for students to develop a deep and appropriate understanding of this concept. It can be very difficult to uncover misconceptions without asking targeted discussion questions. It may be helpful to explore some of the common student misconceptions prior to engaging in this investigation. We have provided a list of four common misconceptions to be aware of below. However, the University of California, Berkeley, has compiled a longer list of misconceptions that exist about evolution and natural selection, which is available at **https://evolution.berkeley.edu/evolibrary/misconceptions_faq.php#a3**.

- Listed below are four misconceptions to look out for during this lesson and how to address them:
  1. Students may understand *variants* in a population to mean "different species." To help prevent this misconception from developing, reinforce the idea that the snails (beans) all belong to a population of the same snail species—the brown-lipped snail.
  2. Students may understand natural selection (and evolution in general) as directional and purposeful. Help students avoid constructing explanations that use the language of agency. Words like "need," "try," or "want" to describe change can reinforce the misconception that a species is purposefully improving toward a solution.
  3. Students may think that natural selection is a random process. This is incorrect. Explain that natural selection is a natural process that occurs as a result of interacting factors in an ecosystem, such as variation and selective pressures that already exist in the environment in which the population occurs. Mutation, the genetic source of the variation that is found, is random; natural selection is not.
  4. Students may believe that *fitness* is all about an individual's survival, even after hearing a careful definition and explanation of fitness as the ability to leave offspring in the next generation. Return to this idea frequently and probe student understanding through regular discussion to uproot this misconception.

PART 1: DATA COLLECTION FOR NATURAL SELECTION SIMULATION

In the first part of this lesson, students model predation of a brown-lipped snail population that demonstrates only three of the color variants (dark, intermediate, light). Students use three different colors of beans (or similar materials) to represent the population. The simulation requires some prior preparation: beans need to be sorted into bags; roles need to be assigned to individuals in student groups; students may need to practice certain roles; and students need to understand the process and constraints of the simulation. You may want to highlight the following connections between the simulation and the ecological context.

- To simulate predation of snails by the song thrush, students use a plastic spoon (beak) to pick up each bean (snail) and put it in a plastic cup (stomach).
- Because the brown-lipped snail is hermaphroditic, and thus can mate with any snail it runs into, the model can be simplified as follows: for each snail that survives a hunting round (60 seconds), students simulate it reproducing one offspring, thus leaving itself and one new snail in the next generation.
- For purposes of this model, we will assume no snail deaths from natural causes from generation to generation.

This part of the lesson sets students up for Part 2, in which they graph the data and observe the changes in the variation present in the population. Because this model shows (1) variation in the population, (2) heritability of that variation, and (3) selection for (or against) some of the variations in the population, students observe natural selection. It is best if students have an opportunity to make claims about what is necessary for natural selection using their data before you explain or summarize these key ideas.

INTRODUCING THE SCENARIO

- Prior to beginning the simulation, introduce students to the scenario they will be investigating through modeling. For this lab, we will investigate whether there is a relationship between phenotypic variation in the brown-lipped land snail (*Cepaea nemoralis*) and the predation of this snail by a common predator, the song thrush (*Turdus philomelos*). Have students read the introduction on **Handout 2.4: Modeling Natural Selection**, and then lead a whole-class discussion to ensure students understand the context prior to modeling how this predator–prey relationship may influence color variation in snails. It may also be helpful to project or display the images from the student handout, included on the next page, to aid students in viewing color or detail.

Handout 2.4

- A few questions that could prompt student thinking during the whole-class discussion are:
  - How could snail color variation impact predation by the song thrush?
  - Since brown-lipped snails are not native to the United States, what are some possible consequences of their introduction?

Guiding Student Thinking

Students should have some early thoughts about characteristics of prey, such as camouflage, that can increase chances of survival. Since the brown-lipped snail is not native to the U.S. but has been introduced, it is a good time to remind students about invasive species. Have students consider what could happen to this species of snail since its main predator, the song thrush, is not in the U.S.

STUDENT ROLES IN THE NATURAL SELECTION SIMULATION

- After introducing students to the scenario they will be modeling, assign the following roles to students and provide a brief explanation of what their role requires. The simulation could be done either as an entire class, if you have a large enough area, or in several smaller groups of three or four students. (Recommendations for the number of students needed for each role are indicated for both small-group and whole-class simulations.)
  - **Song Thrush Birds:** Students in this role will hunt and consume as many snails as they can during a 60-second interval. Students will each

Classroom Ideas

It may save time to consider what roles are best for which students prior to class and have a list posted. While the majority of students will be song thrush birds, the field biologists and data analysts are roles that may be better suited for students who are detail-oriented or confident in their math skills.

be given a plastic spoon and small cup to simulate the beak and stomach of the bird. To simulate the behavior of this predator, students will need to learn a specific hunting behavior. *Hunting behavior:* Students prey on snails (beans) in the plot by scooping up one bean at a time with a plastic spoon (beak) and putting it into a cup (stomach). Starting from a standing position, students must bend down to get the bean, stand up, and *then* put the bean in the cup. (If students put a bean into the cup while bent over, or if they catch and "eat" more than one bean at a time, they must start the simulation over.) It is helpful to have a few students demonstrate this technique before the simulation begins. You may choose to do this demonstration inside, to minimize the amount of instruction that will take place outside. (Assign this role to one or two students per group, or to most of the students if it is a whole-class activity.)

- **Field Biologist:** Students in this role will collect data on the number of snails (beans) consumed after each round of hunting and report this number to the data analyst. (Assign this role to one student per group, or one or two students for each color of bean if it is a whole-class activity.)
- **Data Analyst:** After each round of hunting, students in this role will record and organize data in the data table provided. They will also be responsible for calculating rows C and E. (Assign this role to one student per group, or two students if it is a whole-class activity.)

NATURAL SELECTION SIMULATION PROTOCOL

1. To begin the simulation, introduce students to the materials being used to simulate predation on the snails by the song thrush.
2. Have students randomly scatter 25 of each color of "snail" onto the background plot. These should be evenly scattered, not clumped together.
3. Once the background plot has been populated and the student song thrushes have been taught how to hunt, set a timer for 60 seconds and let them hunt. This is one hunting round. At the end of the round, the song thrushes give their different-colored beans to the field biologists.
4. The field biologists count the total number of each color of snail eaten and report these data to the data analysts.
5. Data analysts enter the data for Generation 1 in Data Table 1 on the handout, shown on the next page for reference.
   - For rows D and E, remind students of the assumption that each surviving snail produces one offspring. For example, if there are 10 light-colored snails remaining, they will each have one light snail offspring. Thus 10 new light snails should be added to the population, for a total of 20 in the population.

- Point out that the population at the end of each hunting round (row E) will be the same as the population at the beginning of the next (row A). Data analysts can simply copy row E from the first round into row A of the next.

