CollegeBoard Pre-AP®

Pre-AP® Biology

TEACHER RESOURCES

Units 3 and 4

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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Genetics

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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.

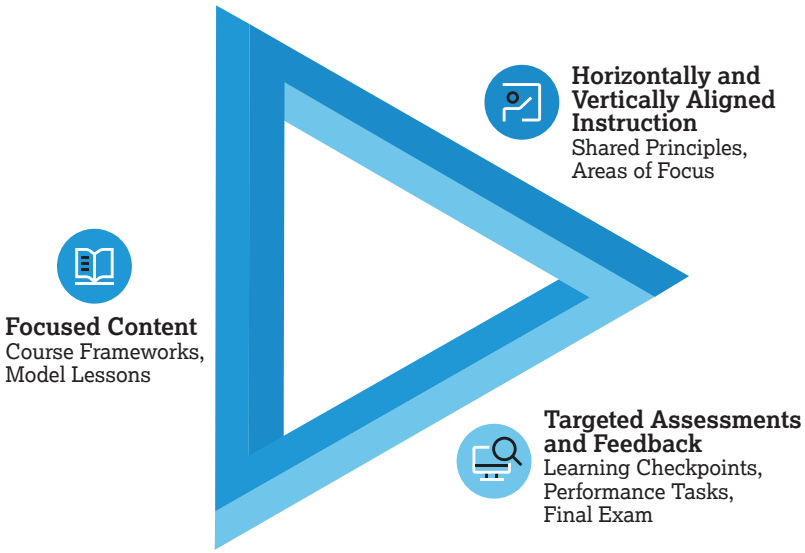
HOW TO GET INVOLVED

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

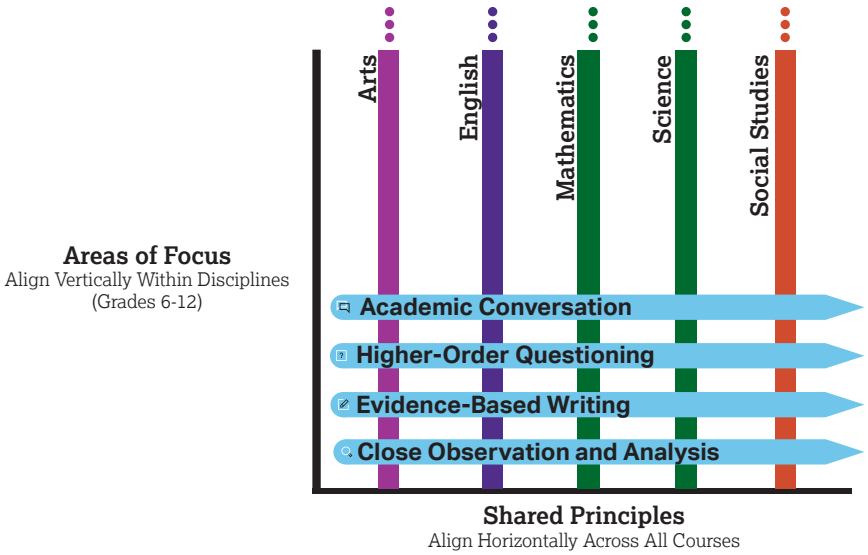
With strategic support, students frequently engage in writing coherent arguments from relevant and valid sources of evidence. Pre-AP courses embrace a purposeful and scaffolded approach to writing that begins with a focus on precise and effective sentences before progressing to longer forms of writing.

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

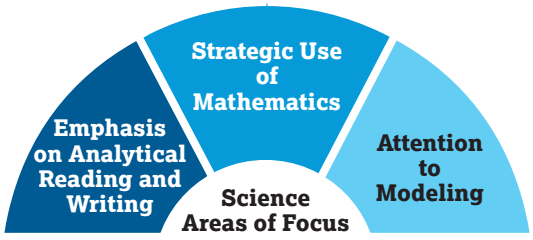
The Pre-AP Biology course emphasizes the integration of content with science practices—powerful reasoning tools that support students in analyzing the natural world around them. Having this ability is one of the hallmarks of scientific literacy and is critical for numerous college and career endeavors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

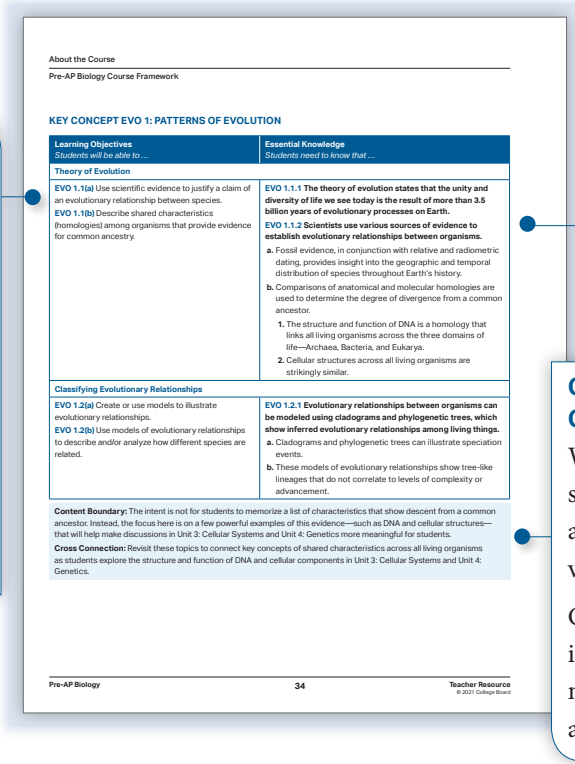
Enduring Understandings

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:

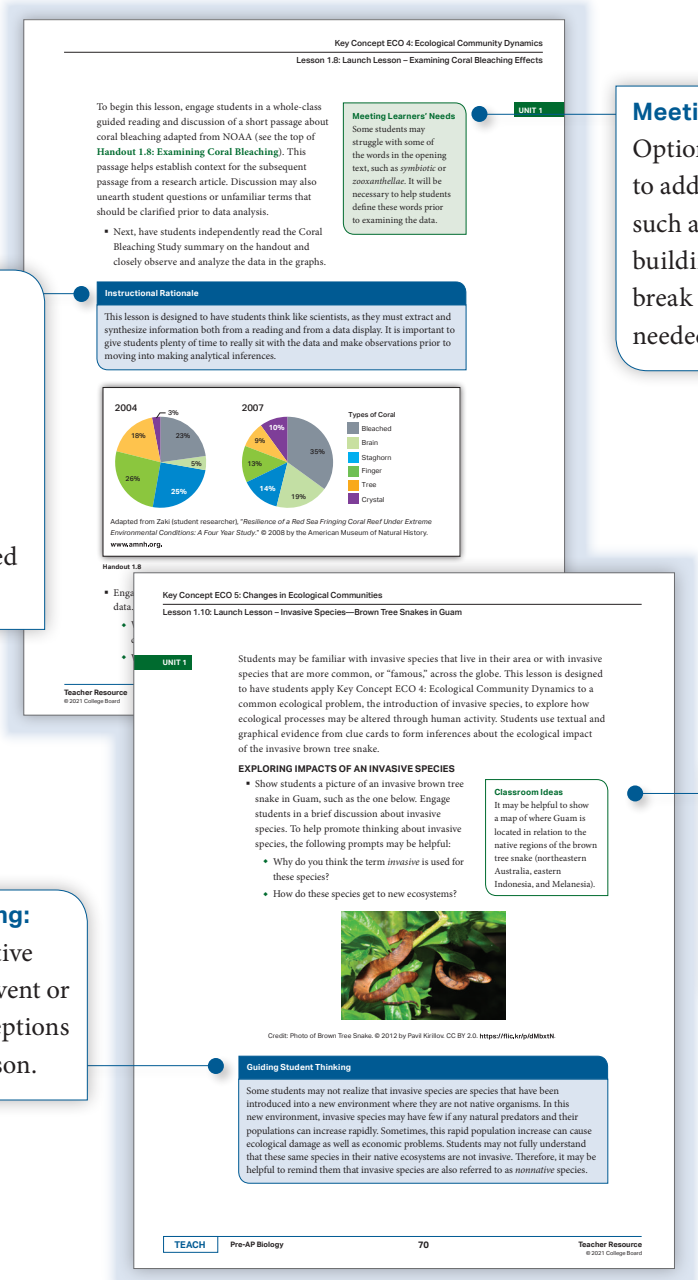
- **Robust instructional support for teachers:** Pre-AP Biology model lessons are comprehensive lesson plans that, along with accompanying student resources, embody the Pre-AP approach to teaching and learning. Model lessons provide clear and substantial instructional guidance to support teachers as 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



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.

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.

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

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

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 3 Cellular Systems	Practice Performance Task	Cellulase	Teacher Resources: Units 3 & 4	Student Resources: Unit 3
	Performance Task	Elodea Experiment		Teacher-distributed handout
Unit 4 Genetics	Practice Performance Task	Thalassemia	Teacher Resources: Units 3 & 4	Student Resources: Unit 4
	Performance Task	Modeling Pigeon Trait Inheritance		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

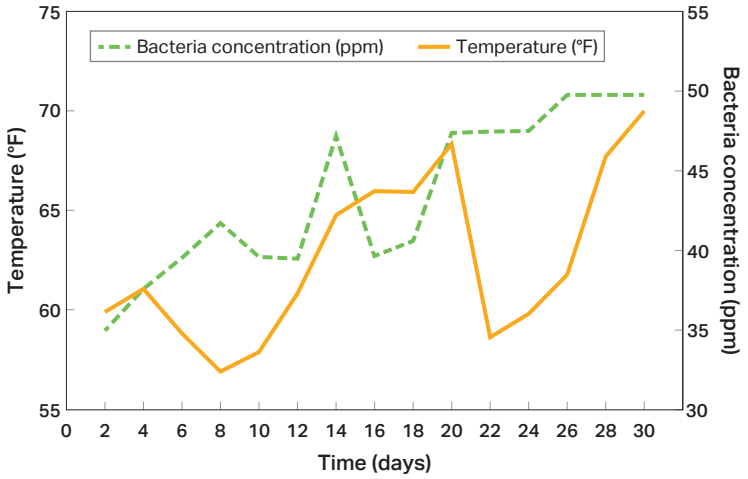
Question Styles	Question sets consist of two to three questions that focus on a single stimulus or group of related stimuli, such as texts, graphs, or tables. Questions are set in authentic biological contexts. *Please see page 62 for a sample question set that illustrates the types of questions included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

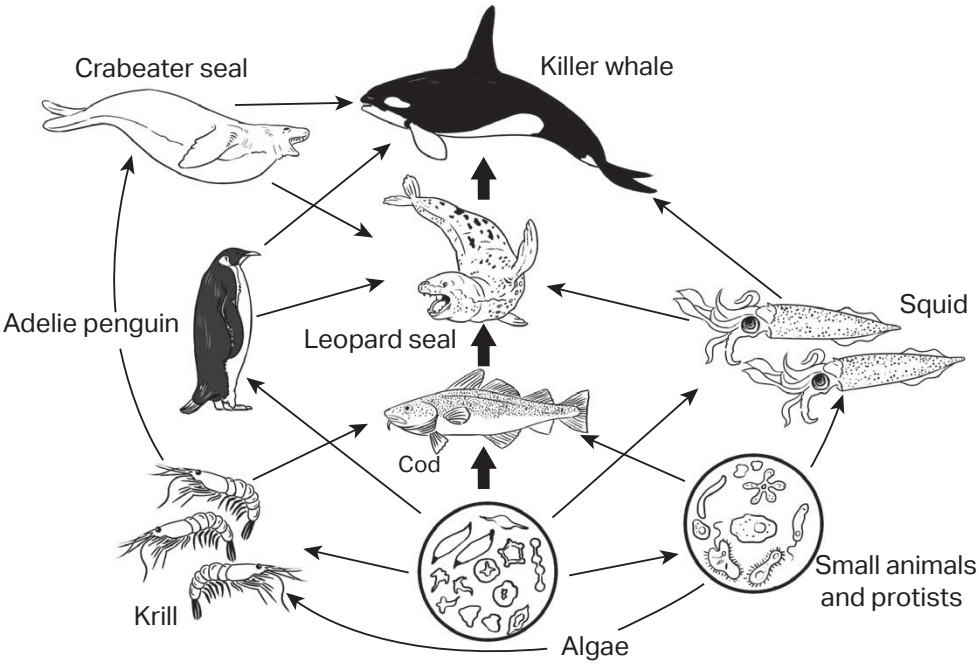
Learning Objective:

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:

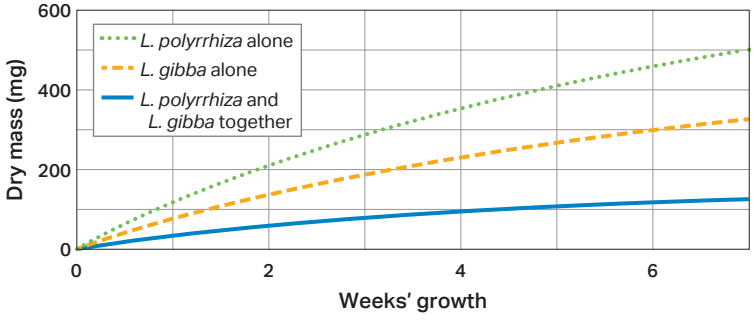
ECO 2.3(a) Create and/or use models to explain the transfer of energy through the food web of a community.

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

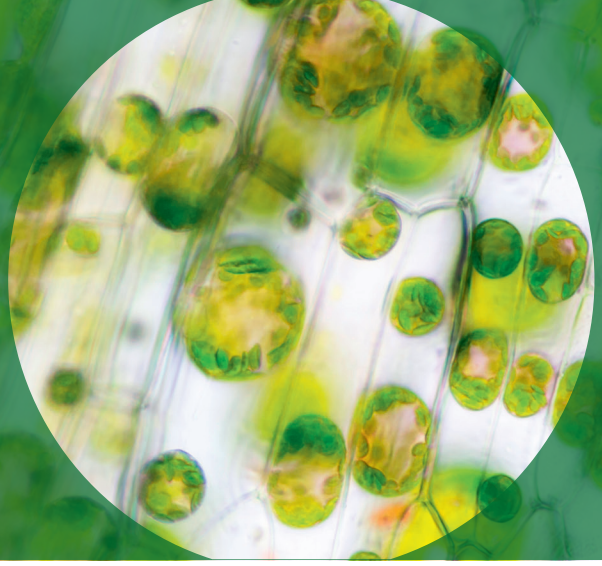
Pre-AP Classroom is the online application through which teachers and students can access Pre-AP instructional resources and assessments. The digital platform is similar to AP Classroom, the online system used for AP courses.

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 3

Unit 3
Cellular Systems



Overview

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

This unit focuses on the following enduring understandings:

- 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.

UNIT 3

- 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

This unit addresses the following 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

UNIT RESOURCES

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

Lessons For Key Concept CELLS 1: Chemistry of Life

Lesson Title	Learning Objectives Addressed	Essential Knowledge Addressed	Suggested Timing	Areas of Focus
3.1: Simulation of Enzymatic and Cellular Reactions	CELLS 1.2(a), CELLS 1.3(a), CELLS 1.3(b)	CELLS 1.2.1c, CELLS 1.3.1b, CELLS 1.3.1c	~60–75 minutes	Emphasis on Analytical Reading and Writing, Attention to Modeling
3.2: Guided Inquiry Investigation – Enzyme Catalysis Lab	CELLS 1.3(a), CELLS 1.3(b), CELLS 1.2(a)	CELLS 1.3.1b, CELLS 1.3.1c, CELLS 1.2.1c	~180 minutes	Strategic Use of Mathematics, Emphasis on Analytical Reading and Writing

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

- Learning Objectives: CELLS 1.1(a), CELLS 1.4(a), CELLS 1.4(b), CELLS 1.4(c)
- Essential Knowledge Statements: CELLS 1.1.1a, CELLS 1.1.1b, CELLS 1.2.1a, CELLS 1.2.1b, CELLS 1.2.1d, CELLS 1.3.1a, CELLS 1.4.1a, CELLS 1.4.1b, CELLS 1.4.2

Practice Performance Task for Unit 3 (~45 minutes)

This practice performance task draws on learning objectives and essential knowledge statements addressed throughout Key Concept CELLS 1: Chemistry of Life.