DATA TABLE 1: COLOR VARIATION IN THE BROWN-LIPPED SNAIL POPULATION OVER TIME

		Generation 1			Generations 1 and 2			Generations 1, 2, and 3		
		Dark	Inter-mediate	Light	Dark	Inter-mediate	Light	Dark	Inter-mediate	Light
A	**Population number at the beginning of the hunting round** (row E of previous generation)	25	25	25						
B	**Number of individuals eaten during hunting**									
C	**Number of surviving individuals** (row A – row B)									
D	**Number of offspring** (same as row C)									
E	**Population number at the end of the hunting round** (row C + row D)									

Handout 2.4

6. Field biologists now add the offspring for each color (row D) to the simulated population in preparation for the next round. Remind students to scatter the beans when adding them to the population rather than clumping them together.
7. Repeat steps 2–6 two more times, as two new generations are added to the population.

Classroom Ideas

If there is enough time, it is a good idea to have all the lab groups pool their data into one table with the class average for each trial. This typically results in better data since it is based on a large sample, and will help prevent a single lab group from generating ideas about natural selection based on a potentially poor data set.

Guiding Student Thinking

Students often struggle with understanding that adaptations and natural selection do not occur at the individual level. Therefore, it is **very** important for students to understand that the change that is happening is between *generations* of a population. For brown-lipped snails, a new generation emerges approximately every 2–5 years. Therefore, these three generations represent a span of time between 6 and 15 years. This model should promote student thinking about evolution occurring at a population level over generations and not to a single individual. You may need to emphasize this with students after the first round of hunting and adding offspring to the population.

PART 2: DATA ANALYSIS FOR NATURAL SELECTION SIMULATION

In this next part of the investigation, students reflect on the data collected as they construct their own understanding of the process of natural selection. This activity includes both small, collaborative group discussions and focused whole-class conversations.

CALCULATING AND GRAPHING RELATIVE FREQUENCY

- First, have each group share their raw data from Data Table 1. Include the totals in a collective version of Data Table 1 that you can display.
- Next, have each student use the collective data table (for Data Table 1) to populate Data Table 2 on Handout 2.4. This will require students to calculate the frequency of each trait in the population for each generation.

- Finally, have students individually graph the relative frequency of each color for the snails based on Data Table 2. This will allow students to start analyzing the data collected and to begin identifying trends.

PEER-TO-PEER EVALUATION OF DATA

- Students will now work in small groups to discuss the data to deepen their understanding of the trends they observed. In order to support peer-to-peer dialogue, have students use the discussion questions on Handout 2.4 shown below to guide them. During the group discussion, circulate around the room and provide support as needed.

GROUP DISCUSSION QUESTIONS: INVESTIGATIONS INTO NATURAL SELECTION

1. How did your population change in just one generation versus after three?
2. What was the most successful color of snail? Why was it so successful?
3. What was the least successful color of snail? Why was it unsuccessful?
4. What do you think would happen to the least successful color if the experiment were to continue five more generations?
5. What is the relationship between color and reproductive rates in snails? Explain your reasoning.
6. Consider your data for this simulation. Would the trends seen in your graph have been the same if:
   (a) Color is not heritable (in other words, a snail could have any color of offspring)? Explain your ideas.
   (b) The environment was different (in other words, the snails weren't being hunted in the current environment/background, but instead in another type of environment/background)? Explain your ideas.
   (c) A new mutation arises that results in individuals possessing a green color trait? Explain your ideas.
   (d) A nonvisual predator was eating the snails? Explain your ideas.
   (e) The light-colored variant has better immunity to a virus that infects the population? Explain your ideas.
   (f) The light-colored snails have five more offspring per round than the rest of the snails? Explain your ideas.

FINAL QUESTIONS: NATURAL SELECTION

1. Explain how the color of the snails influenced the frequency of the different colors found in the population after three generations.
2. Predict how the population of each color snail may change over 10 more generations. Explain your reasoning.
3. Can you think of any other variables that may have altered how the distribution of variation in the population of snails changed over time?
4. Consider the ideas you have discussed in the questions above. As a group, list three factors that must exist in a population for change to occur over generations.

Handout 2.4

Meeting Learners' Needs

Some students may have difficulty understanding what *relative frequency* actually means in this context. These students may need additional support in thinking about this term as either a ratio or a percentage of how often this trait occurs in the total population in this given environment. Help them understand it is a ratio of snail color to total population size:

$$\frac{\text{Number of snails for each color}}{\text{Total snail population}}.$$

Classroom Ideas

You can have groups work on the first set of discussion questions together in class, or at home as homework if pacing is tight. You may also want students to individually complete the final questions as an opportunity for formative assessment.

Guiding Student Thinking

These questions are intended to help students make connections between the trait variations in populations, heritability of those traits, and selective pressures for or against those traits. Encourage students to think about how the color variation in the population may lead to different survival rates (e.g., some colors are easier for predators to see). Also have them consider how a change in a variable, such as the color of the background environment, could result in selection favoring a new trait. Students should see that the relative frequency of traits in the population (color variations in the snails) is therefore influenced by the selective pressure of predation from the birds; this pressure will continue to influence the relative frequency of traits in the population over the next few generations if conditions remain the same. It may be helpful to ask students to generate a list of heritable versus nonheritable characteristics that could be influenced by predation.

CLASS DISCUSSION AND SHARING OF GROUP IDEAS

- Once groups have answered the group discussion questions and final questions, bring the class together to discuss their answers and explanations. Generate a whole-class list of student responses to the final question (question 4, the factors necessary in a population to result in change over time). Lead the class in a discussion to help them evaluate each of the ideas on the list. Cross off ideas as students collectively decide that a factor is not necessary. In the end, only three characteristics should remain:
    - Variation
    - Heritability of that variation
    - Selection for (or against) one or more of the heritable variants
- To conclude this part of the investigation, you may want to show a video to help students connect their new understanding about the process of natural selection with the concepts they learned about common descent with modification (Key Concept EVO 1: Patterns of Evolution). One possible resource is the Stated Clearly video “What Is Natural Selection?” (**http://statedclearly.com/videos/what-is-natural-selection**). A second option is the TED Ed video, “Myths and Misconceptions About Evolution” (**https://ed.ted.com/lessons/myths-and-misconceptions-about-evolution-alex-gendler**).

PART 3: MODIFICATION OF THE NATURAL SELECTION MODEL

In this part of the lesson, students revisit the model involving color variation in snails to deepen their understanding of the factors that influence evolution by natural selection in populations. Student groups propose a modification to the original model and predict whether or how it changes the outcome of natural selection. Students then test their predictions by running a second simulation. They collect data, analyze and compare data across simulations, and present an explanation for how their modifications influenced the effects of natural selection in their model populations.

STUDENT MODIFICATIONS TO THE SIMULATION PROTOCOL

- To begin, prompt student groups to think about how they would like to modify their model. Ask students to revisit their group discussion questions from Handout 2.4, shown below. In particular, student responses to question 6 may spur their creativity as they revise the snail model, so you could display the questions and allow groups time to reflect.

> 6. Consider your data for this simulation. Would the trends seen in your graph have been the same if:
>   (a) Color is not heritable (in other words, a snail could have any color of offspring)? Explain your ideas.
>   (b) The environment was different (in other words, the snails weren't being hunted in the current environment/background, but instead in another type of environment/background)? Explain your ideas.
>   (c) A new mutation arises that results in individuals possessing a green color trait? Explain your ideas.
>   (d) A nonvisual predator was eating the snails? Explain your ideas.
>   (e) The light-colored variant has better immunity to a virus that infects the population? Explain your ideas.
>   (f) The light-colored snails have five more offspring per round than the rest of the snails? Explain your ideas.

Handout 2.4

- Student proposals may include modifications to the model such as changing the reproductive rate of one of the variants; starting the population with more or less variation; changing the environment (gravel or dirt instead of grass, or a different color fabric or background than the one used); or removing heritability of the color trait.
- Next, have student groups write new protocols, taking the following into account:
  - Can the idea be modeled? How? Are additional supplies needed?
  - If the original experiment was done as a whole class, how can the protocol be modified for a small group of students? Factors to consider include size of hunting plot, original population size, and how to assign all the necessary roles to group members.

Instructional Rationale

The focus here is to allow students to engage in an inquiry-based approach to changing the prior model of natural selection. Inquiry-based investigations are extremely important as they elevate students' critical thinking, allow deeper engagement in science practices, and often increase student engagement overall. Student choices about modification also serve as a highly valuable way to assess what students know about mechanisms of natural selection at this point. Therefore, it is beneficial to really allow students to have ownership over changing the protocol. However, some choices by students may result in additional confusion about natural selection if they don't fully attend to the questions above. So, this is also a good opportunity for students to practice developing appropriate scientific questions and predictions, which sometimes requires a bit more teacher guidance.

Classroom Ideas

To help alleviate in-class time constraints, students could collaborate on a shared Google Doc outside class to design the modified protocol so they are ready to begin the simulation the next day. Groups could also trade their experimental protocols and peer edit for clarity and completion. This will save class time and promote peer-to-peer discussion and learning. If class time is not a constraint, students could produce their protocol on chart paper and peer-to-peer collaboration could occur through a gallery walk.

DATA COLLECTION AND ANALYSIS FOR THE REVISED MODEL

Since each modeling protocol may be different, student groups will need to develop their own tables for collecting their data. Students may also need some graph paper for analysis.

- Allow students time to run the new simulation and collect data using their modified protocols.
- Provide student groups with whiteboard space or large banner or chart paper and prompt them to:
  - Write an explanation of how they modified the original protocol.
  - Sketch a graph of their data.
  - Determine whether natural selection occurred in their model, and support their claim with evidence. (Was there variation, heritability, and selection? Can they explain the evidence for each?)
  - Consider whether their model had a similar outcome to the original model and explain why or why not.
- Finally, give each group a few minutes to present their findings to the class. Encourage peer-to-peer dialogue and discussion about each group's findings and how they modeled the process of natural selection.

UNIT 2

PRACTICE PERFORMANCE TASK

Tusklessness in African Elephants

OVERVIEW

DESCRIPTION

Students have an opportunity to demonstrate their understanding of natural selection by investigating a new context: tusklessness in African elephants.

CONTENT FOCUS

This practice performance task is designed to be used in conjunction with Lesson 2.4: Modeling Natural Selection Lab in this key concept (Key Concept EVO 2: Mechanisms of Evolution). The task challenges students to transfer the knowledge about natural selection they have developed thus far to a new scenario, tusklessness in African elephants.

This is a good opportunity to assess student understanding of the natural selection model they investigated in Lesson 2.4, prior to them engaging in the performance task for this unit. You can also use this task as a formative assessment between Parts 2 and 3 of Lesson 2.4.

AREAS OF FOCUS

- Emphasis on Analytical Reading and Writing
- Strategic Use of Mathematics

SUGGESTED TIMING

~45 minutes

HANDOUT

- Practice Performance Task: Tusklessness in African Elephants

MATERIALS

- electronic whiteboard, LCD projector, or other technology for showing an online video
- internet access to the HHMI BioInteractive video “Selection for Tuskless Elephants” (6:40), available at **https://www.biointeractive.org/classroom-resources/selection-tuskless-elephants**

COURSE FRAMEWORK CONNECTIONS

Enduring Understandings	
▪ Biological evolution is observable as phenotypic changes in a population over multiple successive generations. ▪ Speciation, extinction, and the abundance and distribution of organisms occur in response to environmental conditions.	
Learning Objectives	**Essential Knowledge**
EVO 2.2(a) Describe how selective pressures in the environment can affect an organism's fitness. **EVO 2.2(b)** Explain how selective pressures in the environment could cause shifts in phenotypic and/or allele frequencies. **EVO 2.2(c)** Use data to describe how changes in the environment affect phenotypes in a population. **EVO 2.2(d)** Predict how allelic frequencies in a population shift in response to a change in the environment.	**EVO 2.2.1** Darwin's theory of natural selection is that a selective mechanism in biological evolution may lead to adaptations. **a.** Abiotic ecosystem components (e.g., nutrients) and biotic ecosystem components (e.g., predators) act as selective pressures. **b.** Favorable traits in a given environment lead to differential reproductive success, or fitness, and over time can produce changes in phenotypic and/or allele frequencies. **c.** Heritable traits that increase an organism's fitness are called adaptations. **d.** Over time, the relative frequency of adaptations in a population's gene pool can increase. **e.** Patterns of natural selection can include phenomena such as coevolution, artificial selection, and sexual selection. **EVO 2.2.2** Favorable traits are relative to their environment and subject to change. **a.** Changes in the environment happen both naturally (e.g., floods, fires, climate change) and through human-induced activities (e.g., pollution, habitat destruction, climate change).

SUPPORTING STUDENTS

BEFORE THE TASK

- To introduce the new context, have students watch "Selection for Tuskless Elephants" (**https://www.biointeractive.org/classroom-resources/selection-tuskless-elephants**). This video on the phenomenon of tusklessness in Mozambique's Gorongosa National Park provides an introduction to the work of Dr. Joyce Poole. Poole studies how poaching is influencing the frequency of tusklessness in African elephants.
- After students watch the video, have them read the introduction on the handout **Practice Performance Task: Tusklessness in African Elephants**. Then lead a whole-class discussion to ensure that students understand the new context prior to letting them complete the questions. Some probing discussion questions may be:
  - What are tusks? How do they support an elephant's role as an herbivore?

    Tusks are elephants' incisor teeth. Because they are herbivores, elephants use their tusks to help them obtain plant matter to eat—by stripping off the bark from trees, for example.

  - How are the research findings on tusklessness in the national parks of Zambia and Uganda similar to Dr. Poole's findings in Gorongosa National Park?

    All the parks are seeing increased frequency in tuskless elephants, particularly females, due to poachers who are killing the elephants that have tusks.

DURING THE TASK

- Next, have students complete the questions on the handout. The first question has them calculate potential frequencies of the tusklessness trait in the Gorongosa National Park elephant population. Students then use evidence from the text and their data to craft sentences explaining why the frequency of tusklessness in the male population differs from that of the female population. As practiced in Unit 1, each sentence will use one of the following conjunctions: *but*, *because*, *so*. Finally, students are asked to use the principles of natural selection to explain the increase in tusklessness in the elephant population as a whole.