Lessons For Key Concept CELLS 2: Cell Structure and Function

Lesson Title	Learning Objectives Addressed	Essential Knowledge Addressed	Suggested Timing	Areas of Focus
3.3: Launch Lesson – Modeling Cellular Systems	CELLS 1.2(a), CELLS 2.1(a), CELLS 2.2(a), CELLS 2.3(a)	CELLS 1.2.1a, CELLS 1.2.1b, CELLS 1.2.1c, CELLS 1.2.1d, CELLS 2.1.1a, CELLS 2.1.1b, CELLS 2.2.1a, CELLS 2.2.1b 1–4, CELLS 2.3.1a, CELLS 2.3.1b	~90 minutes	Attention to Modeling
3.4: Cell Membrane Bubble Investigation Lab	CELLS 2.1(a)	CELLS 2.1.1a, CELLS 2.1.1b	~60–90 minutes	Attention to Modeling

UNIT 3

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

- Learning Objectives: CELLS 2.3(b)
- Essential Knowledge Statements: CELLS 2.3.2a, CELLS 2.3.2b 1–2

Lessons for Key Concept CELLS 3: Cell Transport and Homeostasis

Lesson Title	Learning Objectives Addressed	Essential Knowledge Addressed	Suggested Timing	Areas of Focus
3.5: Launch Lesson – Introduction to the Role of Water in Cells	CELLS 3.2(c), ECO 1.1(a), ECO 1.1(b)	CELLS 3.2.1, ECO 1.1.1a	~45–60 minutes	Emphasis on Analytical Reading and Writing
3.6: Argument-Driven Inquiry into Tonicity Lab	CELLS 3.2(a), CELLS 3.2(b), CELLS 3.2(c)	CELLS 3.2.1a	~90 minutes	Emphasis on Analytical Reading and Writing, Attention to Modeling

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

- Learning Objectives: CELLS 3.1(a), CELLS 3.1(b), CELLS 3.3(a)
- Essential Knowledge Statements: CELLS 3.1.1a, CELLS 3.1.1b, CELLS 3.1.1c, CELLS 3.2.1b, CELLS 3.2.1c, CELLS 3.3.1a, CELLS 3.3.1b

Key Concept CELLS 4: Organisms Maintaining Homeostasis
There are no provided Pre-AP Lessons for this key concept. As with all key concepts, this key concept is addressed in a learning checkpoint.
All Key Concept CELLS 4 learning objectives and essential knowledge statements should be addressed with teacher-developed materials.

Learning Checkpoint 1: Key Concepts CELLS 1–4 (~45 minutes)
This learning checkpoint assesses learning objectives and essential knowledge statements from Key Concepts CELLS 1 through 4. For sample questions and learning checkpoint details, visit Pre-AP Classroom.

Lessons for Key Concept CELLS 5: Cell Growth and Division

Lesson Title	Learning Objectives Addressed	Essential Knowledge Addressed	Suggested Timing	Areas of Focus
3.7: Launch Lesson – Modeling the Cell Cycle	CELLS 5.1(a), CELLS 5.1(b), CELLS 5.2(a), CELLS 5.2(b), CELLS 5.2(c)	CELLS 5.1.1a, CELLS 5.1.1b, CELLS 5.2.1a, CELLS 5.2.1b, CELLS 5.2.1c	~45–60 minutes	Attention to Modeling
3.8: Modeling Mitosis	CELLS 5.1(a), CELLS 5.2(a), CELLS 5.2(b)	CELLS 5.1.1a, CELLS 5.1.1b, CELLS 5.2.1a	~45–60 minutes	Attention to Modeling

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

- Learning Objectives: CELLS 5.3(a), CELLS 5.3(b)
- Essential Knowledge Statements: CELLS 5.3.1a, CELLS 5.3.1b, CELLS 5.3.1c

UNIT 3

Lessons for Key Concept CELLS 6: Photosynthesis				
Lesson Title	**Learning Objectives Addressed**	**Essential Knowledge Addressed**	**Suggested Timing**	**Areas of Focus**
3.9: Launch Lesson – Exploring Photosynthesis Through Atmospheric Carbon Dioxide Concentrations	CELLS 6.1(a), CELLS 6.1(c)	CELLS 6.1.1a, CELLS 6.1.1b, CELLS 6.1.1d 1–2	~45–60 minutes	Strategic Use of Mathematics
3.10: Model-Based Guided Inquiry – Introduction to Photosynthesis and Light Energy	CELLS 6.1(a), CELLS 6.1(b)	CELLS 6.1.1a, CELLS 6.1.1b	~60 minutes	Attention to Modeling, Emphasis on Analytical Reading and Writing
	The following Key Concept CELLS 6 essential knowledge statement is not addressed in Pre-AP lessons. Address this in teacher-developed materials. ▪ Essential Knowledge Statement: CELLS 6.1.1c			

Lessons for Key Concept CELLS 7: Cellular Respiration and Fermentation				
Lesson Title	**Learning Objectives Addressed**	**Essential Knowledge Addressed**	**Suggested Timing**	**Areas of Focus**
3.11: Model-Based Guided Inquiry Activity – Comparing Cellular Respiration and Photosynthesis	CELLS 7.1(a), CELLS 7.1(b), CELLS 7.1(c)	CELLS 7.1.1a	~45–60 minutes	Attention to Modeling

The following Key Concept 7 learning objectives and essential knowledge statements are not addressed in Pre-AP lessons. Address these in teacher-developed materials.

- Learning Objectives: CELLS 7.2(a), CELLS 7.2(b)
- Essential Knowledge Statements: CELLS 7.1.1b, CELLS 7.1.1c, CELLS 7.1.1d, CELLS 7.1.1e, CELLS 7.2.1a, CELLS 7.2.1b 1–2

Learning Checkpoint 2: Key Concepts CELLS 5–7 (~45 minutes)

This learning checkpoint assesses learning objectives and essential knowledge statements from Key Concepts CELLS 5 through 7. For sample questions and learning checkpoint details, visit Pre-AP Classroom.

Performance Task for Unit 3 (~45 minutes)

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

LESSON 3.1

UNIT 3

Simulation of Enzymatic and Cellular Reactions

OVERVIEW

LESSON DESCRIPTION

Part 1: Introduction to Enzymes

In the first part of this lesson, students engage in an analytical reading about proteins and study models of lactase enzyme activity. They identify reactants and products as they learn the terms *substrate, enzyme, active site*, and *enzyme–substrate complex*.

Part 2: Modeling Enzyme Reactions

Using their hands as models of enzymes, students alter variables such as enzyme concentration, temperature, and pH in order to determine the effects of these variables on the rates of product formation.

Part 3: Analysis

Students graph their data and analyze their results.

CONTENT FOCUS

This lesson is designed as an inquiry-based exploration into enzymes. Students do not need prior knowledge about enzymes, though they should have a basic understanding of chemical reactions and how to write them, as well as an understanding that catalysts increase the likelihood of a chemical reaction occurring by decreasing activation energy.

This lesson is designed to help students understand that enzymes are proteins with the correct shape to catalyze chemical reactions. In addition to allowing students to generate a working mental model of enzyme-catalyzed reactions, this lesson can be used

AREAS OF FOCUS

- Emphasis on Analytical Reading and Writing
- Attention to Modeling

SUGGESTED TIMING

~60–75 minutes

HANDOUTS

- 3.1.A: Importance of Proteins as Enzymes
- 3.1.B: Enzyme and Cellular Reaction Simulations
- 3.1.C: Analysis Questions

MATERIALS

For each student group:

- two shoe boxes, plastic bins, or paper shopping bags cut short
- 100 preassembled and counted pop-bead pairs in a cup or plastic bag
- timer
- bandage tape for taping fingers down
- tennis ball (optional)

UNIT 3

to get students thinking about how they could alter conditions in a real enzyme-catalyzed reaction in order to see the effects of changing variables. Thus, this lesson is a good contextual launching point to understanding the role macromolecules play in organisms and is an important first exposure to this concept before the subsequent inquiry-based lab where students alter variables of their own choosing.

COURSE FRAMEWORK CONNECTIONS

Enduring Understandings	
▪ Four classes of macromolecules serve as the primary building blocks of biological systems.	
Learning Objectives	**Essential Knowledge**
CELLS 1.2(a) Explain the role macromolecules play in supporting cellular function.	**CELLS 1.2.1** Each class of macromolecule carries out specific functions in biological systems. **c.** Proteins are responsible for numerous cellular functions, such as catalyzing reactions, providing structure, and aiding in cell transport and signaling.
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. **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.

SETUP AND PREPARATION NOTES

- If pop beads are not available, then wooden and plastic toothpicks may also be used. You will need both types: wooden ones that break easily and plastic ones that do not.

SAFETY NOTES

All general safety guidelines should be followed.

UNIT 3

PART 1: INTRODUCTION TO ENZYMES

In the first part of this lesson, students engage in an analytical reading about proteins.

- To begin, have students use the My Notes column on their handout to record key information about proteins from the reading. They should also use that space to create their own definitions of the following terms: *substrate, enzyme, active site,* and *enzyme–substrate complex*.
- Lead a whole-class discussion to go over the key ideas and terms from the reading. You may want to make a list on the board of the key terms so all students can see them.
- Next, have students closely analyze the enzyme models on **Handout 3.1.A: Importance of Proteins as Enzymes**. This introduction is best completed in a collaborative small-group setting. (Groups of three are optimal for the modeling portion of the lesson.) Instruct groups to come to a consensus on each question before recording their ideas and to make note of any conflicting ideas that they were unable to resolve.
- Throughout this portion of the lesson, consult with each group during their discussions to be certain students have a clear understanding of the function of enzymes. Checking the work of one student in the group may be sufficient since groups are working toward a consensus.
- After students have completed investigating, labeling, and answering the questions associated with Model 1, lead a whole-class debrief on their solutions. Sample responses are provided on the next page for reference.

Meeting Learners' Needs

This activity is designed as an inquiry-based exploration and does not require prior knowledge about enzymes. However, if you feel students would benefit from visualizing how proteins have specific shapes that allow them to perform specific functions, a good activity prior to this lesson would be "Pencil Transferase" from *The American Biology Teacher*, available at **https://bit.ly/2PMWjOZ**.

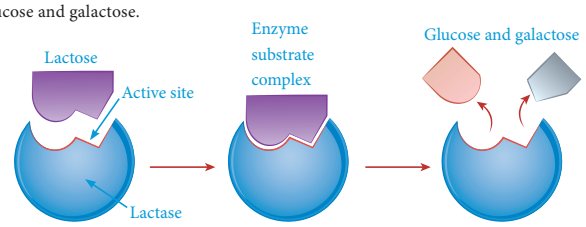
Instructional Rationale

Part 1 of this lesson is designed for students to explore models of enzyme activity through an inquiry-based method. This allows them an opportunity to work together through peer-to-peer discussions as they analyze the model and draw conclusions.

UNIT 3

MODEL 1 – LACTASE BREAKS DOWN LACTOSE

Enzymes are active in all cells as well as in the digestive system. Lactase is found in the digestive system, and is one of many enzymes in mammalian intestines that help break down food molecules into pieces small enough to be absorbed into our cells. Specifically, lactase breaks the sugar lactose, a disaccharide, into two monomers, glucose and galactose.



Model 1: Lactase breaks down lactose

1. Model 1 represents a reaction in which lactose is broken apart with the assistance of the enzyme lactase. Label the following on Model 1:
   - Lactose
   - Lactase
   - The active site of lactase
   - The enzyme–substrate complex (the temporary molecule formed when the substrate is in the active site of the enzyme)
   - The products of the reaction (glucose and galactose)

2. Using the names of the reactants and products (instead of chemical formulas), write a chemical equation for the reaction catalyzed in Model 1. *Hint:* Only reactants and products are included in a chemical reaction.

   lactose → glucose + galactose

   Note: Students may choose to put lactase as a reactant and a product because they see it at both the beginning and end of the reaction shown in the model. However, since lactase is neither a product nor a reactant, have them remove this from their reaction.

3. Referring to the chemical reaction you wrote for the question above, is lactase a reactant, a product, or neither? Explain how you know.

   Lactase is not used in the reaction; it is the same at the start of the reaction as it is when the reaction is complete. Thus, it is neither a reactant nor a product.

4. Describe the role the enzyme lactase played in the reaction.

   Lactase catalyzed the reaction in which the complex sugar (disaccharide) lactose was broken into the simple sugars glucose and galactose (monosaccharides).

5. What do you think could happen to the enzyme lactase at the end of the reaction?

   Lactase could be used again to cause another molecule of lactose to break into glucose and galactose.

6. Enzymes play very specific roles in cells, and will work only on specific substrates. For example, while lactase breaks down lactose, lipase is an enzyme that breaks down lipid molecules. Using lipase and lactase as examples, describe how most enzymes are named.

   Most enzyme names end in "-ase" and refer to the molecules the enzymes break down. **Lip**ase breaks down **lip**ids; **lac**tase breaks down **lac**tose.

Handout 3.1.A

Classroom Ideas

For an additional resource to support students in understanding the role of lactase, see HHMI BioInteractive's 53-second animation "Lactose Digestion in Infants" at **https://www.biointeractive.org/classroom-resources/lactose-digestion-infants**.

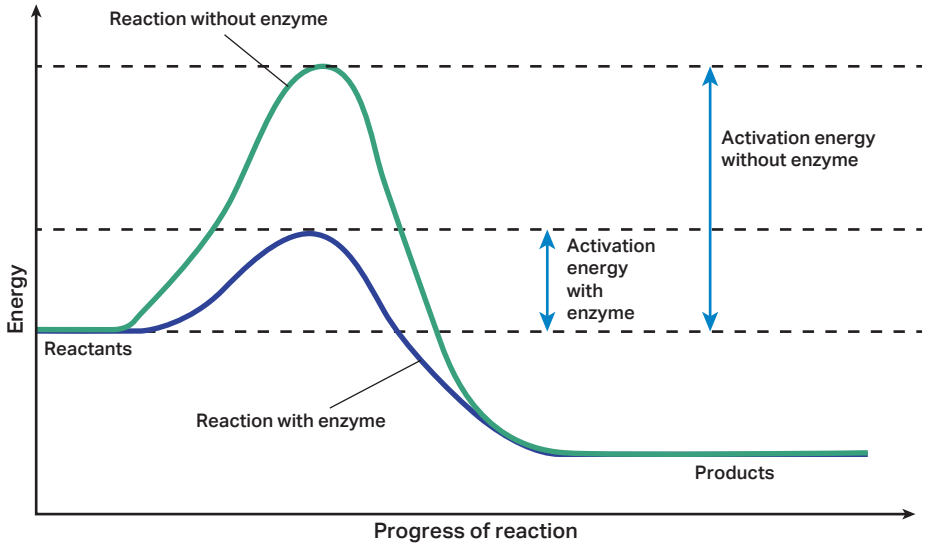
7. Suppose the image below is a model of a different disaccharide, sucrose.

Would lactase be able to break down sucrose? Explain your answer in terms of the model.

No. The sucrose molecule has the wrong shape for the active site of this enzyme; lactase would not be able to break down sucrose.

Handout 3.1.A

- Finally, it is important to summarize and discuss how enzymes are able to speed up reaction rates in living systems. Display the graph below or sketch one similar to it for the whole class to see.



Energy in reactions with and without enzymes

- Ask students to closely observe and analyze the graph. Then, ask:
  - How does the presence of enzymes change the energy needed for a reaction to occur?

    Because enzymes act as catalysts, they decrease the activation energy needed to start a reaction.
- Now students are ready to move on to investigating Model 2. Remind them to read the paragraph associated with the model before answering the questions. Questions and student responses are included on the next page for reference.

UNIT 3

1. Using your new knowledge of enzyme active sites, describe why temperature changes can impair an enzyme's ability to catalyze reactions.

   Because the shape of the active site changes, the substrate cannot fit in the active site, and the enzyme cannot catalyze the reaction.

2. What questions do you have?

   Student questions will vary.

Handout 3.1.A

- After students have completed the handout, lead a whole-class debrief and invite them to share some of their questions. Record student questions for the whole class to see.