SCORING GUIDELINES

There are 9 possible points for this performance task.

Question 1

Sample Solutions	Points Possible
(a) Frequency of Tusklessness in Females $$\frac{78\,(\text{tuskless females})}{260\,(\text{total female elephants})} = 0.3 \times 100 = 30\%$$ (b) Frequency of Tusklessness in Males $$\frac{27\,(\text{tuskless males})}{270\,(\text{total male elephants})} = 0.1 \times 100 = 10\%$$ (c) Frequency of Tusklessness in Elephant Population $$\frac{105\,(\text{tuskless females + males})}{530\,(\text{total elephant population})} = 0.2 \times 100 = 20\%$$	**3 points maximum** 1 point for each correct solution with work shown *Scoring note for parts (b) and (c)*: Some students who are more proficient in mathematics may quickly see that 27 is 10% of 270 in part (b) or that the average of the two frequencies (30% and 10%) is 20% for part (c). So, you may decide to award these points without work shown. However, it is always a good habit for students to show work so that they make their thinking visible, which can help prevent them from making careless computational errors.
Targeted Feedback for Student Responses	
Some students may struggle to begin to set up this calculation. If so, provide the hint that to find the frequency of tusklessness they first need to find the percentage of female elephants that are tuskless in the entire population. You may even want to help start the setup by providing the words instead of the numbers (i.e., frequency of tusklessness in females = number of tuskless females/total number of females).	

TEACHER NOTES AND REFLECTIONS

Question 2

Sample Solutions	Points Possible
Answers will vary. An example of a 3-point answer is: ▪ Tuskless males are more likely to survive than males with tusks **because** poachers do not target tuskless males. ▪ The frequency of tusklessness in the total population is 20%, **but** it is only 10% in the male population. ▪ Tuskless males have a hard time mating, **so** the frequency of tusklessness in the male population is lower than in the female population.	**3 points maximum** 1 point for each appropriate sentence that uses evidence from the text or data table *Scoring note*: A student should not lose a point for referencing an incorrect calculation from Question 1 if their reasoning is still appropriate. For example, if a student had incorrectly calculated 1% rather than 10%, in the example above, they should still get a point for the first sentence.

Targeted Feedback for Student Responses
Have students who do not provide appropriate evidence return to the text and underline or highlight portions that may provide this type of evidence.

TEACHER NOTES AND REFLECTIONS

Question 3

Sample Solutions	Points Possible
▪ *Selective Pressure*: Students should identify that poaching is a selective pressure for the African elephants that works against elephants with tusks. ▪ *Variation*: There are two different forms of the trait—elephants with tusks and elephants born tuskless. ▪ *Heritability*: Since more tuskless elephants are surviving poaching events, they are allowed opportunities to reproduce and pass along the trait of tusklessness to their offspring. Therefore, over time, there may be more tusklessness present in the population.	**3 points maximum** 1 point for appropriate use of the idea of *selective pressure* 1 point for appropriate use of the idea of *variation* 1 point for appropriate use of the idea of *heritability*
Targeted Feedback for Student Responses	
Students who only provide one or two of these concepts should return to the discussion questions and final questions from the natural selection lab to find additional factors.	

TEACHER NOTES AND REFLECTIONS

UNIT 2

LESSON 2.5

Launch Lesson – Introduction to the Process of Speciation—Salamander Evolution

OVERVIEW

LESSON DESCRIPTION

Part 1: Introduction to the *Ensatina* Salamanders of California
Students watch and discuss a video clip that introduces the context and ideas about geographic mechanisms of adaptive divergence for California salamanders in the genus *Ensatina*.

Part 2: Further Investigation into Salamander Evolution
Students work in groups to examine further research on the evolution of these salamanders and how reproductive isolation may also play a role in keeping these subspecies distinct, even in areas where interbreeding can occur.

Students then do a gallery walk to examine and discuss peers' ideas. Finally, a whole-class discussion generates key ideas about the process of speciation.

CONTENT FOCUS

In the lesson on *Archaeopteryx* for Key Concept EVO 1: Patterns of Evolution, students were introduced to how scientists use shared morphological characteristics in the fossil record to establish common ancestry. Now that students have gained a deeper understanding of the mechanisms that allow for adaptations and species' characteristics to change over time through natural selection, they are ready to more deeply explore the process of speciation. This short investigation into

AREA OF FOCUS

- Emphasis on Analytical Reading and Writing

SUGGESTED TIMING

~45 minutes

HANDOUTS

- 2.5.A: Introduction to the *Ensatina* Salamanders of California
- 2.5.B: Further Investigation into Salamander Evolution

MATERIALS

- LCD projector, electronic whiteboard, or other technology for showing an online video and image
- internet access to the PBS *Deep Look* video "Ensatina Salamanders are Heading for a Family Split" (4:38), at **https://www.pbs.org/video/ensatina-salamanders-are-heading-for-a-family-split-miidxi/**
- materials to present group work: whiteboards or large poster paper, neon dry-erase markers

California salamanders of the genus *Ensatina* introduces students to ways in which reduced gene flow can serve as a mechanism for speciation—in this case, in the form of reproductive isolation due to geographic barriers. This lesson should be completed before any formal discussion about speciation.

COURSE FRAMEWORK CONNECTIONS

Enduring Understandings	
▪ Speciation, extinction, and the abundance and distribution of organisms occur in response to environmental conditions.	
Learning Objectives	**Essential Knowledge**
EVO 3.1(a) Explain how geographic separation events can lead to the formation of new species. **EVO 3.1(b)** Describe mechanisms that contribute to reproductive separation that could lead to speciation.	**EVO 3.1.1** Speciation occurs when populations of the same species are separated, resulting in reduced gene flow, which over time allows populations to become genetically distinct from one another. **a.** Geographic separation: a physical barrier (e.g., rivers changing course, glacial movement, continental drift). **b.** Habitat specialization: niche differentiation from others in the population. **c.** Behavioral separation: different mating habits, times, or locations from others in the population. **d.** Mechanical separation: structural differences in sex organs that make individuals within a population unable to reproduce with one another.

UNIT 2

PART 1: INTRODUCTION TO THE *ENSATINA* SALAMANDERS OF CALIFORNIA

The first part of this launch lesson introduces students to possible causes of speciation. It leverages students' prior knowledge about how camouflage and mimicry may be favored traits in some environments, as they may decrease selective pressure, and also elicits prior knowledge of how different environments have varying pressures.

- First, call students' attention to the driving questions and ideas for investigation found on **Handout 2.5.A: Introduction to the *Ensatina* Salamanders of California** (also shown below). Explain that they will consider these questions while they watch a video.

1. How did the subspecies adapt differently to their new environments as they migrated south?

2. What selective pressures may have led to the survival of these new traits in the salamanders?

3. What has caused the reduced gene flow between the subspecies?

Handout 2.5.A

- Next, ask students to record their notes and observations as they watch the PBS *Deep Look* video "Ensatina Salamanders are Heading for a Family Split" (**https://www.pbs.org/video/ensatina-salamanders-are-heading-for-a-family-split-miidxi/**). Narration introduces students to possible driving factors that, over time, may lead to speciation.

- After showing the video, lead a whole-class discussion that allows students to share their notes and observations. While students should feel free to share any of their observations, the main goal here is to work toward answering the three driving questions. During the discussion, encourage students to recall prior knowledge about pressures of predation that could lead to differential survival for organisms that demonstrate camouflage or that mimic toxic prey. By the end of this discussion, students should have an understanding of the answers to the three questions:
  - How did the subspecies adapt differently to their new environments as they migrated south?

    There were two migratory routes followed by the salamanders: one along the Sierra Nevada mountain chain, where animals moved into the forest region; the other along the coastal mountains. Along the forested route, the salamanders with spots that helped them blend in survived. Along the coastal routes, salamanders that mimicked the appearance of a dangerously poisonous newt from the region were the ones that survived.
  - What selective pressures may have led to the survival of these new traits in the salamanders?

    Predation pressures in the new forested and coastal environments differed from pressures in the northern environment, so new traits were favored, such as large spots for camouflage and bright colors for mimicry.
  - What has caused the reduced gene flow between the subspecies?

    The forested and coastal regions are physically separated by a large area known as the Central Valley. This separation meant that salamanders from one region did not have as much opportunity to mate with those from the other. Therefore, the two populations of salamanders faced reduced gene flow due to geographic barriers.

Guiding Student Thinking

This is a good opportunity to reinforce ideas of natural selection that students may continue to struggle with. Remind students that these variations in subspecies occurred over **many** generations (millions of years). During this time, individuals that demonstrated genetic mutations allowing for better camouflage or warning mimicry survived more often than individuals that did not. Their survival allowed for increased chances of producing offspring with these same traits.

PART 2: FURTHER INVESTIGATION INTO SALAMANDER EVOLUTION

In this part of the lesson, students further investigate how the development of subspecies of *Ensatina* salamanders advances our understanding of the process of speciation.

- First, have students work in pairs or small groups to read the opening text and examine the map and table on **Handout 2.5.B: Further Investigation into Salamander Evolution**. The text gives more insight into why these subspecies remain distinct, even in areas that are not separated geographically. The map and table provide information about the salamanders' range and morphology. You may want to project images from the handout to help students see some of the details and colors.

> **Meeting Learners' Needs**
> If your students have difficulty with the opening text, you may want to have them take turns reading it aloud. This way, you can pause during the reading to clarify any potentially challenging words or phrases.

- After students have finished reading the opening text and examining the table, have them use the Notes column in the table to record their responses to the following questions:
  - What are the three subspecies that demonstrate camouflage adaptations?
  - What two subspecies along the coastal region demonstrate mimicry of toxic newts?
  - What two species did Dr. Devitt study?

  Having students respond to these basic text-dependent questions about the salamanders is a good way to ensure they are aware of which subspecies are being referred to in the text and their notes before beginning the higher-order thinking questions on the handout.
- Once you feel that all the student groups have a good understanding of the context and various subspecies, you can have them begin answering the set of four questions on Handout 2.5.B. Remind them that while they are doing this as a group and should discuss and collaborate on ideas and answers, they should also record them individually on their own handouts so they have them after the lesson.
- When students have completed the questions, allow each group to present their answer to question 4 for other student groups to see—on small or medium whiteboards, on large poster paper, or written in neon dry-erase marker on lab tables. Have students

> **Classroom Ideas**
> During the gallery walk, you might have one student from each group stay with their presentation to discuss it with classmates. You could also give these students a different colored marker to record any revisions to their presentations that stem from the gallery walk.

conduct a gallery walk of the group work and engage in peer-to-peer discussion as they examine each other's ideas. Students should make modifications to their own ideas based on these discussions with their peers.

Instructional Rationale

The study of speciation is often complex, so it's important not to present speciation as occurring in "clean-cut" moments where we can easily deduce lineage-splitting events. Therefore, this lesson purposefully focuses on a phenomenon, the California salamanders, which allows an opportunity to discuss the natural processes that lead to speciation without being definitive on whether speciation is occurring, or has occurred, in these subgroups. This allows students to generate diverse and viable ideas about speciation that will spark valuable peer-to-peer discussion.

- Finally, lead a whole-class discussion that allows students to share their ideas and answers to the four questions. For question 4, which was already discussed during the gallery walk, record on the board a class list of conclusions about speciation, and encourage students to highlight any new or conflicting ideas they identified from their peers' answers. Students should add to their own handouts any conclusions not already recorded. Some sample responses for the questions are provided on the next page.

EXTENDING THE LESSON

This launch task prepares students for deeper work examining speciation events and exploring how those are modeled through the use of phylogenetic trees. The following resources may be valuable as next-step lessons:

- HHMI's Lizard Evolution Virtual Lab (**www.hhmi.org/biointeractive/lizard-evolution-virtual-lab**)
- HHMI's Sorting Finch Species: Click and Learn (**www.hhmi.org/biointeractive/sorting-finch-species**)
- Understanding Phylogenies from the University of California, Berkeley (**https://evolution.berkeley.edu/evolibrary/article/evo_05**)

1. Typically hybrid offspring are not well adapted to their environment and are therefore less likely to survive. Explain this statement.

   Since hybrid offspring have a mix of characteristics from both subspecies, they don't blend in well nor do they fully mimic the toxic newt. Therefore, they will not reduce predation pressure and will likely not survive. They are also less likely to find mates and produce viable offspring.

2. Describe how Dr. Devitt's research findings also contribute to our understanding of why there continue to be distinct subspecies where the ring rejoins at the southern tip of the Central Valley.

   Devitt's findings suggest there may also be a reproductive barrier since "*eschscholtzii*, at least, has evolved such that the females no longer recognize *klauberi* as potential mates." Therefore, there remains reduced gene flow between the subspecies on the southern tip even though they live in the same area and do not face geographic barriers.

3. Do you think the splitting of the *Ensatina* salamanders is an example of speciation? Justify your answer.

   Student answers will vary here. Since even scientists are split on this issue, this allows for a diversity of viable answers. However, students should justify their answers with appropriate evidence that discusses the ideas of being able to interbreed, hybrids being less viable, and reduction of gene flow.

4. As a group, write at least three statements that describe how the development of new species (speciation) can occur.

   Sample responses:

   - Speciation occurs when genetic changes result in two or more new species where previously there had just been one species.
   - Speciation occurs over many generations.
   - In order for speciation to occur, there must be mechanisms of reduced gene flow.
   - Physical barriers can result in reduced gene flow. Examples of barriers include rivers, mountains, and large spaces between individuals (geographic isolation).
   - Reproductive barriers can also reduce gene flow. Examples of reproductive barriers include mating rituals, times, and locations.

Handout 2.5.B

Unit 2

Performance Task

PERFORMANCE TASK

The Flashy Guppy Data Analysis

OVERVIEW

DESCRIPTION

Students use their analytical reading skills to extract information from a real-world study on the variance in guppy populations found in river ecosystems in Trinidad.