PART 2: MODELING ENZYME REACTIONS

In this part of the lesson, student groups simulate enzyme-catalyzed reactions under different conditions and collect data on reaction rates.

- To begin, have students work through the warm-up investigation on **Handout 3.1.B: Enzyme and Cellular Reaction Simulations**. Students will practice breaking apart pop-bead "dimers" with one hand (i.e., the model enzyme) to determine the "active site" of their model enzyme. For question 1, encourage students to practice enough to become efficient and "sure" of what the active site is; otherwise, their technique may change throughout and influence the data.
- Once students have identified their active sites, briefly discuss their responses as a class. Sample responses are provided below for reference.

WARM-UP INVESTIGATION

Before your group starts this investigation, individually do the following:

1. Pick up a model lactose. Using only one hand, take it apart. Pay attention to what part of your hand you use to do this. In the space below, describe the active site of your model enzyme (in this case, your hand).

   Most students use some combination of their thumb and another finger, or the thumb and the palm of their hand. (Let students practice enough to become efficient and "sure" of what the active site is, otherwise their technique will change throughout and may influence the data.)

Handout 3.1.B

2. Consider your bin of lactose models. What are some variables or factors that you think might affect how many lactose molecules can be disassembled in a given period of time?

   Student answers will vary. Some might include how many lactose molecules are available or how many lactase models are used, or students might have noticed differences between the rate of individuals in their working groups.

Handout 3.1.B

- Next, have students work in groups of four to carry out the experimental procedures on their handout. Remind students to determine which role each group member will have in the simulation. The roles are enzyme(s), thermal energy (i.e., shakes the bin), timer, and data recorder.
- You can use the following support to aid student inquiry in Experiment 1: Lactose Hydrolysis With and Without an Enzyme.
  - Reinforce with students that they are recording the total number of substrate molecules broken over the course of the 90 seconds. The data taken at 30 and 60 seconds is so they can graph and compute a rate; however, students sometimes think they need to start the count over at each 30-second data recording point.

Classroom Ideas

For a more guided approach, you could have all groups work at the same time while you give instructions and keep time. This gives you more control over the classroom and the ability to address questions or concerns as they arise, while still keeping the students highly engaged.

Guiding Student Thinking

This simulation is designed to help students see that enzymes do not move a substrate molecule to another location before acting on it. Therefore, a second bin is used to make it easier for students to keep track of how many substrate molecules they break and to reassemble them at the end of each trial. Consider discussing this if students are forming misconceptions about enzymes sorting molecules into new locations.

UNIT 3

- Ideally students who are using their hands to simulate enzymes should not look at the bin to grab a substrate molecule, since enzymes do not actively seek out substrate. As the bin is being shaken by a team member, students should only grab a substrate molecule when it touches part of their active site. It is up to you how much you want to reinforce this aspect of the simulation. Doing so may help students conceptualize why temperature of reaction is important (with no thermal energy, the molecules do not move around). However, reinforcing this idea may be one too many details for students to keep track of.
- Students quickly catch on that nothing happens in the bin with no enzyme. While this may be obvious, it helps them conceptualize what is or isn't happening in a chemical reaction they cannot see.

Classroom Ideas
To decrease the number of pop-bead pairs that need to be assembled, this experiment was written for students to run the no-enzyme trial for a full 90 seconds after the enzyme trial. Alternatively, a second bin of pop-bead pairs could be used so that both trials can be run at the same time.

- You can use the following support to aid students with Experiment 2: Lactose Hydrolysis with Different Enzyme Concentrations.
  - The purpose of this experiment is for students to see that as enzyme concentration increases, so does the rate of the reaction. However, when enzyme concentration is too high, the rate cannot increase anymore because all the substrate is used up. Starting with fewer lactose molecules and/or adding a trial with five enzymes may increase the chance that student groups see both of these trends in the data. This experiment is the most time-consuming, both because it has more trials and because students will have to spend more time reassembling the pop-bead pairs between trials.
- You can use the following support to aid students with Experiment 3: Lactose Hydrolysis with Different Substrate Concentrations.
  - The purpose of this experiment is for students to learn that the rate of enzyme activity will necessarily fall as the concentration of substrate decreases until the substrate is used up in the reaction. *Note:* Because students have likely become more efficient at breaking the pop beads since Experiment 1, the data from Experiment 1 should not be reused.

- You can use the following support to aid students with Experiment 4: Lactose Hydrolysis with Denatured Enzymes.
  - To save time, students can reuse their enzyme data from the first trial. This is not a problem as it could have been in Experiment 3, since students will be comparing a working enzyme (data from Experiment 1) to a non-working enzyme. Even if they have become more efficient at breaking the pop beads in the previous trials, their data from Experiment 1 will definitely show a higher rate of enzyme activity than their data from the denatured trial.

PART 3: ANALYSIS

In this last part of the lesson, students analyze data collected from their simulations and make claims about the structure and function of enzymes.

- After students have finished their experiments, have them complete **Handout 3.1.C: Analysis Questions**. These questions can be completed in class or assigned as homework to save class time.
- To answer these questions, students can use the data collected by their group. Alternatively, you can set up a way for the groups in the class to pool their data and compute averages.
- Finally, lead a whole-class discussion about some or all of these questions. Sample responses are provided for reference starting on the next page. Analyzing these simulations will also help students design their experiments in the next lesson.

Classroom Ideas

Students may try to find another active site for their model enzyme molecule (their hand), which is why the tape is highly recommended. It is much harder for students to find another way to break the pop-bead pairs when their active site is completely immobilized. If no tape is available or if students have known adhesive allergies, it is important to emphasize that enzymes are not problem-solvers, and they cannot find a different solution when their active site is changed.

Meeting Learners' Needs

For the questions that involve graphing, the titles and axes on the provided grids have been left blank so that, when appropriate, you can expect students to determine for themselves which variable belongs on which axis, how to space the units along the axes, and how to title their graphs. If your students are not proficient in graphing, you can work together as a class to set up each graph before students plot their data.

Analysis Questions

EXPERIMENT 1: LACTOSE HYDROLYSIS WITH AND WITHOUT AN ENZYME

1. Using the data you collected in Experiment 1, calculate the rate of product formation per minute with and without enzyme. Show your work.

   Student calculations should show the total number of lactose molecules broken after 1.5 minutes, divided by 1.5 minutes. The experiment without enzyme should have a rate of 0, while rates for the experiment with enzyme will vary with their data.

2. What is the overall effect of an enzyme on the rate of lactose hydrolysis?

   The presence of an enzyme increases the rate of product formation.

3. What is the purpose of the "no-enzyme" condition in this experimental design?

   The no-enzyme experiment serves as a control; it shows us that the reaction cannot occur without the presence of an enzyme.

EXPERIMENT 2: LACTOSE HYDROLYSIS WITH DIFFERENT ENZYME CONCENTRATIONS

4. Consider the experimental design of Experiment 2. Identify the variables in this trial:

   (a) Independent variable:

   the number of enzyme molecules in the reaction (enzyme concentration)

   (b) Dependent variable:

   the number of lactose molecules that were broken in 1.5 minutes

Handout 3.1.C

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5. Construct a graph of the data you collected in Experiment 2, using the grid below.

   Enzyme concentration belongs on the *x*-axis and number of lactose molecules broken in 90 seconds on the *y*-axis. Ideally students would construct a line graph, as this is continuous data. An example of a title might be "The Effect of Enzyme Concentration on the Number of Lactose Molecules Broken."

   The trends in the data should show an increase in lactose molecules broken as the enzyme concentration increases. Depending on how proficient students are at breaking the lactose models, the data should level off at the higher enzyme concentrations. This is because all the substrate molecules are broken before the end of 90 seconds at the higher enzyme concentrations.

6. What trend or trends do you see as a result of increasing enzyme concentration on the rate of product formation?

   The rate of reaction increases with increasing enzyme concentration, but once there are enough enzymes that the substrate is all reacted upon, the rate levels off.

7. Assuming the bin were big enough, what would the results be if 10 enzymes were added? 100? Explain.

   With more enzyme molecules, the initial rate of reaction might be faster, but the overall number of lactose molecules broken cannot change because the substrate runs out.

8. What is the limiting factor on the rate of product formation when there is one enzyme in the reaction?

   When the enzyme concentration is low, that concentration is the limiting factor on the rate of reaction.

9. What is the limiting factor on the rate of reaction when there are four enzymes in the reaction?

   When the enzyme concentration is high, the limiting factor is the substrate. Once all the substrate is acted upon, no more reactions can occur.

Handout 3.1.C

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EXPERIMENT 3: LACTOSE HYDROLYSIS WITH DIFFERENT SUBSTRATE CONCENTRATIONS

10. Consider the experimental design of Experiment 3. Identify the variables in this trial:

    (a) Independent variable:

    substrate concentration

    (b) Dependent variable:

    the number of lactose molecules that were broken in 1.5 minutes.

11. Construct a graph of the data you collected in Experiment 3, using the grid below.

    The *x*-axis should be substrate concentration, and the *y*-axis should be the number of lactose molecules broken per 1.5 minutes. The data is again continuous, so students should construct a line graph. An example of a student title might be "The Effect of Substrate Concentration on the Number of Lactose Molecules Broken."

12. What trend or trends do you see as a result of increasing substrate concentration on the rate of product formation?

    As substrate concentration increases, so does the number of substrate molecules that are broken into monomers. However, as the substrate concentration increases, the reaction rate will level off because the enzymes are all being used.

13. Assuming the bin were big enough, what would the results be if the substrate concentration had been increased to 150 molecules of lactose per bin? 500? Explain.

    There will be no increase in rate of reaction if the substrate concentration increase is this high, because the number of enzymes limits the number of reactions that can be catalyzed.

14. What is the limiting factor on the rate of product formation in this experiment?

    At the beginning of the experiment when substrate concentration is low, the substrate concentration is the limiting factor. However, when substrate concentration is high, the concentration of enzymes limits the reaction rate.

Handout 3.1.C

EXPERIMENT 4: LACTOSE HYDROLYSIS WITH DENATURED ENZYMES

15. Changes in what kinds of variables in a cell can cause the proteins to denature?

    Changes in pH and increases in temperature can denature enzymes. Students may come up with other answers, depending on their knowledge prior to this activity.

16. Optimal human body temperature averages around 98.6°F (37°C). Considering what you learned in the activity, explain why exposure to extreme heat results in dangerous medical conditions such as heat stroke.

    If your temperature rises too high, your enzymes can denature and all cellular reactions will slow or stop.

17. Fevers in mammals are a natural defense against bacterial and viral infections. Viruses and bacteria rely on properly shaped enzymes to complete their life cycles during an infection. State one hypothesis about how fevers help fight infections.

    As your temperature rises, the enzymes of the infectious agents are denatured, slowing their ability to grow and multiply in your body.

18. The normal pH range for human blood and most body tissues is considered to be 7.25–7.35. One possible complication of diabetes is a condition known as ketoacidosis, which causes blood to become more acidic. Explain why this condition can be dangerous, given what you know about proteins and changes in their pH.

    Changes in the pH of your blood will result in denaturing enzymes in your blood. Because blood provides the cells of your body with needed fluids, the pH of your body cells will change as well. The result is that cellular reactions that require enzymes will slow, including the reactions that convert energy for your cells.

Handout 3.1.C

UNIT 3

LESSON 3.2

Guided Inquiry Investigation – Enzyme Catalysis Lab

OVERVIEW

LESSON DESCRIPTION

Part 1: Background on Enzymes
As preparation for the investigation, students extract information from an introductory text about enzymes and apply that knowledge to label a process model and a graphical representation of enzyme activity. The reading is only necessary if students did not complete Lesson 3.1: Simulation of Enzymatic and Cellular Reactions.

Part 2: Establishing a Baseline for Catalase
Students become oriented to the experimental setup and may do a test run of the investigation. Next they collect data to establish a baseline rate for the catalase enzyme reaction.

Part 3: Guided Inquiry Investigation – Factors that Influence Enzyme Reactions
Students develop their own questions about factors that might influence enzymatic rates. In small teams, students design an investigation to answer their selected question using a planning template and then carry out their guided inquiry investigations.

Part 4: Sharing Student Work
Students share their findings using an Experimental Results Reporting Tool in a curated gallery walk.

AREAS OF FOCUS

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

SUGGESTED TIMING

~180 minutes

HANDOUTS

- 3.2.A: Exploring Enzymes
- 3.2.B: Catalase Investigation – Establishing a Baseline Reaction Rate
- 3.2.C: Experimental Design Plan
- 3.2.D: Experimental Results Reporting Tool

MATERIALS

For each student group:

- reaction chamber
  - 125 ml Erlenmeyer flask
  - one-hole rubber stopper, size 5
  - 5 mm (gauge) glass tubing
  - plastic/rubber (flexible) tubing
- 50 ml beaker
- 10 ml graduated cylinder

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CONTENT FOCUS

Students learn the role enzymes play in catalyzing chemical reactions in living organisms. They identify key factors that affect enzyme activity and describe how changes in factors such as temperature, pH, enzyme concentration, substrate concentration, ion concentration, and other factors increase or decrease enzyme activity. Students connect enzyme activity to the specificity of the shape of an enzyme's active site, and discover that if certain factors in the environment are altered, this can denature the protein structure of the enzyme's active site and reduce its activity. Students also make connections to other topics throughout Unit 3, including the roles macromolecules play in supporting cellular function, the importance of maintaining homeostasis in cells and organisms, and the consequences of disrupting homeostasis.

- 100 ml graduated cylinder
- tube clamp (pinchcock, hoffman, etc.)
- plastic tub (no larger than 7×11 inches needed—approximately 2-quart size)
- support rod and burette clamp
- fresh catalase solution
  - yeast (not rapid rise)
  - water
  - 250 ml flask or beaker
  - stirring rod
- fresh 3% hydrogen peroxide (H_2O_2)
- 1 ml graduated pipettes
- timer
- thermometer

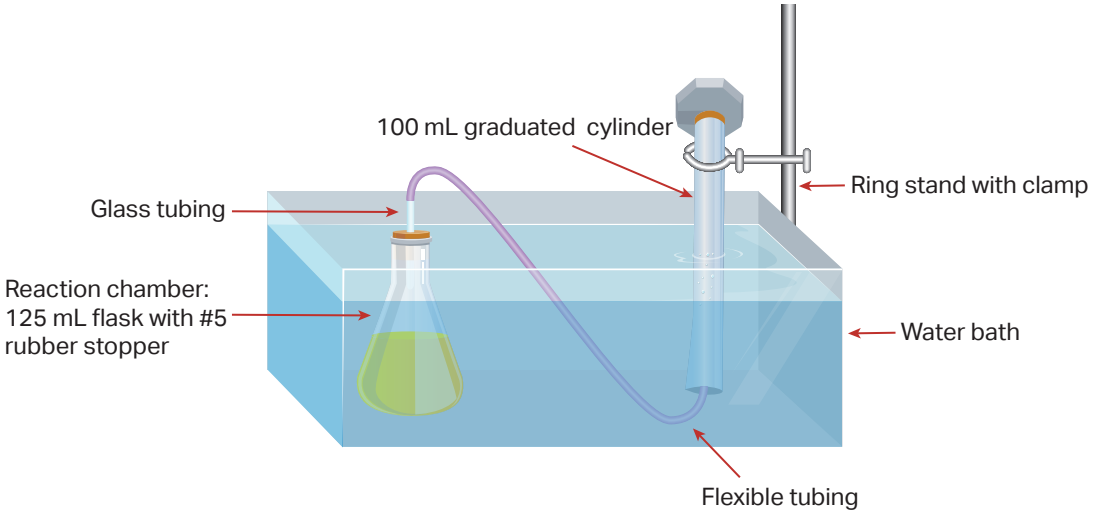
COURSE FRAMEWORK CONNECTIONS

Enduring Understandings	
▪ Four classes of macromolecules serve as the primary building blocks of biological systems.	
Learning Objectives	**Essential Knowledge**
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 are essential for maintaining life processes. **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.

CELLS 1.2(a) Explain the role macromolecules play in supporting cellular function.	**CELLS 1.2.1** Each class of macromolecule carries out specific biological functions in biological systems. **c.** Proteins are responsible for numerous cellular functions such as catalyzing reactions, providing structure, and aiding in cell transport and signaling.