This lesson is based on “Sex and the Single Guppy.” © 2010 by PBS. **http://www.pbs.org/wgbh/evolution/sex/guppy/low_bandwidth.html**.

CONTENT FOCUS

Students demonstrate their understanding of the factors of inheritance, differential reproduction, and selective pressures in unique environments. They utilize their knowledge of these factors to describe how natural selection influences phenotype frequency in a population.

AREAS OF FOCUS

- Emphasis on Analytical Reading and Writing
- Strategic Use of Mathematics

SUGGESTED TIMING

~45 minutes

HANDOUT

- Unit 2 Performance Task: The Flashy Guppy Data Analysis

MATERIALS

The following materials are optional:

- calculator
- ruler
- colored pencils

UNIT 2

COURSE FRAMEWORK CONNECTIONS

Enduring Understandings	
▪ Biological evolution is observable as phenotypic changes in a population over multiple successive generations.	
Learning Objectives	**Essential Knowledge**
EVO 2.2(a) Describe how selective pressures in the environment can affect an organism's fitness. **EVO 2.2(b)** Explain how selective pressures in the environment could cause shifts in phenotypic and/or allele frequencies. **EVO 2.2(c)** Use data to describe how changes in the environment affect phenotypes in a population. **EVO 2.2(d)** Predict how allelic frequencies in a population shift in response to a change in the environment.	**EVO 2.2.1** Darwin's theory of natural selection is that a selective mechanism in biological evolution may lead to adaptations. **a.** Abiotic ecosystem components (e.g., nutrients) and biotic ecosystem components (e.g., predators) act as selective pressures. **b.** Favorable traits in a given environment lead to differential reproductive success, or fitness, and over time can produce changes in phenotypic and/ or allele frequencies. **c.** Heritable traits that increase an organism's fitness are called adaptations. **d.** Over time, the relative frequency of adaptations in a population's gene pool can increase. **e.** Patterns of natural selection can include phenomena such as coevolution, artificial selection, and sexual selection. **EVO 2.2.2** Favorable traits are relative to their environment and subject to change. **a.** Changes in the environment happen both naturally (e.g., floods, fires, climate change) and through human-induced activities (e.g., pollution, habitat destruction, climate change).

SUPPORTING STUDENTS

BEFORE THE TASK

- Since there is an extended text used to introduce this performance task, remind students of the effective reading strategies they can use to annotate and extract information and highlight key ideas.
- If timing is an issue for completing this performance task, you may want to ask students to do the reading and annotation of the introductory text at home the night before.

DURING THE TASK

Support students in successfully completing this performance task by doing the following:

- Some students may need additional support in accessing the text in this performance task. If so, you may want students to work collaboratively in pairs to annotate the text and share key ideas. You may also want to chunk the reading for students and have a short debrief on it as a whole class prior to them engaging in the performance task questions.
- To aid students in viewing details and/or color of images on the handout, use an LCD projector or electronic whiteboard to display the images for the class.
- Since there is a lot of data to analyze in this performance task, students are provided reflection questions after each data set. These are not intended to be scored, since concepts associated with these questions are assessed later in Part 2. However, you may want to encourage students to use their ideas captured in these reflection questions in order to provide more coherent final answers in the scored Part 2 portions.

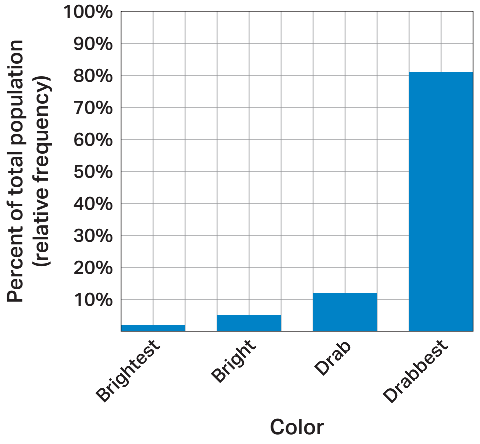
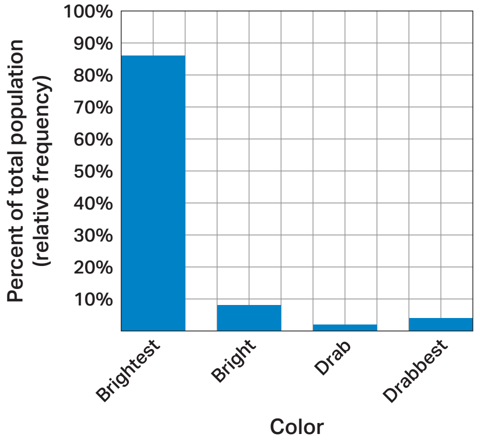
UNIT 2

SCORING GUIDELINES

There are 26 possible points for this performance task.

Part 1: Data Analysis (10 points maximum)

Sites 1–3

Sample Solutions	Points Possible
Site 1 Drab = 12% Drabbest = 81%  **Site 2** Brightest = 86% Bright = 8% Drab = 2% Drabbest = 4% 	**Site 1 Solutions: 2 points maximum** **Site 2 Solutions: 4 points maximum** **Site 3 Solutions: 4 points maximum** 0.5 point for correct percentage of population in table 0.5 point for correct percentage of population on graph

Continues on next page.

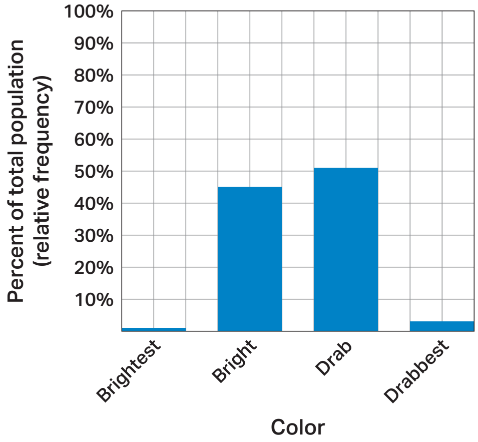
Site 3

Brightest = 1%

Bright = 45%

Drab = 51%

Drabbest = 3%



Targeted Feedback for Student Responses

If students struggle with their calculations for frequency, it would be good to have them return to question 1 of the practice performance task on tuskless elephants. You can also first provide additional hints that frequency is a ratio or percentage, e.g., number of bright guppies/total guppies, and then have students complete the data analysis.

TEACHER NOTES AND REFLECTIONS

UNIT 2

Part 2: Drawing Conclusions (16 points maximum)

Question 1

Sample Solutions	Points Possible
Explanation: Shifts in phenotype frequencies in populations due to natural selection take many generations to occur. Data: He collected data after at least 220 weeks (over 4 years) or 9 generations. This allowed enough time to see if selective forces were influencing the guppy's phenotype frequencies.	**2 points maximum** 1 point for explanation 1 point for use of data *Scoring note:* Students may select any of the experimental sites to reference the length of time that the data were collected to support their explanation.

Targeted Feedback for Student Responses

Students often struggle with understanding how long it may take to see changes in populations. If they don't provide data to support their answers, point students to comparing the number of generations across the three sites and encourage them to then think about their answer based on how long the study lasted.

TEACHER NOTES AND REFLECTIONS

Question 2

Sample Solutions	Points Possible
(a) Sample answer: The surrounding environment (e.g., sand, rocks, submerged vegetation) may vary in different areas of the stream and so coloration will vary, helping the guppies better blend in and avoid predation. (b) Sample answer 1: The new environment may have fewer predators, and therefore camouflage would offer less of a benefit. Sample answer 2: The new environment may have a different substrate (such as rocks instead of sand) and the guppy's coloration would be less effective for camouflage.	**2 points maximum** (a) 1 point for environmental pressures for camouflage (b) 1 point for one way the selective pressures change the guppy's fitness

Targeted Feedback for Student Responses
If students have trouble generating valid selective pressures, have them return to the opening text that provided background information on the habitat and predator population that guppies face in rivers. This should help students generate some better ideas about what advantages guppies could possess to increase their survival and/or reproduction chances.

TEACHER NOTES AND REFLECTIONS

Question 3

Sample Solutions

Claim 1: Refute

Evidence	Reasoning
Experimental site 2 is a shallow pool with only one kind of predator. The most abundant trait in the site 2 population was the brightest coloration. This represented 86% of the guppy population.	Since predation risk in shallow pools is low, the greatest pressure on the males is to mate (sexual selection). The brightest males mate more often and therefore continue to pass on that gene to new male offspring in the next generation. That is why after many generations, they make up the largest percentage of the guppy population.

Claim 2: Support

Evidence	Reasoning
Experimental site 1 is a deep pool with numerous predators so predation pressure is high. The most abundant trait in the population in site 1 was the drabbest coloration, seen in 81% of the male guppy population. There were very few of the brightest males in the population, at only 2%.	In this part of the river, the greatest pressure on the males is predation. The brightest males are most likely getting eaten and therefore do not produce many offspring that would contribute these genes to the next generation. However, the drabbest males are more likely to survive to pass along their genes, which is why they make up the largest percentage of the guppy population.

Points Possible

6 points maximum

(3 pts per claim)

1 point for correctly supporting or refuting each claim

1 point for appropriate evidence

1 point for appropriate reasoning

Targeted Feedback for Student Responses

Some students may struggle with coordinating both the evidence and reasoning for whether they feel the claim should be refuted or supported. In these cases, help them return to the guiding questions for each experimental site and have them work with a partner to compare their data analysis and conclusions about selective pressures.

TEACHER NOTES AND REFLECTIONS

Question 4

Sample Solutions		Points Possible
Claim: When predation pressure is moderate, the two intermediate groups, bright and drab, are most successful.		**3 points maximum** 1 point for crafting an appropriate claim 1 point for appropriate evidence used to support the claim 1 point for appropriate reasoning to support evidence and claim *Scoring note:* There are many appropriate claims that students may craft from the data provided. The one at left is just one illustrative example.
Evidence	**Reasoning**	
In experimental site 3, there was a moderate amount of predation. The bright and the drab guppies were most abundant. Bright made up 45% of the population, and drab made up 51% of the population.	Since this site contains a moderate number of predators, the pressures on both predation and mating are relatively equal. Therefore, the two intermediate phenotypes (bright and drab) were more abundant as the brightest males were most likely to be eaten more but also mated more often, whereas the drabbest males mated less but were also likely to be eaten less often.	

Targeted Feedback for Student Responses
Similar to question 3, some students may struggle with writing an appropriate claim, and coordinating both the evidence and reasoning to support that claim. In these cases, help students return to the guiding questions for that experimental site and have them work with a partner to compare their data analysis, claims, evidence, and reasoning about that site.

TEACHER NOTES AND REFLECTIONS

Question 5

Sample Solutions	Points Possible
▪ Students should indicate that they would need evidence that the color traits are heritable. ▪ Students need to discuss that while they did see evidence for selection here based on predation, they would need more trials. ▪ Students should want to collect more information about reproductive rates across the many color variants to ensure differential reproduction.	**3 points maximum** 1 point for heritability 1 point for selection 1 point for reproduction
Targeted Feedback for Student Responses	
This is really the capstone understanding of the factors that influence frequency shifts of phenotypes in populations through natural selection. So if students struggle to provide all three factors, encourage them to return to Lesson 2.4: Modeling Natural Selection Lab or the practice performance task for this unit to review these factors and provide appropriate descriptions of each one.	

TEACHER NOTES AND REFLECTIONS

The Flashy Guppy Data Analysis

PERFORMANCE TASK

Read the following information, then complete Parts 1 and 2.

INTRODUCTION: THE FLASHY GUPPY

A properly dressed male guppy, with its bright blue spots and brilliant splashes of orange, can't help but stand out. But for a fish that spends its life swimming among predators, it seems that good camouflage would have a big advantage over colors that attract attention. If flashiness is a liability, why do we still see this trait in the population?

ENDLER'S RESEARCH

When evolutionary biologist John Endler began studying Trinidad's wild guppies in the 1970s, he was struck by the wide variation among guppies from different streams, even among guppies living in different parts of the same stream. Males from one pool sported vivid blue and orange splotches along their sides, while those farther downstream carried only modest dots of color near their tails. Endler also observed differences in the distribution of guppy predators, and in the color and size of gravel in different stream locations.

Endler photographed hundreds of guppies and carefully collected data about their size, color, and the size and placement of their spots. He began to see a strong correlation between where guppies lived in a particular stream and whether the fish were bright or drab. But what was responsible for these trends in coloration? And if bright colors made guppies more conspicuous to predators, why should males be colorful at all? To find out, Endler formed a hypothesis based on his observations, and then set out to test it. His results proved to be one of evolutionary biology's most important discoveries.

GUPPY HABITAT TYPES

Guppies usually occupy the entire length of Trinidad's Aripo River, and often so do their predators, such as pike cichlids, blue acara, and rivulus. However, different sections of the river offer unique environmental characteristics and pressures that may influence the color variation seen in the guppies (see the table on the next page).

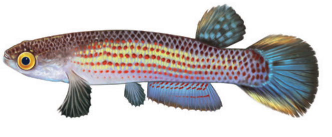
RIVER SECTION POPULATIONS

	Deep Pool	Pool Behind Natural Dam	Shallow Pool
Description	Deep section along the waterway	Pool formed by a low-lying rock dam; the dam limits upstream movement of some of the largest predators	Shallow area along the waterway, where only small fish can live
Population	▪ Guppies ▪ A variety of predators	▪ Guppies ▪ Some predators (no large ones)	▪ Guppies ▪ Smallest and least effective predators
Predation Risk	High	Moderate	Low

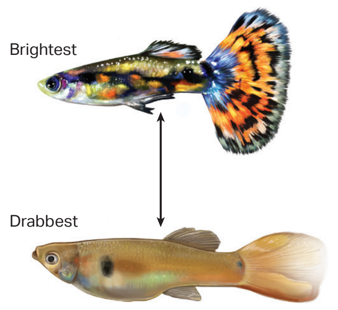
SPECIES INFORMATION

Guppies collected during the experiment were classified into four color variants: brightest, bright, drab, and drabbest. Endler was interested in studying whether the pressures for mating and predation influenced the frequency of the color variations found in different populations along the river. The table shown provides information about the guppies Endler studied and their predators.