SETUP AND PREPARATION NOTES

- The following materials should be collected and set up before beginning the investigation:



Preparing the Reaction Chamber Apparatus

- Each group will use a reaction chamber apparatus. To prepare this:
  1. Insert a size 5 one-hole rubber stopper into a 125 mL Erlenmeyer flask.
  2. In the one-hole rubber stopper, insert a short piece of glass tubing so that you have approximately 5 cm of tubing sticking out from both ends of the stopper.
  3. Attach flexible plastic tubing (approximately 12–18 inches) to the outside end of the glass tubing. This serves as the conduit for the escaping gas bubbles.
  4. For the water bath, a small to medium-sized plastic rectangular container works well. Set out plenty of tap water **the day before** students do the baseline investigation so it has a chance to stabilize at room temperature.

5. A 100 mL graduated cylinder will be used for collecting the oxygen gas during the investigation. You may use either glass or plastic. To reduce the chance of error, have students use a ring stand and clamp to hold the graduated cylinder in position during the experiment.

- You can decide whether you want to set up parts of the reaction chamber apparatus ahead of time for your students, or you can also let student groups in each class assemble the reaction chambers themselves. If students set up the reaction chambers, you will need to allow additional time for the investigation, as student groups often need a bit of help with the setup. Regardless of what you choose, glassware from the reaction chambers needs to be washed thoroughly between classes; therefore, parts of the chambers will need to be set up again.

Preparing the Catalase Solution

- Prepare a catalase solution for each class by using 1 package (7 g) of yeast in 200 mL warm water. To ensure that very little gas will be produced before use, do **not** add sugar. Also, do **not** use rapid rise yeast for the baseline, although this might be an option you make available to students during the student-led inquiry portion of the lab.
- Make the yeast solution about an hour before class and keep it in a warm incubator (25–30°C) or warm water bath for the day. If you cannot keep it warm throughout the day, you can make different batches throughout the day for each class, as needed.

Preparing for the Student-Designed Portion of the Investigation

- Gather materials for the student-designed portion of this guided inquiry investigation. Below is a list of potential options, though your list will vary based on your students' needs.
  - **Temperature:** ice, hot water, thermometers, hot plates or Bunsen burners
  - **pH:** buffers at three different pH values (e.g., pH 3, 7, and 11) or weak concentrations of HCl and NaOH, pH paper

    Note: Buffers may give mixed results; directly adding an acid like HCl or a base like NaOH provides more consistent results.
  - **Salinity:** salt, balance, containers for salt solutions
  - **Substrate concentration:** hydrogen peroxide of various concentrations

    Note: Hydrogen peroxide from the store is typically 3% concentration. Higher concentrations can be found from chemical supply companies, or, of course, you can dilute the standard peroxide with water.

- **Enzyme concentration:** enzyme packets, balance, container for enzyme solution

  Note: Remember your starting solution is 7 g yeast to 200 mL water.
- **Types of yeast:** different brands of yeast, rapid rise yeast, or you can even visit a microbrewery or go online and purchase different strains of yeast
- Depending on students' investigations, they will also likely need some glassware such as beakers, flasks, or test tubes and test tube clamps.

SAFETY NOTES

All general safety guidelines should be followed.

UNIT 3

PART 1: BACKGROUND ON ENZYMES

Part 1 of this lesson gives students an introduction to enzymes by having them read and analyze a text before applying that knowledge to a model reaction. The reading is only needed if they did not complete Lesson 3.1: Simulation of Enzymatic and Cellular Reactions.

- First, have students read the excerpt from a *Scientific American* article about enzymes, found on **Handout 3.2.A: Exploring Enzymes**. This will give students a first look at the importance of enzymes in organisms as well as specifically introduce them to the enzyme catalase, which they will be using in this investigation. **If students completed Lesson 3.1, then you may want to begin with the next step—the introduction to catalase**.
- Next, have students read the short introduction to catalase on the handout and label both the model of the catalase reaction with hydrogen peroxide and the graph that represents the change in energy during enzymatic reactions.
- Once students have completed labeling the two diagrams, lead a whole-class discussion so students can share the labels they selected for their diagrams. It may also be helpful to ask a few probing questions about enzymes and catalase to ensure that students have a good background understanding prior to beginning the investigation. To spark student thinking, you may want to ask some of these questions:
  - Describe the monomers that make up enzymes.

    Since enzymes are proteins, the building blocks (monomers) are amino acids.
  - Explain how an organism benefits from enzymatic reactions.

    Enzymes allow chemical reactions to take place faster than those reactions would naturally occur at the internal temperature of most organisms. In the case of catalase, it benefits the organism by breaking down a toxin (hydrogen peroxide).
  - Why did the article use the analogy of a lock and key to describe enzymes and substrates?

    The shape of the substrate and the active site of the enzyme are unique in that they will only bind with each other, similar to a lock and key.

Meeting Learner's Needs
If students did complete Lesson 3.1 but need some additional reinforcement about the role of enzymes, you may want them to read the article excerpt. This will give them another opportunity to extract key characteristics about enzymes from the text prior to applying that knowledge to the model of catalase and the activation energy graph.

UNIT 3

Guiding Student Thinking

Since this is an introduction to how the complementary structures of a specific enzyme and substrate enable a chemical reaction to occur, the lock and key theory of fit is still a productive analogy to reference. However, it is also useful to build on that discussion to introduce the induced-fit theory, which assumes that the substrate plays a role in determining the final shape of the enzyme and that the enzyme is partially flexible. You can explain to students that the flexibility of the active site is why some compounds are actually able to bind to the enzyme without producing a reaction; this is because the enzyme has been distorted too much. Therefore, some compounds may bind to catalase, but only hydrogen peroxide is capable of inducing a chemical reaction.

PART 2: ESTABLISHING A BASELINE FOR CATALASE

In this part of the lesson, students become oriented to the experimental setup and may perform a test run of the investigation. Students then collect data to establish a baseline rate for the catalase enzyme reaction. Be sure to explain to students that yeast was used to prepare the catalase solution. This will help students make connections to how enzymes support the cellular processes of living organisms.

ORIENTING STUDENTS TO THE INVESTIGATION

Since this laboratory investigation has many important steps, it is helpful to familiarize students with the procedure using steps such as the following:

- First, have students read about the materials, procedure, and steps of the lab. See **Handout 3.2.B: Catalase Investigation – Establishing a Baseline Reaction Rate**.
- Next, walk through a step-by-step demonstration of how to set up the reaction chamber and collect the data. In this walk-through, you don't need to run a real reaction; let students experience that for the first time on their own. Just provide the visual support of how everything fits together and what purpose each piece of equipment serves.
- Establish student groups of three or four. Have group members decide which role they will play in the lab, based on the role descriptions on the

Meeting Learners' Needs

If students struggle to complete the models for Applying Information About Catalase on their handout, you should have them return to the reading in Part 1 of this lesson, and revisit the key concepts outlined in the introductory text. They should use reading annotation strategies to extract that information in order to complete their models.

handout; this will allow everyone to know what they will be doing before the investigation begins.

- It is strongly recommended that you allow students to do a practice run. Have them practice collecting the oxygen in the tube, reading the tube, and recording the data. As the handout explains, students should use **20 mL** of hydrogen peroxide in this practice run instead of the normal 10 mL; therefore, the reaction is more likely to go very quickly. With 20 mL of hydrogen peroxide, the gas production will typically empty the cylinder of water in under 3 minutes. If needed, you may also review certain aspects of laboratory equipment, such as the correct names of glassware (e.g., beakers versus flasks) or how to read measurements by observing the meniscus curve.
- Students should conduct this practice run (and their experimental runs) for 5 minutes or until the amount of oxygen produced reaches 100 mL—whichever comes first. If oxygen production hits 100 mL before the clock hits 5 minutes, students should record 100 mL in their data table for all times after they hit 100 mL. This will indicate that oxygen production after that point was at 100 mL or greater since the equipment does not allow them to measure beyond 100 mL.
- If student groups make a mistake on their first attempt, allow them to try again. There should be ample time for groups to conduct a second attempt. Rarely will a team need more than two practice runs.

ESTABLISHING A BASELINE

At this point, students can proceed with setting up their equipment and running their baseline tests. This should take approximately 20 minutes. Students will also record their group's data to determine a class average.

- Provide a method for students to share their group's data, which will contribute to determining a class average. The class average will be used to create a graph. One suggested method for sharing data is creating a Google Sheet. Students can come up to a computer and input their team data or share the document via Google Classroom and input data for homework. Either method is a very quick way for students to get a class average, and they can they use Google Sheets to quickly generate a graph of the class average.
- The graph will be used to calculate the initial reaction rate for the baseline reaction. In the student-led inquiry part of the lab, most groups will be able to use this baseline value to evaluate the effect of manipulating a variable.

UNIT 3

PART 3: GUIDED INQUIRY INVESTIGATION – FACTORS THAT INFLUENCE ENZYME REACTIONS

In this part of the lesson, students develop their own questions about factors that might influence enzymatic rates and design their own investigation to answer their selected question. Students use **Handout 3.2.C: Experimental Design Plan** as a guide through this process, then carry out their guided inquiry investigations.

Instructional Rationale

This portion of the investigation is the most critical. Allowing students an opportunity to develop their own questions about factors that influence enzyme reactions provides great feedback about what they think affects cellular systems. This inquiry-based investigation also provides much deeper critical thinking for students about the role of enzymes and the factors that affect the reaction rates.

- To lead into the guided inquiry portion of this investigation, post question 1 from the handout:

> How does _____ influence the rate of catalase's breakdown of hydrogen peroxide (H_2O_2)?

Handout 3.2.C

- Have students think quietly for 2–3 minutes and jot down their ideas using the space provided on the handout.
- Next, have students join their lab groups again and share what they jotted down. Give them some time to have a peer-to-peer dialogue about their ideas and even generate new ideas together.
- Pull the class together and chart all the different variables they have come up with. Conduct a brief discussion to combine similar ideas and eliminate variables that may not be practical or scientifically sound to test. Again, students should actively engage in the critique of suggested variables and designs.
- Now have each student group review the list and choose the two or three variables they would have the most interest in testing. For each variable, have them write an appropriate research question, as directed on the handout.
  - Encourage students to select variables and develop questions to which they don't actually know the answer.

- Walk around and check student questions—move students away from questions that don't address what we see in the real world or that don't add to our scientific understanding.
- Once the class has a list of variables they want to test, it is helpful to write next to each variable what the baseline was. For example, record the amount of yeast (1.0 mL), amount of H_2O_2 (10 mL), temperature of the water bath (23°C), salinity (0%), and pH (take pH of your basic setup); these should be consistent for any student experiment in which results are compared with the class baseline. (Note that in the suggested procedures for modifying salinity and pH, students create a new baseline, as these procedures involve changing the hydrogen peroxide concentration from what was used in the class baseline).

- Negotiate, assign, or use some other protocol to determine which lab group will work with which variable.
- At some point, return to your master list of variables. Remind students that whichever variables they did **not** choose to work with now become key, constant variables in their experiment that they need to be sure are kept consistent from test to test.
- Once a team has been assigned their variable and has their research question approved, they should work together to complete the Experimental Design Form, which begins on the second page of the handout. They can use class time to complete this or complete it as homework.
- Students should share their completed form with you, and you should sign off on it when it meets your approval. If fixes need to be made, send students back to make those fixes and then resubmit the form.
- When a team has had their experimental design approved, they should begin implementing data collection.

GUIDANCE ON STUDENT-LED INVESTIGATIONS

- The amount of support you provide your students during this portion of the investigation will depend on how much experience your students have had in the lab, as well as your own current comfort level.
- It is best to provide guidance when student groups submit their proposals as a way to support a plan that has a reasonable chance of producing useful information. Even in student-led inquiry investigations, it is not productive to allow students to run investigations in which the potential for success is low or nonexistent. However, there is educational value in allowing students to carry out their design on their own and discover the flaws in the design. It's even better if you can provide students with the time to correct those flaws and run the experiment again.

UNIT 3

- If you haven't run this type of enzyme reaction investigation before, below are some potential procedures students may submit. Of course, these don't represent all the viable options, but they will help you think through a few examples of what the students may be submitting.

Potential Procedure for Testing the Effect of Temperature on Enzyme Activity

1. Repeat the procedure for establishing a baseline, but at three different temperatures: 10°C, 37°C, and 100°C (boiled catalase). You may easily do this by using the following procedures:
   (a) **10°C:** Set up your reaction chamber with 10 mL of H_2O_2. Place the reaction chamber in the water bath and add ice to the water bath so that it and the contents of the reaction chamber are chilled to 10°C for 5 minutes before running the experiment. Keep adding ice to keep the temperature at 10°C or colder.
   (b) **37°C:** Set up your reaction chamber with 10 mL of H_2O_2. Place the reaction chamber in the water bath and add warm water to the bath so that it and the contents of the reaction chamber are warmed to 37°C for 5 minutes before running the experiment. Keep adding warm water to keep the temperature at 37°C.
   (c) **100°C** (boiled catalase): We can't use a water bath of boiling water since that could injure a student. Rather than keeping the reaction vessel in boiling water during the experiment, we will instead boil the catalase solution for 5 minutes. Then, after the catalase solution has cooled, you can run the experiment in room-temperature water (but with already boiled catalase).
2. Create a data table and record your data.
3. Plot the data on the same graph as your baseline. The line you created with the class baseline data represents enzyme activity at room temperature (about 23°C). Don't forget to clearly label your axes and plotted lines and title your graph.
4. Calculate the initial reaction rates for your three experimental groups.
5. Create a second graph, plotting the reaction rate vs. temperature; include your baseline reaction rate to represent room temperature.

A sample Experimental Design Form for testing the effect of temperature on enzyme activity is shown on the next two pages with sample responses for reference.

UNIT 3

Experimental Design Form

Name(s): _____

Research Question *(What are you trying to find out?)*	How does temperature affect the rate at which catalase breaks down the substrate hydrogen peroxide?			
Hypotheses	H_o (Null) A change in temperature will have no effect on the rate at which catalase breaks down hydrogen peroxide.			
	H_1 (Alternative) *If … then … because* If the enzyme reaction takes place in an environmental temperature of 37°C, then the reaction rate will be at its optimum, because an increase in temperature from room temperature increases the kinetic energy in the system, which increases the movement of molecules in the environment, thereby increasing the chances that enzymes will have collisions with their substrates. 37°C is human body temperature, so at this temperature enzyme activity increases, but there is not so much heat that the enzyme will become denatured.			
Independent Variable *(Include units.)*	Temperature (°C)			
Levels of Independent Variable	10°C	23°C	37°C	100°C
Number of Repeated Trials *(Time limits us to one of each new trial. There will be multiple repeated trials for the control if comparing results against the class baseline.)*	1	10 (or, the number of groups in the class)	1	1
Dependent Variable *(Include units.)*	Amount of oxygen produced (mL)			
Controlled Factors or Constants *(Include what you consider to be the **5–8** most important variables to control, and state how they will be controlled.)*	Amount of fresh catalase solution (1 mL) Concentration of substrate (3%) Amount of substrate (10 mL) pH (7) Salinity (0%) Size of reaction chamber (125 mL flask)			
Control Group *(Include an explanation of why it is a controlled experiment.)*	23°C will serve as the control group. The baseline experiments were run at 23°C, thus it becomes the comparison point for our additional trials.			

Handout 3.2.C

Procedure Modifications *(Describe the modifications you will make to the initial protocol for your investigation.)*	The experiment will be run the same as the baseline, except that we will change the temperature of the water bath and incubate the hydrogen peroxide in the reaction chamber in the water bath for 5 minutes before running the reaction. For the 100°C test, we will boil the catalase solution for 5 minutes and then run the reaction in a room-temperature bath since it is not safe to work with a water bath that hot, but the enzyme will have been exposed to the high temperature.
Data Collection *(Create a prototype data table that you could use to collect data during your experiment.)*	
Type of Graph *(What type of graph will you use? Why? Describe or sketch how you will set up each axis for your graph.)*	Two types of line graphs: First graph: *x*-axis = time in 30-second intervals up to 5 minutes and *y*-axis = oxygen production in mL. One line will be created for each temperature tested. Using the first graph, initial reaction rates will be calculated; the calculated reaction rates will be used to create the second graph. Second graph: *x*-axis = temperature range from 0° to 100°C in intervals of 10°C and the *y*-axis = reaction rate.

Time (minutes and seconds)	0:00	0:30	1:30	2:00	2:30	3:00	3:30	4:00	4:30	5:00
10°C										
23°C										
37°C										
100°C										

PREDICTING RESULTS

1. What will your results look like if you fail to reject your null hypothesis?

   All temperature groups will have essentially the same reaction rate.

2. What will your results look like if you reject your null hypothesis?

   There will be a significant difference in the reaction rates of different temperature groups.

3. What will your results look like if your alternative hypothesis is supported?

   The 37°C reaction will have the fastest rate, 23°C will have the second fastest rate, the 10°C reaction will have the second slowest reaction rate, and the 100°C reaction will show little to no activity.

4. What will your results look like if your alternative hypothesis is not supported?

   The 37°C tube will not have the fastest reaction rate.

TEACHER APPROVAL

Approved _____

Teacher's Signature: _____

Handout 3.2.C

Potential Procedure for Testing the Effect of Enzyme Concentration on Enzyme Activity

1. Repeat the procedure for establishing a baseline, but use three different levels of enzyme concentration: 75%, 50%, and 25%. You may easily do this by using the following procedures:
   (a) 75% concentration: Follow the procedure but use **0.75 mL catalase solution** in the reaction chamber, instead of 1.0 mL.
   (b) 50% concentration: Follow the procedure but use **0.50 mL catalase solution** in the reaction chamber, instead of 1.0 mL.
   (c) 25% concentration: Follow the procedure but use **0.25 mL catalase solution** in the reaction chamber, instead of 1.0 mL.
2. Create a data table and record your data.
3. Plot the data on the same graph as your baseline graph. Don't forget to clearly label the enzyme concentrations on your plotted lines.
4. Calculate the initial reaction rates for your three experimental groups.
5. Create a second graph, plotting the reaction rate vs. the enzyme concentration; include your baseline reaction rate to represent 100% concentration.

Potential Procedure for Testing the Effect of pH on Enzyme Activity

Note: Students testing the effects of changes in pH may need additional teacher guidance. The procedure below does not allow for comparison with the class baseline because it involves a different hydrogen peroxide concentration. Instead, the procedure involves examining the effects of pH values above and below the natural pH of the human body, which is close to 7.

1. Repeat the procedure for establishing a baseline, but use three different hydrogen peroxide solutions at three different pH values: pH 4, pH 7, and pH 10. You will compare reaction rates with that of the pH 7 solution, rather than the class baseline. The human body has a pH value near 7. You may easily set this up by using the following procedures:
   (a) **pH 4:** Make a 3.0% solution of H_2O_2 at pH 4 by adding 5 mL of H_2O_2 to 5 mL of pH 4 buffer.
   (b) **pH 7:** Make a 3.0% solution of H_2O_2 at pH 7 by adding 5 mL of H_2O_2 to 5 mL of pH 7 buffer.
   (c) **pH 10:** Make a 3.0% solution of H_2O_2 at pH 10 by adding 5 mL of H_2O_2 to 5 mL of pH 10 buffer.

UNIT 3

2. Create a data table and record your data.
3. Plot the data. Don't forget to clearly label your axes and plotted lines and title your graph.
4. Calculate the initial reaction rates for your three groups.
5. Create a second graph, plotting the reaction rate vs. pH; compare your pH groups.

Potential Procedure for Testing the Effect of Substrate Concentration on Enzyme Activity

1. Repeat the procedure for establishing a baseline, but use three different substrate concentrations: 0%, 0.3%, and 1.5%. You may easily do this by using the following procedures:
   (a) **0%:** Use 10 mL distilled water only.
   (b) **0.3%:** Prepare this by adding 3 mL of H_2O_2 to 7 mL of distilled water.
   (c) **1.5%:** Prepare this by adding 5 mL of H_2O_2 to 5 mL of distilled water.
2. Create a data table and record your data.
3. Plot the data on the same graph as your baseline. The line you created with the class baseline data represents enzyme activity at a substrate concentration of 3%. Don't forget to clearly label your axes and plotted lines and title your graph.
4. Calculate the initial reaction rates for your three experimental groups.
5. Create a second graph, plotting the reaction rate vs. substrate concentration; include your baseline reaction rate to represent a 3% substrate concentration.

Potential Procedure for Testing the Effect of Salinity on Enzyme Activity

Note: Students testing the effects of modifying salinity may need additional guidance. This procedure does not allow for comparison with the class baseline because it involves a different hydrogen peroxide concentration. This procedure will include a new baseline, with 0% salinity.

1. Repeat the procedure for establishing a baseline, but use four different levels of salinity: 20% NaCl, 10% NaCl, 2% NaCl, and 0% NaCl. You will use the 0% NaCl solution described below as the baseline for your experiment, rather than the class baseline. A sample procedure is as follows:
   (a) **20% NaCl:** Make a 1.5% solution of H_2O_2 containing 20% NaCl by dissolving 10 g of NaCl in 50 mL of water and then adding 5 mL of this solution to 5 mL of H_2O_2.
   (b) **10% NaCl:** Make a 1.5% solution of H_2O_2 containing 10% NaCl by dissolving 5 g of NaCl in 50 mL of water and then adding 5 mL of this solution to 5 mL of H_2O_2.

(c) **2% NaCl:** Make a 1.5% solution of H_2O_2 containing 2% NaCl by dissolving 1g of NaCl in 50 mL of water and then adding 5 mL of this solution to 5 mL of H_2O_2.

(d) **0% NaCl:** (New baseline) Prepare this by adding 5 mL of distilled water to 5 mL of H_2O_2.

2. Create a data table and record your data.
3. Plot the data. Don't forget to clearly label your axes and plotted lines and title your graph.
4. Calculate the initial reaction rates for your three experimental groups and your new baseline.
5. Create a second graph, plotting the reaction rate vs. salinity.

PART 4: SHARING STUDENT WORK

To conclude the lesson, students share their findings using an Experimental Results Reporting Tool in a curated gallery walk where they engage in a peer-to-peer critique and discussion of results.

Instructional Rationale

The gallery walk in this lesson is crucial; it allows students to engage in critique, which is an important part of scientific argumentation and also provides more insight into their understanding of what affects enzyme functionality.

- Provide each student with a copy of **Handout 3.2.D: Experimental Results Reporting Tool**. If time permits, group members may work together in class completing the reporting tool or, to save class time, you may assign it as homework. If students do have class time to work together, you should stress that the table on the final page of the handout should be completed individually because the questions ask students to reflect on their own learning.
- Before beginning the class-curated gallery walk, each group should select one group member's reporting tool to share with the class. The selected reporting tool can be displayed on a table, posted on a wall, posted on a display board, etc.—somewhere that other groups will be able to easily view the document.
- The class will then participate in the curated gallery walk. This walk provides a method for groups to share their results and to learn about how the other variables (those they didn't test) influenced the reaction rate of catalase.

UNIT 3

- In the curated gallery walk several things will be happening:
  - The curator for each group will stay with the display during the class gallery walk. Their job will be to give a brief verbal overview of their research findings to visiting groups and answer any questions visiting group members might have about their research.
  - The remaining group members will travel together to visit each of the other groups. During each visit, it will be the traveling group members' job to learn about how each of the variables tested by the other research groups in the class affected enzyme activity. The group should have a plan for documenting the information they gather, which can be shared and discussed later. (Students can use their lab books to record their findings, or you may create a document for them to use during the gallery walk.)
  - Curators and their reporting tools should be spread around the room. Then, set up a rotation so that one group is visiting each curator during each cycle. Have each group visit the curator for 3–5 minutes and then instruct them to rotate to the next designated curator. Repeat this process until all groups have had a chance to visit each curator. (This will typically take 30–45 minutes.)
  - After the gallery walk, the traveling group members will reunite with their curator and have a discussion about:
    - The feedback the curator received from visiting groups about their research.
    - The claims and supporting evidence the traveling members gathered about how the other tested variables impacted enzyme activity.
- All group members are responsible and accountable for describing and justifying the influence of not only the variable tested by their group on enzyme activity but also the variables tested by the rest of the class.
- You may wish to have students create a product that gives them an opportunity to synthesize the information they gathered about all variables that were researched in class. Creating this project can allow students to build a broad understanding of how various factors can influence the rate of an enzyme reaction.

PRACTICE PERFORMANCE TASK

Cellulase

UNIT 3

OVERVIEW

DESCRIPTION

This practice performance task allows students an opportunity to transfer the knowledge they developed in Lesson 3.2: Guided Inquiry Investigation – Enzyme Catalysis Lab to a novel enzyme and substrate context, the enzyme cellulase. Students read a passage about the role of the enzyme cellulase in digestion in cows and apply evidence from the passage evaluating and revising a model and analyzing data.

CONTENT FOCUS

Students differentiate between the roles various macromolecules play in supporting cellular systems and demonstrate understanding of enzyme activity as they engage in model-based explanations. Finally, students illustrate their knowledge of experimental design as they analyze data and elaborate on further steps in a study on what influences cellulase reaction rates.

AREA OF FOCUS

- Emphasis on Analytical Reading and Writing

SUGGESTED TIMING

~45 minutes

HANDOUT

- Unit 3 Practice Performance Task: Cellulase

MATERIALS

- copies of the scoring guidelines for student use (optional)

COURSE FRAMEWORK CONNECTIONS

Enduring Understandings	
▪ Four classes of macromolecules serve as the primary building blocks of biological systems.	
Learning Objectives	**Essential Knowledge**
CELLS 1.1(a) Differentiate between the major macromolecules based on their structure and/or function.	**CELLS 1.1.1** The four classes of organic macromolecules are proteins, carbohydrates, lipids, and nucleic acids. Each class has unique chemical structures.

Continues on next page.

	b. Most macromolecules are polymers that are made up of specific, smaller subunits called monomers.
CELLS 1.2(a) Explain the role macromolecules play in supporting cellular function.	**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. **c.** Proteins are responsible for numerous cellular functions, such as catalyzing reactions, providing structure, and aiding in cell transport and signaling.
CELLS 1.3(a) Describe the effect of enzymes on the rate of chemical reactions in biological systems.	**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.

SUPPORTING STUDENTS

BEFORE THE TASK

- Some students may need additional support in unpacking the information from the introductory text prior to beginning this practice performance task. If so, you may want to encourage students to first work in groups to underline key concepts in the text while also circling any words they do not know the meaning of. Lead a whole-class debrief on students' ideas about the key concepts and define any words students have circled prior to engaging them in the rest of the practice performance task.

DURING THE TASK

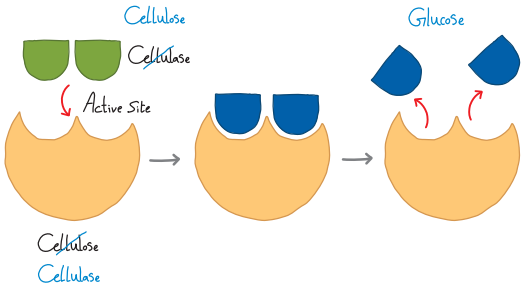
- You can have students work individually or in pairs. Allow students 20–30 minutes to complete the task.
- After students have worked on the practice performance task for 20–30 minutes, you may want to have them engage in some peer-to-peer review by assessing another student's or pair's work using the scoring guidelines.
- To close this performance task, you may want to lead a whole-class discussion of the task by inviting students to ask questions, review their solutions, share their struggles, and examine any new insights they formed. You can also highlight examples of how the performance task required knowledge and skills they gained in Lesson 3.2: Guided Inquiry Investigation – Enzyme Catalysis Lab.

UNIT 3

SCORING GUIDELINES

There are 13 possible points for this performance task.

Question 1

Sample Solutions	Points Possible
Sample response:  *Scoring note:* This is a simplified model of the breakdown of cellulose by cellulase. While there are intermediate steps before glucose is produced, students do not need to understand all the steps in the breakdown of this macromolecule. This simplified model is effective at demonstrating their understanding of enzyme activity.	**2 points maximum** 1 point for the revision to correct the labeling of the enzyme and substrate by swapping the labels *cellulase* and *cellulose* 1 point for correctly adding the label *glucose* to the product

Targeted Feedback for Student Responses

If students struggle to correct the model, have them return to the passage and find evidence of how the reaction progresses in order to correct their model.

TEACHER NOTES AND REFLECTIONS

Question 2

Sample Solutions	Points Possible
Sample response 1: Enzymes such as cellulase are proteins, so they have amino acid building blocks and they help speed up chemical reactions in cells. Cellulose is a carbohydrate made up of simple sugars, which cells can use as a source of energy. Sample response 2: The monomers of enzymes such as cellulase are amino acids. The monomers of carbohydrates such as cellulose are sugars. Enzymes are catalysts in cells and carbohydrates can be used for structure like in the cell walls of plants.	**4 points maximum** 1 point for each correct identification of monomers—amino acids for cellulase and simple sugars for cellulose 1 point for correct description of the role of enzymes as catalysts in cellular systems 1 point for correct description of a role of carbohydrates in cellular systems (either as an energy source or structural support)
Targeted Feedback for Student Responses	
If students struggle to provide all the correct information for this question, have them return to their reading notes from Lesson 3.1 or 3.2, then work to revise their answers.	

TEACHER NOTES AND REFLECTIONS

Question 3

Sample Solutions	Points Possible
Sample response: Enzymes are specific to a substrate due to the unique fit of an enzyme's active site with the substrate. So, the active site of amylase will not fit with cellulose and therefore will not break it down.	**2 points maximum** 1 point for explanation of active site and substrate compatibility 1 point for connection to the context of amylase and cellulose

Targeted Feedback for Student Responses

Students should recall induced-fit theory from Lesson 3.2. You could guide them to conduct some background research on induced-fit theory in order to correct their answers to this question.

TEACHER NOTES AND REFLECTIONS

Question 4

Sample Solutions

(a) The reaction rate is highest at 60°C.

(b) Sample response:

Independent Variable	Dependent Variable	Controlled Variables
pH	Methane gas production	Temperature Time Concentrations of cellulase, cellulose, and bacteria

Points Possible

5 points maximum

(a) 1 point for identifying the temperature at which the cellulase reaction rate is the highest

(b) 1 point for reasonable independent variable

1 point for reasonable dependent variable

1 point for listing 1–2 controlled variables; 2 points for listing 3 or more

Scoring notes: There are numerous other reasonable independent variables students can choose, including enzyme concentration, substrate concentration, and salinity.

While both methane and carbon dioxide gas are products of fermentation in the digestive system of cows, it is not necessary for students to correctly identify the specific gas produced to receive the point, as long as the answer is reasonable.

Targeted Feedback for Student Responses

If students are missing appropriate solutions for this question, have them work with a partner to compare their answers. Together they should reexamine the data provided and come to a consensus on appropriate solutions to the questions.

TEACHER NOTES AND REFLECTIONS

UNIT 3

LESSON 3.3

Launch Lesson – Modeling Cellular Systems

OVERVIEW

LESSON DESCRIPTION

Part 1: Eliciting Prior Knowledge of Cell Structures and Their Functions
Students use guiding questions to extract information from a short introductory text. They then discuss these questions with a partner and in a whole-class discussion. This part of the lesson is designed to elicit students' prior knowledge about cell structures.

Part 2: Modeling Cell Structures Based on Function
Students analyze cell structure cards—and determine a creative representation of the structure—to create a model of a plant cell. Students engage in peer review and reflection on their models.

Part 3: Examining Specialized Cell Structures
Students make predictions about cell structures in various types of specialized cells.

CONTENT FOCUS

This launch lesson is designed to elicit students' prior knowledge from middle school regarding cellular structures and functions. Therefore, this task can be used as a formative assessment to see what prior knowledge they can recall. Students work in pairs and in larger groups to model a system that includes all cell structures and consider efficiency when determining the arrangement of cell structures when they design their models. After students develop their models, they consider specialized cells and the structural differences that allow such cells to perform specific roles within a multicellular organism.