PREDATORS AND PREY IN ENDLER'S STUDY

	Description	Images
Predators	Common name: Pike cichlid Scientific name: *Crenicichla alta* Size: Up to 12 in. (approximately 30 cm)	
	Common name: Blue acara Scientific name: *Aequidens pulcher* Size: Up to 7 in. (approximately 18 cm)	
	Common name: Rivulus Scientific name: *Rivulus hartii* Size: Up to 5 in. (approximately 12.5 cm)	

PERFORMANCE TASK

Prey	Common name: Guppy or millions fish Scientific name: *Poecilia reticulata* Sex of individuals in study: Male Size: 1.4 in. (approximately 3.5 cm) Color variations in population: ▪ Brightest ▪ Bright ▪ Drab ▪ Drabbest	

Text and data above are excerpted and adapted from "Sex and the Single Guppy." © 2010 by PBS. **http://www.pbs.org/wgbh/evolution/sex/guppy/low_bandwidth.html**.

PART 1: ANALYZING DATA

The data sets shown are representative of findings from Endler's research. Examine the data and complete the tables and graphs.

Experimental Site 1 Information

River Site: Deep pool

Number and Type of Predators: 30 rivulus, 30 blue acara, 30 pike cichlid

Guppy Total Population: 210

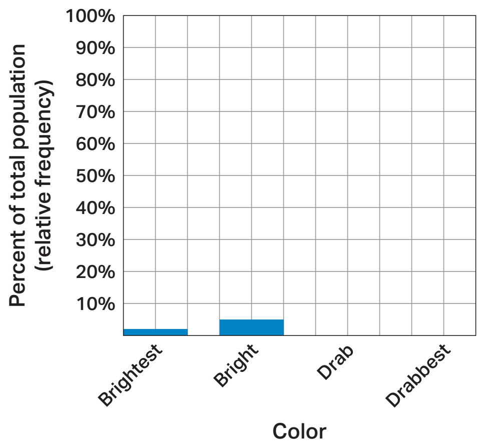
Number of Generations: 10

Number of Weeks: 286

Data Collected

	Brightest	Bright	Drab	Drabbest
Number of Guppies	4	11	25	170
Percent of Population *(rounded)*	2%	5%		

Data Analysis



PERFORMANCE TASK

REFLECTION QUESTIONS

1. Which type of guppy is most successful in this environment?

2. Why do you think this is the case? What is the advantage of this common phenotype in this environment?

Experimental Site 2 Information

River Site: Shallow pool

Number and Type of Predators: 30 rivulus

Guppy Total Population: 236

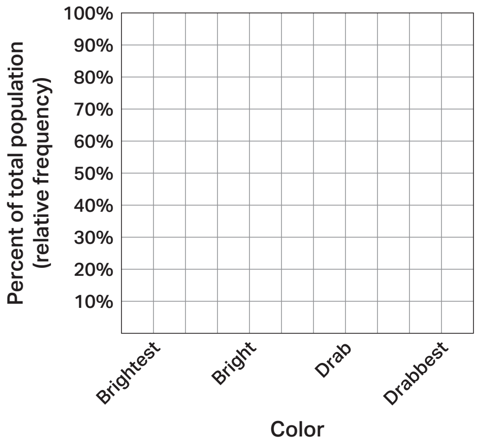
Number of Generations: 10

Number of Weeks: 265

Data Collected

	Brightest	Bright	Drab	Drabbest
Number of Guppies	**204**	**18**	**5**	**9**
Percent of Population *(rounded)*				

Data Analysis



REFLECTION QUESTIONS

1. Which type of guppy is most successful in this environment?

2. Why do you think this is the case? What is the advantage of this common phenotype in this environment?

PERFORMANCE TASK

3. How does this result differ from Site 1? If the results are different, provide some reasoning as to why.

Experimental Site 3 Information

River Site: Pool behind natural dam

Number and Type of Predators: 30 pike cichlid, 30 blue acara

Guppy Total Population: 218

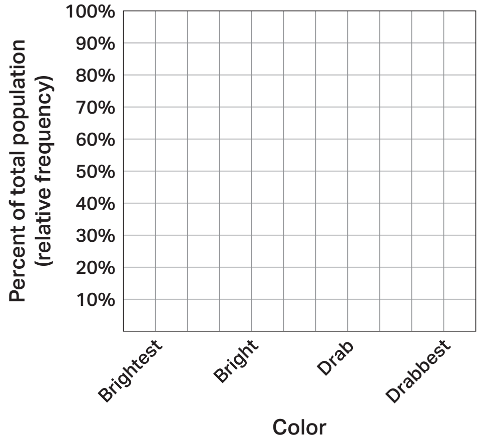
Number of Generations: 9

Number of Weeks: 220

Data Collected

	Brightest	Bright	Drab	Drabbest
Number of Guppies	2	98	111	7
Percent of Population *(rounded)*				

Data Analysis



REFLECTION QUESTIONS

1. Which type of guppy is most successful in this environment?

2. Why do you think this is the case? What is the advantage of this common phenotype in this environment?

PERFORMANCE TASK

3. How does this result differ from Sites 1 and 2? If the results are different, provide some reasoning as to why.

PART 2: DRAWING CONCLUSIONS

1. For each of the three experimental sites, examine the number of weeks that the study lasted. Explain why you think Endler waited this length of time to collect data. Use one or more of the data sets to help illustrate your explanation.

2. Endler also noticed that even the colors in the drabbest male guppies varied from one another in different areas of the river.

   (a) What could be a cause for this difference in coloration?

   (b) If a drabbest male was moved from one area of the river to a new area, how might the selective pressures change the guppy's fitness?

3. Analyze the two claims made on the next page. For each one, decide whether the information provided in the reading and data sets supports or refutes that claim. Then provide evidence and reasoning to support your decision.

Claim 1: When very few predators are present, the most fit color variation is the drabbest male.

Support or Refute? ____________

Evidence (from reading and/or data sets)	Reasoning

Claim 2: When many predators are present, the most fit color variation is the drabbest male.

Support or Refute? ____________

Evidence (from reading and/or data sets)	Reasoning

PERFORMANCE TASK

4. Using the background information and data sets, craft another claim about what occurs when there are moderate numbers of predators in the environment. Be sure to support your claim by using the evidence provided. Justify your claim and evidence with reasoning about natural selection principles.

Claim:

Evidence (from reading and/or data sets)	Reasoning

5. **Conclusion:** Make a claim about whether natural selection is acting on the color variations in guppies. Use evidence from the background reading and data sets and reasoning to support your claim. If there is a line of evidence that is missing but necessary for your claim to be supported, identify it.