AREA OF FOCUS

- Attention to Modeling

SUGGESTED TIMING

~90 minutes

HANDOUTS

- 3.3.A: Recalling Prior Knowledge of Cells
- 3.3.B: Cell Structure Cards
- 3.3.C: Modeling Cell Structure and Function
- 3.3.D: Model of Cell Structure Overview – Peer Reflection
- 3.3.E: Examining Specialized Cells

MATERIALS

- modeling materials: options could include dry-erase markers with mini-whiteboards; medium-sized construction paper, pencils, and markers; or laptops/tablets
- cell structure cards, cut out

COURSE FRAMEWORK CONNECTIONS

Enduring Understandings	
▪ 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.	
Learning Objectives	**Essential Knowledge**
CELLS 1.2(a) Explain the role macromolecules play in supporting cellular function.	**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.
CELLS 2.1(a) Provide evidence to support the claim that all biological systems demonstrate some shared characteristics.	**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(a) Develop and/or use models to compare and contrast cell structures of different 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).
CELLS 2.3(a) Explain how cell structures in different types of organisms enable specialized cell functions.	**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).

SETUP AND PREPARATION NOTES

- To begin, prepare seven work stations, each with two of the cell structure cards from **Handout 3.3.B: Cell Structure Cards**. The cards should be cut out and securely affixed to the work stations so they don't get lost.

UNIT 3

PART 1: ELICITING PRIOR KNOWLEDGE OF CELL STRUCTURES AND THEIR FUNCTIONS

In the first part of this lesson, students use guiding questions to extract information from a short introductory text. They then discuss these questions with a partner and in a whole-class discussion. Since many students were introduced to cell structures in middle school, this part of the lesson is designed to elicit their prior knowledge.

- To begin, ask students to read the guiding questions at the top of **Handout 3.3.A: Recalling Prior Knowledge of Cells**. Then give them 5–10 minutes to read the article as they keep the questions in mind. Encourage them to highlight or underline information from the text that helps answer the guiding questions.
- After students are finished reading, allow them a few minutes to brainstorm answers to the guiding questions. Then, have them turn to a partner and discuss their ideas and answers.
- Lead a whole-class discussion about the guiding questions. Encourage students to revise their answers based on the class discussion. Let them share their answers as well as add to or help critique other students' answers so that the discussion yields the most robust answers possible.

Consider the following guiding questions as you read the passage below.

- What functions must the cell perform?

  The cell must acquire energy to fuel cell processes, including protein production, the storage and recycling of materials, and the movement of materials in and out of the cell.

- How is a cell like a system?

  Cell structures work together to perform essential functions necessary for the organism to live. The function of one structure may depend on the product of another structure. For example, enzymes drive many cellular processes. These proteins are built on ribosomes. Without ribosomes, other cell processes would cease.

- What does it mean that the form of a cell's structures often predicts their function?

  Because cell structures serve specialized roles in the cell, they have shapes that help make that function as efficient as possible. The article mentions muscle cells being flexible because they need to contract, or nerve cells being very thin and long so they can send messages quickly.

Handout 3.3.A

UNIT 3

Guiding Student Thinking

Students should have been introduced to the idea of "form fits function" in Unit 2: Evolution. However, this was most likely introduced at a macro scale (e.g., adaptations such as pine needles having reduced surface area and a waxy coating to survive in cold climates that receive frozen precipitation) rather than the micro scale of a cell. Therefore, this is a good opportunity to remind students that in the same way physical characteristics of organisms may help predict their environments or ecological role, cell structures help provide insight into their specialized function within the cell. We will return to this idea again at the end of this lesson.

PART 2: MODELING CELL STRUCTURES BASED ON FUNCTION

In the second part of this lesson, students analyze cell structure cards—and determine a creative representation of each structure—to create a model of a plant cell. Students think creatively to represent organelles based on their function and also engage in peer review and reflection on their models. Before this part of the lesson, students should already have a good working knowledge of cell structures and their functions.

CREATING THE MODELS

- Have students work in groups that are as small as possible (ideally pairs) so that each student is fully engaged. Provide students with **Handout 3.3.C: Modeling Cell Structure and Function**. Give each group supplies for creating their model such as dry-erase markers and a mini-whiteboard; medium-sized construction paper, pencils, and markers; or a laptop or tablet. Ideally, the materials used should allow students to easily revise their work. Assign groups to start at different work stations so students will be evenly spread out.
- As directed on the handout, students will create a model of a cell by reading the description on each card and then creating an illustration that best

Classroom Ideas

There are many ways to run this part of the lesson. The approach described in the lesson involves distributing cards among multiple work stations and having students rotate through the stations; this minimizes time spent cutting out cards. If you don't have space for work stations, then you can make a set of cards for each pair of students to use at their lab desk.

Meeting Learners' Needs

If students are having trouble getting started, you may want to generate some examples together as a class before students begin the group work.

represents the role of that cell structure. Students will repeat this process for all the cards as they move through the work stations.

- Allow students approximately 5 minutes at each station (or per two structure cards) before telling them to switch. Remind students that as they add to their model, they will need to consider the placement of each cell structure to ensure that the model represents a cell as an efficient system. This will likely require revisions to their model as they get new cell structures and information.
- For each structure represented, students should use the table on the handout to record the placement and description of the representation chosen, as well as justify that choice of representation and placement within the model.
- After students have finished their model, allow them to review their table and model and discuss any necessary revisions with their partner. If students are working on whiteboards, have them take a picture of the model to study later.

PEER ASSESSMENT OF CELL MODELS

- Give each student pair a new, blank cellular structure model overview table from **Handout 3.3.D: Model of Cell Structure Overview – Peer Reflection**.
- Student pairs will now exchange their cell model with another student pair and use the model created by their peers to fill in the blank overview table. They will need to rely on the unlabeled representations in the model to determine what cell structure they represent. They should then craft a reasonable explanation of why that representation is justified for that structure.
- Once both groups are finished completing the new tables, they should review their solutions together, using both their original handout (3.3.C) and their peer-reflection handout (3.3.D) to guide their discussion. Be sure students discuss each structure and come to a consensus on the role and whether the representation was reasonable. This peer-to-peer dialogue should lead to some revisions of student models and thoughts about cellular structures and their associated functions.

Instructional Rationale

The peer review and discussion of the models in this part of the lesson is very valuable, as it allows students to really think more deeply about cell structures and functions. However, it is important to closely monitor student group discussion during this part of the lesson so you can correct any potential misconceptions or student challenges with adequately describing the functions of cell structures.

UNIT 3

- Once all student groups have finished, lead a whole-class discussion to allow them to share what representations they chose for their structures and why. Record student ideas on the board; you can record multiple ideas for each structure. By the end of the discussion, a complete list of cell structures and ways of representing them should be visible for students.

Guiding Student Thinking

This is a great opportunity to have students connect knowledge from Unit 1: Ecological Systems—specifically, organisms' roles in the ecosystem—with how cell structures support those roles (e.g., plants contain chloroplasts for photosynthesis). It is also important for students to be able to compare and contrast differences between plant and animal cells and connect these differences to the energetic processes these organisms use to acquire energy. Challenge students to think about why plant cells contain mitochondria as well as chloroplasts. This is useful foreshadowing of later lessons on photosynthesis and cellular respiration, as a common misconception students have is that plants exclusively use photosynthesis to acquire the energy they need to perform cellular functions.

PART 3: EXAMINING SPECIALIZED CELL STRUCTURES

The final part of the lesson is designed to have students apply their understanding of cell structures and functions to some examples of specialized cells.

- After students have completed the modeling activity, invite them to closely observe and analyze the images of muscle cells, neurons, and red blood cells on **Handout 3.3.E: Examining Specialized Cells**. Encourage them to make predictions about the different functions these cells perform, and therefore the structures they contain. As instructed on the handout, students will then fill out a table with their ideas.
- While students are not likely to know how red blood cells are formed or that they lack most organelles, these cells are interesting to consider and can help students understand that not all structures they represented in their models will be found in all cells. Even if students cannot completely fill out the table, challenge them to at least describe the shapes and structures they see and to make predictions about how they support the function of the cell.
- Finally, lead a whole-class discussion that allows students to share the ideas they recorded. Be sure to include summary discussion questions such as the following:

- Which structures are common to all cell types? What are the functions of these essential structures?

  All cells possess a plasma membrane, ribosomes, genetic material, and cytoplasm. All cells have membranes that separate the cell from the external environment and contain the cytoplasm, which includes water, organic molecules, and ions. Organisms require genetic information to direct the synthesis of proteins, which is carried out in the ribosomes. *Note:* It is important to highlight for students that most red blood cells lack ribosomes once they reach maturity, but they do start out with them.

- Biological systems must maintain efficiency. What are some design elements that would increase the efficiency of a cellular structure?

  Students should recall previous discussion of how "form fits function." Answers will vary based on what design elements students focus on. For example, they could highlight how the folding of internal membranes (e.g., in mitochondria and chloroplasts) increases the surface area for chemical reactions to take place. If students have already explored ratios of surface area to volume in earlier lessons, then the concept of cell size can also be discussed here.

Meeting Learners' Needs

Prior to this part of the lesson, you may want to lead a brief class discussion on the differences between eukaryotic and prokaryotic cells, as well as between animal and plant cells. Students should recall many of these differences from middle school life science, but some discussion questions to elicit prior knowledge may be helpful for students who are having trouble recalling differences.

Cell Type	Cell Structure Differences	Justification
Muscle cells	An abundance of mitochondria	Muscle tissue is responsible for movement and requires large amounts of energy. Therefore, there will be high numbers of mitochondria in these types of cells.
Neurons	Long, narrow extensions (dendrites and axons)	Neurons are specialized cells that carry messages within the human nervous system. They do share some similarities with other cells, but they also have specialized features, such as dendrites, that enable them to carry out their role of sending messages quickly.
Red blood cells	Lack many organelles but have cell membranes and cytoplasm	The primary function of red blood cells is to transport oxygen. Red blood cells do not have nuclei or many other organelles, which leaves more room in the cytoplasm for the hemoglobin needed for transporting oxygen. (Red blood cells are manufactured in the bone marrow. When they are mature, the nucleus and other organelles are expelled.)

Handout 3.3.E

UNIT 3

LESSON 3.4

Cell Membrane Bubble Investigation Lab

OVERVIEW

LESSON DESCRIPTION

Part 1: Introduction to Elicit Prior Knowledge of Cell Membranes

Students apply what they know about the phospholipid bilayer to predict how a bubble solution forms a bubble. This is accomplished through guided questions and illustrated models and should be completed and checked for understanding before students begin the lab.

Part 2: Modeling Cell Membrane Properties

Students work through five different mini-experiments with bubble solution. The experiments model the properties of membranes such as fluidity, self-healing properties, the ability for membranes to fuse and divide, and the mosaic model (when proteins are added).

Part 3: Drawing Conclusions About Cell Membrane Properties

In this part of the investigation, students apply what they have observed to explain properties of membranes.

CONTENT FOCUS

This lesson focuses on plasma membranes as a shared characteristic among all organisms. In this lab activity, students use bubble solution to simulate the behavior of cell membranes. Before beginning the lab, it is helpful for students to have a basic understanding of the phospholipid bilayer and how it forms. This requires them to understand that the phospholipid molecule has a hydrophilic end and a hydrophobic one,

AREA OF FOCUS

- Attention to Modeling

SUGGESTED TIMING

~60–90 minutes

HANDOUTS

- 3.4.A: Soap Bubbles Versus Phospholipid Bilayers
- 3.4.B: Modeling Cell Membrane Properties
- 3.4.C: Drawing Conclusions About Cell Membrane Properties

MATERIALS

- spray bottles or damp cloths
- newspaper (optional, to protect surfaces from bubble solution)
- pipettes or bendable straws
- spool of cotton thread or kite string
- forceps for placing thread loops on bubbles (optional)
- scissors

and that water is found both inside and outside the cell. This lab can be done before students are aware of protein channels and/or how molecules pass into and out of the cells. The aim is to help students visualize the fluid properties of the membrane, which are necessary for the function and flexibility of the cell. Thus, as long as students are familiar with the basics of the bilayer, the experiment can be an introduction to membranes and membrane properties. This lab introduces but does not completely demonstrate selective permeability, so teachers should be prepared to reinforce this topic with their own lesson plans.

- small, shallow aluminum pans for bubble solution
- materials for making square cell frames (pipe cleaners, bendable straws, or aluminum hobby wire)
- bubble solution

COURSE FRAMEWORK CONNECTIONS

Enduring Understandings	
▪ 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.	
Learning Objectives	**Essential Knowledge**
CELLS 2.1(a) Provide evidence to support the claim that all biological systems demonstrate some shared characteristics.	**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.

UNIT 3

SETUP AND PREPARATION NOTES

- Students will be blowing air through straws or pipettes. Remind them not to share these materials with one another.
- Bubble solution—in general the solution is 10 parts water to 1 part dishwashing soap to 0.25 part corn syrup or glycerin. For example:
  - 1,000 mL of water
  - 100 mL dish soap
  - 25 mL corn syrup or glycerin
- Glycerin is the most effective for making a bubble solution that withstands experimentation (i.e., bubbles that don't pop as easily). It can be found at most drugstores or large general stores. Make sure you use dishwashing soap and not just any soap. The bubble solution can be placed in gallon containers (e.g., plastic milk jugs) the night before so they are easy to pour at student workstations the next day.
- Instead of students using their desk or lab tabletops, you may want them to work in a shallow aluminum foil baking pan.

SAFETY NOTES

All general safety guidelines should be followed.

UNIT 3

PART 1: INTRODUCTION TO ELICIT PRIOR KNOWLEDGE OF CELL MEMBRANES

The introduction to this lab elicits prior knowledge from students regarding the properties of phospholipids and how those properties result in the formation of bilayers in an aqueous environment.

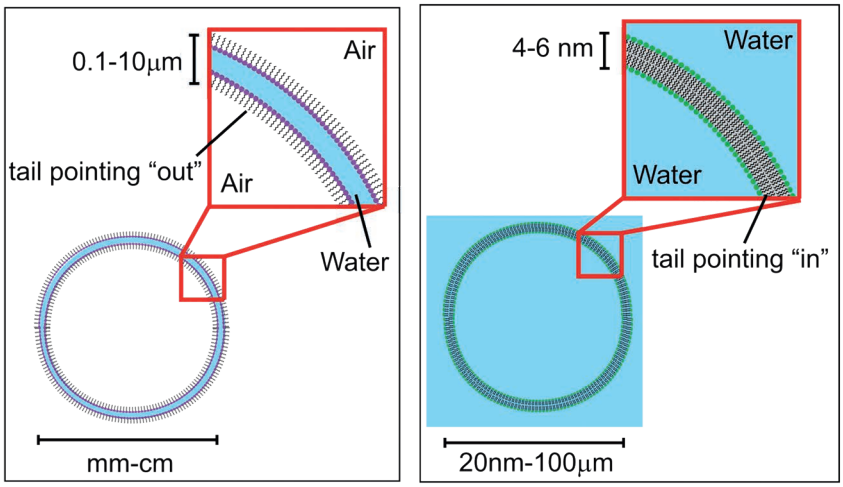
- Before having students engage in this lab activity, lead a discussion that reviews a few key aspects of cell membranes with which they should be familiar. You can ask questions such as the following:
  - Where are cell membranes found in living organisms?

    The cell membrane is the boundary between the cell and its environment. In addition to being the outer border of a cell, membranes are found within the cell: Organelles in the eukaryotic cell are bound by membranes. Such membrane-bound organelles include the nucleus, the endoplasmic reticulum, the Golgi apparatus, and vesicles, to name a few.

  - Why are cell membranes important?

    The cell membrane creates a protective barrier between the internal contents of the cell and the surrounding environment. However, it is selectively permeable and therefore allows necessary transport of materials into and out of the cell.
- Following the discussion, have students complete **Handout 3.4.A: Soap Bubbles Versus Phospholipid Bilayers**. First they will label the hydrophobic and hydrophilic regions of a phospholipid on Model 1 in the handout. Next, they identify on the diagram where water is located relative to a cell membrane and explain how a phospholipid bilayer can self-assemble. For Model 2 they use their understanding of the phospholipid bilayer to draw a model of detergent films that make up bubbles.
- Once students have completed Handout 3.4.A, have each of them work with a partner to compare their models and descriptions of both the lipid bilayer and the soap bubble. Sample responses for Models 1 and 2 are provided on the next page for reference.
- If time prohibits you from verifying every student's hand-drawn model of the bubble, you may want to show the sample image on the next page to the class to make sure students can visualize why bubble films approximate the behavior of lipid bilayers. Students should understand that because the tails of the lipids in detergent are hydrophobic, they will point away from the water. In this case, that means the tails point out of the bilayer, while the heads are associated with the water found inside the bilayer.

UNIT 3



Credit: By MDougM [Public domain], from Wikimedia Commons.
https://commons.wikimedia.org/wiki/File:Lipid_vesicle_vs_soap_bubble.svg.

MODEL 1

1. On the single phospholipid molecule, label the hydrophilic part of the molecule and the hydrophobic part of the molecule. Include a brief description here of what hydrophobic and hydrophilic mean.

   Students should label the "tails" of the phospholipid molecule as hydrophobic and the "head" as hydrophilic. Their descriptions should indicate that these terms are based on the chemical makeup of the molecules involved. Hydrophilic molecules are polar molecules that are attracted to water; nonpolar molecules are hydrophobic, meaning they do not readily bond with water.

2. Imagine the phospholipid bilayer above represents the cross section of a cell membrane. Write "water" where you would find water in this model.

   Students should indicate that there is water inside the cell as well as outside of the cell.

3. In your own words, explain why a phospholipid bilayer self-assembles when phospholipids are surrounded by water.

   Student explanations should include that phospholipid bilayers form in water because the individual phospholipid molecules arrange themselves due to their hydrophobic and hydrophilic properties. Specifically, the heads of the molecules are hydrophilic and are thus attracted to water, while the tails are hydrophobic and avoid water. By arranging themselves in the bilayer as shown, the tails are protected from water while the heads associate with water.

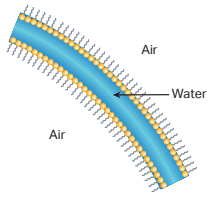
UNIT 3

MODEL 2

MODEL 2 – A MODEL OF A SOAP BUBBLE

Consider what you know about the phospholipid bilayer of cell membranes and the information about bubbles you just read. In the space below, draw a model of the detergent bilayer that forms the bubble film. Label the location of water and air.

Student illustrations should show a thin layer of water with lipid-like molecules on either side. Because the tails of these lipids are hydrophobic, they will point away from the water, causing the tails to point out of the bilayer, while the heads are associated with the water that is found inside the bilayer. Student illustrations may look something like this:



Handout 3.4.A

PART 2: MODELING CELL MEMBRANE PROPERTIES

In this part of the lesson, students use bubble solution to simulate properties of membranes. There are five different experiments within this investigation. Each one allows students to make observations that will help them build a mental model of a membrane as a dynamic, fluid, and flexible structure. Students should also be able to demonstrate the fission and fusion of vesicles or cells and the presence of transport proteins on membranes.

- Descriptions of each experiment are found in **Handout 3.4.B: Modeling Cell Membrane Properties**, shown on the next page with summaries of expected student observations for each part of the lab. Have students work in pairs for this part of the lesson, if possible.

Meeting Learners' Needs

If students have difficulty starting their model, remind them to actually visualize a bubble they have seen or made with a bubble maker (blowing through a wand). They should be able to visualize that there is air inside the bubble. Then encourage them to think about where the water would be since the bubble is a mixture of soap and water. This will help them realize that the hydrophobic tails will point away from the water layer.

Classroom Ideas

To minimize time spent cleaning up at the end of this lab, it is very helpful to lay newspaper on lab benches and even on the floors around the work area. Bubble solution is slippery and hard to fully clean off surfaces. If possible, pour the bubble solution into trays or pans already placed in the location where they will be used.

UNIT 3

EXPERIMENT 1

Observations *Record your observations of the experiment.*	**Cell Membrane Connections** *Describe how this experiment models a property of the cell membrane.*
We first noticed that the light reflected colors off the bubble, and the colors seemed to move and swirl around. The bubble solution appeared to flow within the film. As we gently bounced the straw on the bubble, it changed from round to flatter. It eventually popped, but until then it was able to change shape.	The cell membrane is not rigid; it is dynamic and flexible.

Handout 3.4.B

EXPERIMENT 2

Observations *Record your observations of the experiment.*	**Cell Membrane Connections** *Describe how this experiment models a property of the cell membrane.*
As long as our finger was wet with bubble solution, we were able to push it into the bubble and pull it out without popping the bubble. The same was true with our pencil. We were even able to put a hand into the bubble up to the wrist before the bubble popped. However, when we tried this with dry hands, the bubble popped immediately. The bubble solution on our fingers, pencils, and hands seemed to help prevent the bubble from popping.	The cell membrane allows some objects to move in and out of the cell without disrupting the integrity of the membrane.

Handout 3.4.B

UNIT 3

EXPERIMENT 3

Observations *Record your observations of the experiment.*	Cell Membrane Connections *Describe how this experiment models a property of the cell membrane.*
The thread was able to cut the bubble in half! However, this was hard and it took us a few tries to do it without popping the bubble.	The cell membrane is flexible and this property is necessary when cells divide.

Handout 3.4.B

EXPERIMENT 4

Observations *Record your observations of the experiment.*	Cell Membrane Connections *Describe how this experiment models a property of the cell membrane.*
After a few tries, we were able to get the two bubbles to become one bubble.	The cell membrane can incorporate things into itself. In exocytosis, for example, a vesicle membrane can fuse with the cell membrane.

Handout 3.4.B

EXPERIMENT 5

Observations *Record your observations of the experiment.*	Cell Membrane Connections *Describe how this experiment models a property of the cell membrane.*
After we successfully added our loop to the bubble film without popping it, we were able to break the bubble film inside the loop without popping the film outside the loop! Then we were able to pass the tip of a dry pencil and other small objects through the hole inside the loop.	The cell membrane is selectively permeable and allows some things to move through easily (osmosis), whereas others require energy (active transport).

Handout 3.4.B

Classroom Ideas

To make a square frame for Experiment 5, students can bend pipe cleaners or aluminum hobby wire found at most craft stores, or use straws folded into one another—similar to the method used to make quadrats in the lab in Unit 1: Ecological Systems. You will need to either help your students make these or make them ahead of time. Each square frame should be approximately 10 cm on each side.

UNIT 3

Guiding Student Thinking

At this point in the investigation, students may need help refining their cell membrane connections. As you circulate from group to group, help correct any misconceptions or inaccurate statements you see by asking students to use their observations to help illustrate how the investigation is modeling a specific property of a cell membrane. Part 3 of this lab will also help students refine their thinking about these connections.

PART 3: DRAWING CONCLUSIONS ABOUT CELL MEMBRANE PROPERTIES

In this portion of the lesson, students identify and describe the properties of membranes and support their understanding with the observations they made during Part 2.

- First, have students continue to work with their partner to complete the table on **Handout 3.4.C: Drawing Conclusions About Cell Membrane Properties**.
- Next, have pairs work with another student pair to compare their ideas and descriptions. Have the groups engage in peer-to-peer discussion to come to a consensus on which experiments modeled which properties of the cell membrane.

Classroom Ideas

If time permits, it's also helpful to have students generate a consensus form of their charts either on poster paper or with neon markers on their lab tables. You can then have them do a gallery walk to compare and contrast the conclusions generated.

Instructional Rationale

This part of the lesson, where students engage in an academic conversation with their peers about their models, is critical in helping solidify their conceptual understanding of the important characteristics of the cell membrane. This part of the lesson allows students to reflect on and refine their understanding of the cell membrane as they critique their own ideas and their peers'.

- Finally, bring students back together to discuss their conclusions as a whole group. To ensure that they see appropriate descriptions and evidence, it is helpful to develop one table for all students to see, such as the one on the next page.

UNIT 3

Drawing Conclusions About Cell Membrane Properties

In these investigations you observed some (but not all) special behaviors or properties of cell membranes. Using the observations and descriptions you recorded from your experiments, describe the properties of membranes and how the bubble model demonstrates their properties.

Properties of Cell Membranes	What does this mean?	What is your evidence from the bubble model?
Cell membranes are flexible (fluid).	This means that cell membranes can change shape without breaking, and that molecules in the membrane can flow like a liquid within it.	In Experiment 1, we could see the bubble solution swirling around in the bubble, and in Experiment 5, we could see the loop moving around in the bubble. In Experiment 1, the bubble film could also change shape and then change back.
Cell membranes have the ability to self-seal—to fix small tears in their structure.	This means that a small hole in the membrane can be fixed by the membrane itself.	We could stick objects through the bubble without popping it, especially if the objects we used were first dipped in bubble solution, like in Experiment 2.
Cell membranes contain molecules other than phospholipids.	This means that the membrane can have components other than lipids.	We were able to add a loop of thread to the membrane without breaking the membrane.
Cell membranes are selectively permeable.	This means that membranes can let some things pass through.	During Experiment 5 we were able to poke a hole in the membrane, which allowed anything small enough to get through that hole to pass through the membrane.
Cells can split into new cells; vesicles can be broken off membrane-bound organelles and can fuse with other membrane-bound structures.	This means that cells or pieces of cells can break off when the membrane splits, or membrane-bound organelles such as vesicles can fuse with other membrane-bound structures.	During Experiments 3 and 4, we were able to split a bubble and merge two bubbles without popping them.

Handout 3.4.C

UNIT 3

LESSON 3.5

Launch Lesson – Introduction to the Role of Water in Cells

OVERVIEW

LESSON DESCRIPTION

Part 1: Exploring Properties of Water

In this brief investigation, students draw on prior knowledge about the importance of water and explore its unique properties as they make observations about water droplets.

Part 2: Background Reading on Properties of Water

Students engage in an analytical reading of a text about the properties of water that are responsible for its unique role in cells.

Part 3: Applying Understanding of Water's Properties

Students synthesize prior knowledge with new information from the reading to model how water moves into and through a plant to reach the cells of the leaves (sites of photosynthesis).

AREA OF FOCUS

- Emphasis on Analytical Reading and Writing

SUGGESTED TIMING

~45–60 minutes

HANDOUTS

- 3.5.A: The Basics About Water
- 3.5.B: Modeling Movement of Water in Plants

MATERIALS

For each student pair:

- 1 large sheet wax paper
- 125 mL or 50 mL beaker of water
- 2 plastic pipettes
- 2 toothpicks
- dish soap

CONTENT FOCUS

This lesson elicits prior knowledge from Unit 1: Ecological Systems with regard to the movement of water and nutrients in ecosystems. It then extends and deepens students' understanding of how cellular systems (and therefore organisms) rely on water's unique properties to transport substances in and out of cells. Students also integrate new knowledge with prior knowledge by modeling the movement of water through a plant. Understanding gained in this lesson will help launch subsequent lessons on the structure of the cell membrane and passive cell transport such as osmosis.

COURSE FRAMEWORK CONNECTIONS

Enduring Understandings	
▪ Biological systems must respond to changes in internal and external environments in order to maintain dynamic homeostasis.	
Learning Objectives	**Essential Knowledge**
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.
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.

UNIT 3

PART 1: EXPLORING PROPERTIES OF WATER

In the first part of this lesson, students make observations and ask questions about the unique properties of water as they work in pairs to investigate the behavior of water droplets.

- To begin, distribute materials or have each student pair gather their materials. Then, have students use their pipette to place two or three drops of water on their wax paper in different locations.
- Next, give students an opportunity to move and touch the water droplets with their toothpicks and make observations. Students should discuss initial observations with their partners and record key observations and questions. To guide student thinking and exploration, you may want to ask some of these questions:
  - Can you move the toothpick inside a water drop without it popping?
  - Is it possible to move a water drop to a different location without it popping?
  - Can you combine two or more of your drops into one larger drop?
- Now provide students with a small drop of dish soap on the corner of their wax paper. Students may need to add two or three more drops of water to their wax paper if they don't have enough individual drops remaining.
- Students should now dip the tip of their toothpick in the soap and repeat the same investigation of the water droplets. (They will notice immediately that this causes the drop to flatten.)
- Finally, have students share their observations about the behavior of water and the possible effects of the dish soap. Record all student observations for the whole class to see. As a class, students should then analyze these observations and generate at least three or four questions about the properties of water that could be investigated. Again, record all questions for the whole class to see.

Instructional Rationale

This is a simple investigation, but it can yield productive questions that spark student interest and foster understanding about many important concepts in upcoming lessons. These concepts include the structure and function of the cell membrane's phospholipid bilayer and cellular transport across the membrane.

PART 2: BACKGROUND READING ON PROPERTIES OF WATER

Now that students have generated some questions about the properties of water, they have the opportunity to research these questions by reading about the chemical composition and properties of water. The reading, adapted from articles by the United

States Geological Survey, provides students with critical background information about how the chemical properties of water are responsible for the important role it plays in cellular systems.

- To begin, have students independently read and analyze the passage on **Handout 3.5.A: The Basics About Water**, highlighting and summarizing important information as they read. Encourage students to record ideas and thoughts in their own words in the "My Notes" section rather than simply copying from the article.
- To ensure that students extract the appropriate terminology and key concepts, lead a whole-class discussion on the article once they have finished reading and analyzing it. Invite students to share what they have summarized in their notes sections and prompt student thinking and reflection with the following questions:
  - Why is water referred to as a polar molecule?

    A water molecule is referred to as a polar molecule because the hydrogen atoms tend to align along one side of the water molecule, giving that side of the molecule a slight positive charge and the other side a slight negative one. This is because the atoms in the molecule are covalently bonded (i.e., they share electrons) and the electrons tend to spend more time around the oxygen atom than they do around the hydrogen atoms.

  - In paragraph 6, water is described as the universal solvent. In your own words, what does this mean?

    Water is attracted to lots of other kinds of molecules, and sometimes that attraction leads it to disrupt the forces that hold those other molecules together, which makes the substance dissolve. Water is called the universal solvent because it can break down so many other kinds of substances.

  - Why do you think the chemical properties of water are important to cellular systems?

    Water is vital as a universal solvent as it breaks down important ions needed for living systems, and the cohesive and adhesive properties of water allow the transport of those materials through living systems (e.g., capillary flow).

Meeting Learners' Needs
Students may struggle with understanding how chemical bonds and the shape of water molecules result in differences in electronegativity between oxygen and hydrogen in a water molecule. You may want to further explain these concepts by displaying some illustrations or simulations such as those from Lumen Learning and The Concord Consortium, available at **https://courses.lumenlearning.com/boundless-biology/chapter/water**.

- Allow students time after the discussion to return to the questions generated as a class after the investigation of water properties on the wax paper. Have them work with their partners to see if they can answer the questions they had about water by using the appropriate concepts learned in the reading, such as adhesion, cohesion, hydrophilic and hydrophobic molecules, etc.

Guiding Student Thinking

You may want to lead a guided, whole-class discussion of one of the questions to help students make strong connections between how the properties of water, such as adhesion, cohesion, and surface tension, contributed to what they observed in their investigation.

PART 3: APPLYING UNDERSTANDING OF WATER PROPERTIES

In this part of the lesson, students synthesize prior knowledge with new information from the reading to model how water moves into and through a plant to reach the cells of the leaves (sites of photosynthesis).

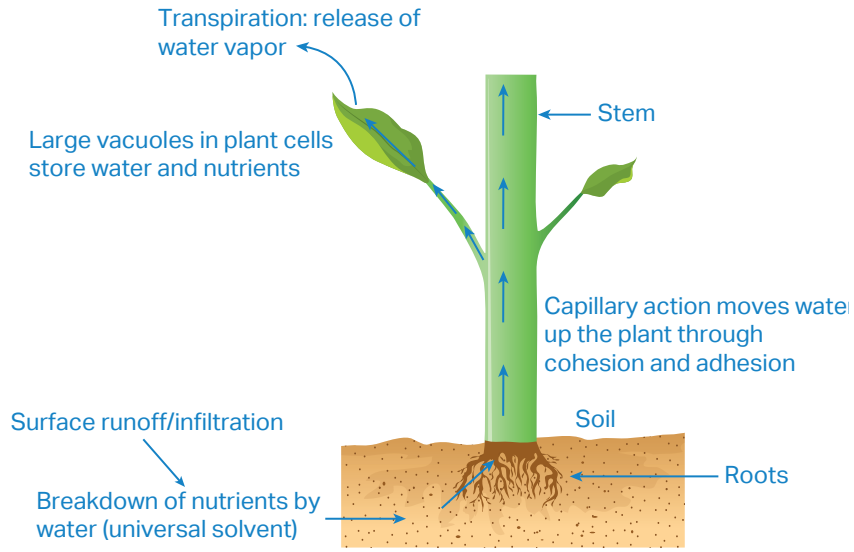
Classroom Ideas
This modeling exercise could also be given as homework or as a formative assessment since it makes strong connections across the units.

- Have students work in pairs or individually to draw a model of the movement of water from the soil up to the leaves of the plant, using **Handout 3.5.B: Modeling Movement of Water in Plants**.
- Challenge students to use as many key terms and concepts as they can when creating their model. Encourage them to also use terms and concepts from prior lessons, such as aspects of the water cycle (e.g., transpiration) and the cellular structure of the plant cells in the leaves.
- After developing their model, students should summarize all the processes included in the model and identify any key connections between processes. They can write this information in the left column of the table on the handout.
- Students should then partner with another student (or with a pair of students, if working in pairs already) to compare and critique each other's models. After groups have had some time to discuss their ideas, students should make any necessary revisions to their models and explain these changes in the right column of the table.
- Finally, invite students to share aspects of their models and summaries with the class. As students share this information, record it on the board to generate one collective model for the class. A sample model and student responses are shown on the next page.

UNIT 3

Modeling Movement of Water in Plants

Use the figure to draw a model that shows how water flows through a plant. Use specific terms and concepts that you have learned about previously (e.g., transpiration) as well as new information you extracted from your reading. Then follow your teacher's instructions to complete the table below.



Summary of Initial Model	Revisions to the Model
Student answers will vary but should include: • How the water cycle plays a role in the transport of water to plants (surface runoff and infiltration) and out of plants (transpiration). • How the chemical properties of water allow it to break down nutrients in the soil. • How the water and nutrients are then transported to the leaves (site of photosynthesis) through capillary action. Students should also indicate cellular structures, such as the large vacuoles in plant cells that store the water and nutrients.	Student answers will vary.

Handout 3.5.B

UNIT 3

LESSON 3.6

Argument-Driven Inquiry into Tonicity Lab

OVERVIEW

LESSON DESCRIPTION

Part 1: Investigating Effects of Tonicity on Plant Cells

Students model the responses of cells when introduced to one of three types of solution environments: isotonic, hypertonic, and hypotonic.

Part 2: Investigating the Effects of Soil Salinity on Crop Production

Students investigate whether the quantity of dissolved salts in a solution will affect seed germination. Students then apply their findings to propose solutions to a real-world challenge in agriculture.

CONTENT FOCUS

This lesson challenges students to investigate the effect of various types of solutions on cells and the resulting impact on the overall organism. Students create models that represent a cell under isotonic, hypertonic, and hypotonic conditions, then apply what they have learned as they complete an inquiry investigation exploring the effect of various solutions on seed germination. Students lean on their prior knowledge of cellular structures, such as the cell wall, central vacuoles, and chloroplasts, to extend their thinking about cell transport.

AREAS OF FOCUS

- Emphasis on Analytical Reading and Writing
- Attention to Modeling

SUGGESTED TIMING

~90 minutes

HANDOUT

- 3.6: Investigating Tonicity

MATERIALS

- balloons (3 per group)
- aluminum loaf pan (3 per group or minimum of 1 per group if students are reusing the pan for each model)
- masking tape
- scissors
- LCD projector, electronic whiteboard, or other technology for showing an online video
- internet access to the Sick Science! video "Growing and Shrinking Egg" (1:24), available at **https://www.youtube.com/watch?v=aIbeHs2opEM**
- materials for a visual presentation,

i.e., markers, pencils, and posterboard; whiteboards and dry-erase markers; or laptops or tablets

COURSE FRAMEWORK CONNECTIONS

Enduring Understandings	
▪ 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.	
Learning Objectives	**Essential Knowledge**
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.

SETUP AND PREPARATION NOTES

- Part 2 of this laboratory lesson requires two to three days for seeds to germinate. You will likely want to have students complete the laboratory setup on the first day, prior to beginning Part 1. You may also want to have students read the introductory information in Part 2 and discuss their predictions at the same time (see Part 2 for more details). The following materials are needed for the Part 2 setup:
  - small zip-top plastic bags with half a paper towel (5 per group)
  - markers
  - mung beans or radish seeds (10 per bag)
  - five prepared salt solutions using table salt and distilled water: 0%, 0.625%, 1.25%, 2.5%, 5%

SAFETY NOTES

All general safety guidelines should be followed.

UNIT 3

PART 1: INVESTIGATING EFFECTS OF TONICITY ON PLANT CELLS

In this part of the laboratory lesson, students predict what differences they might expect to observe among plant cells introduced to environments with different tonicities. They then explore these changes in the cell from a systems perspective, focusing on the role of water.

- To begin, have students read Part 1 of **Handout 3.6: Investigating Tonicity** and work in groups of three, if possible, to predict how a cell will look or react when placed in solutions with different tonicities.
- After students have had some time to discuss the prediction questions, provide them with modeling materials and prompt them to begin building the three models described on the handout. (If students are working with only one loaf pan, they can create one model at a time and reuse the pan for each model.)
  - First, students will need to cut their loaf pan(s) in half. They then should tape these two parts of the pan back together, sliding one into the other to make a much smaller pan. (A balloon inflated to its maximum size should barely fit.) This pan represents the cell wall of the plant cell. Since the edges of the pan may be sharp from cutting, have students put masking tape around each cut edge as a barrier.
  - Next, students should place a balloon inside the pan to model the cell's membrane. For each model, students should blow up the balloon to the appropriate level to represent the cell in one of the following environments: hypertonic, isotonic, hypotonic.
- For each of the three models, group members should work together to:
  - Describe the shape of the cell membrane and the cell's volume inside the cell wall.
  - Use their model to make predictions about the rigidity of the cell wall in each of these different environments.

Meeting Learners' Needs
If students are having difficulty making connections between the modeling materials and plant cell structure, it may be helpful for them to work on drawing a representation of each cell first and then constructing their models. Or, they may benefit from alternating between these tasks.

Then, students will use their models to help them sketch a cell in each of the three environments. As indicated on the handout, students' sketches should show whether the solute concentration is higher inside or outside the cell. Students should also use arrows to represent the movement of water into or out of the cell and label each type of element in the drawing. While students specifically modeled the changing shape of the cell membrane, they should also include in their sketches the changing shape of the vacuole.

UNIT 3

Guiding Student Thinking

At this point, allow students to struggle through the creation of the models rather than telling them what each model should look like. They will have opportunities to review and revise their work later. Encourage them to return to the introduction on the handout for information needed to create their cell models in each type of solution.

- Encourage students to work with another group to compare their sketches and models and make appropriate revisions based on peer-to-peer dialogue. Then, lead a whole-class debrief using some guiding questions such as the following:
  - How does the plant cell wall function differently than the cell membrane?

    The cell wall surrounds the cell membrane in plant cells and provides structure and support to the plant. The cell membrane regulates the transport of materials into and out of the cell.

  - How do vacuoles in animal cells differ from those in plant cells?

    Unlike animal cell vacuoles, the vacuoles in plant cells can fill as much as 90% of the intracellular space. Plant cells change in size and pressure as vacuoles' volume changes under varying osmotic conditions.

  - Why would it be important for cell walls to remain fairly rigid?

    Students should recall from Unit 1: Ecological Systems that plants are primary producers and acquire energy via photosynthesis. Cell walls help plants remain upright, which is beneficial for capturing sunlight. This question provides a good opportunity to introduce students to the idea of turgor pressure. Turgor pressure keeps a plant from wilting.
- Next, show students a short video demonstrating tonicity using an egg (**https://www.youtube.com/watch?v=aIbeHs2opEM**).
- Then, lead a whole-class discussion to help students make connections between the observable changes to the egg and their models.
  - What happens to the egg under isotonic, hypertonic, and hypotonic conditions?
  - What similarities or differences do you notice between the egg and your model of a plant cell?
  - For the sketches that you drew, how did you represent the concentration of particles inside and outside the cell?
  - What might cause water to flow into a cell?
  - What might cause water to flow out of a cell?
  - How might you represent water flowing in and out of a cell at equal rates?

- To conclude this part of the lesson, display a short video clip of plant cells responding to a hypertonic environment. These can be found by searching online; for example, see **https://www.youtube.com/watch?v=zVvHn6Sj9PQ**. Ask students to describe what is happening to the plant cells as they are exposed to a hypertonic solution, and discuss whether the results support or contradict their predictions and models.

PART 2: INVESTIGATING THE EFFECTS OF SOIL SALINITY ON CROP PRODUCTION

In this part of the investigation, students measure how different solutions containing various concentrations of solutes affect the germination and growth of mung beans. Students then use their findings to reason about a persistent challenge in agriculture.

As mentioned in the Setup and Preparation Notes, the lab setup for Part 2 must be performed two to three days in advance. Therefore, you may wish to carry out the "Introduction and Setup" section of Part 2 before beginning Part 1 of this lesson.

INTRODUCTION AND SETUP

- To begin, have students read the introductory section of Part 2 on Handout 3.6 and work with a partner or in a small group to answer the prediction questions.
- Now, students will have an opportunity to test some of their predictions. Pass out lab materials to each group and have them set up the experiment. A portion of the student handout, showing the preparation procedure, is shown below for reference.

SETUP PROCEDURE

1. Set aside a zip-top plastic bag for each of the five salt solutions. Label each bag with your group's initials and the assigned salt concentration.
2. Place a folded paper towel in each bag and add the appropriate salt solution until the paper towel is completely saturated. (Make sure there is no standing water in the bag.)
3. Place 10 mung bean seeds in the fold of the wet paper towel in the bag.
4. Seal the bag, making sure it contains some air.
5. Place your prepared "soils" in a warm, dark location for approximately two to three days.

Handout 3.6

UNIT 3

MAKING OBSERVATIONS AND COLLECTING DATA

- After two to three days, retrieve the seeds. Before students make observations, remind them about the problem of soil salinization and their initial predictions. Then, discuss the following questions:
  - Although we did not use soil, which part of the lab setup mimics the growth medium of soil?

    Paper towel
  - Why did we use 10 seeds instead of 1 for each type of soil?

    A larger sample size decreases percent error and allows for calculation of rates (percentages/ratios).
  - What is the function of the seed structure (mung bean)?

    Reproduction
  - Is the seed made up of plant cells? Explain your thinking.

    Answers may vary but could include: Yes, the seed is made up of plant cells. Since a plant is expected to develop from the seed, and cell division is required to generate new cells, the seed must be composed of cells.
  - What are some methods we could use to measure germination and growth?

    Answers may vary but could include counting the number of beans that have sprouted for each environment.
- Use student answers provided in the last question to come to a whole-class decision about how to measure germination and growth. Since they will be examining an aggregate of group data, it is important to agree upon one method of measurement.
- Now, have student groups work together to collect data and make observations about germination and growth, as directed on the handout. Circulate around the room while student groups are working to listen and help guide their thinking.
- Allow ample time for students to make observations and record their data in the table provided on their handout. Once all groups are finished, have each group share their results with the whole class. Students should record whole-class data for each concentration on the table as well.
- Lead a short whole-class debrief on the data collected. Some questions to spark student thinking about the data prior to their deeper analysis could include:
  - Why was it necessary to test a 0% concentration of salt in this experiment?

- What potential sources of error should we be aware of when using this method?
- Why was it necessary to choose one method of measurement for all groups to use?

ANALYZING DATA AND MAKING CLAIMS

- Next, have student groups use the handout to analyze their data and make claims about the effects of salt levels on crop growth and on plant cells. Students will use the claim-evidence-reasoning framework to develop arguments. Students may also want to revisit their models from Part 1.

PRESENTATIONS AND PEER REVIEW

- After student groups have finished constructing their arguments, have them work together to present their findings in a clear, visually appealing poster that they will use during the peer-review portion of the lesson. Remind students to review the reflection questions as a group and make sure all members are prepared to answer them.
- When students are ready to engage in peer review, designate two members of each group as presenters and two members as reviewers. Explain to students that presenters will stay with their poster and present their group's claims, evidence, and reasoning. Reviewers will rotate around to other groups and ask questions and provide feedback. During the second round of peer review, group members will switch roles.

Meeting Learners' Needs

You may want to explain the claim-evidence-reasoning framework in more detail or remind students about these key ideas:

- Present your evidence in a form that is easy to read and interpret and that highlights your key findings.
- Check that your claim answers the primary research question and is supported by your evidence.
- Explain your findings and support your claims with scientific principles, also called the *rationale*.

Classroom Ideas

Creating presentations on whiteboards instead of posters allows more opportunities for students to revise their work. They could also create presentations on lab tables with neon markers.

Instructional Rationale

This part of the lesson allows students an opportunity to practice their scientific communication skills. It also encourages students to apply what they learned in this lesson as they provide peer critiques as reviewers. Allowing students time to revise their arguments based on peer critique is also very valuable as it helps solidify their conceptual understanding of tonicity and provides great feedback on any areas where they may need additional instruction or support.

UNIT 3

- Remind students that the goal of this exercise is to identify ways to improve and strengthen their arguments, not to convince others that their argument is best. Students should record ideas for improvement, as well as effective methods or reasoning used by other groups.
- After all students have had an opportunity to give and gather feedback, have groups discuss any new ideas or revisions they want to make to their final arguments.

Classroom Ideas

To ensure every student reviewer has a question to ask, you may want to print the reflection questions in the student handout on cards and ask students to pick a question to take with them as they rotate to various stations.

PROPOSING SOLUTIONS AND FUTURE RESEARCH

- To wrap up this laboratory lesson, have students individually write up proposals to help farmers successfully control and monitor salt levels in soil to prevent crop failure. This portion of the student handout is shown here for reference.

PROPOSING SOLUTIONS AND FUTURE RESEARCH

Working on your own, craft a proposal that could help farmers control and monitor salt levels in soil to prevent crop failure. Your proposal should be an application of both of your group's claims. Cite evidence from your experiment and scientific principles to support your proposal. Also identify opportunities for further research that could help strengthen your proposal, and describe how you might conduct a follow-up study.

Handout 3.6

- Invite students to share their ideas and future research questions in a whole-group discussion.

  Answers will vary. Possible research questions might include the following:

  - What types of plants (food crops) are salt-tolerant?
  - Which types of soil conservation techniques might be employed to protect soil from salinization?
  - How might salty soils be remediated?

LESSON 3.7

UNIT 3

Launch Lesson – Modeling the Cell Cycle

OVERVIEW

LESSON DESCRIPTION

Part 1: Overview of the Cell Cycle and Mitosis
This part of the lesson elicits students' prior knowledge of the cell cycle, including events in mitosis. Students then watch a short video on the cell cycle and engage in discussion to confirm or revise their initial thoughts.

Part 2: Visualizing Cell Division
Students work with a partner on a card-matching activity that asks them to pair descriptions of the phases of mitosis with the appropriate illustrations.

CONTENT FOCUS

It is likely that many students were introduced to the concept of the cell cycle and cellular division by mitosis in middle school life science. Therefore, this lesson begins by eliciting students' prior knowledge about these concepts. The lesson is intended to deepen their understanding of the importance of the individual phases of the cell cycle—i.e., the need for the cell to increase in size and replicate its DNA to prepare for mitosis. The lesson also explores disruptions to the cell cycle that result in uncontrolled cell growth and replication (e.g., cancer).

AREA OF FOCUS

- Attention to Modeling

SUGGESTED TIMING

~45–60 minutes

HANDOUTS

- 3.7.A: What Do You Know About the Cell Cycle?
- 3.7.B: Mitosis Cards

MATERIALS

- LCD projector, electronic whiteboard, or other technology for showing an online video
- internet access to the Amoeba Sisters videos "The Cell Cycle" (9:18) at **https://www.youtube.com/watch?v=QVCjdNxJreE** and "Mitosis" (8:26) at **https://www.youtube.com/watch?v=f-ldPgEfAHI**

UNIT 3

COURSE FRAMEWORK CONNECTIONS

Enduring Understandings	
▪ Biological systems have specialized structures that enable specific functions necessary to sustain life. ▪ In order to sustain complex processes, biological systems must have mechanisms for growth and repair.	
Learning Objectives	**Essential Knowledge**
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.
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.

UNIT 3

PART 1: OVERVIEW OF THE CELL CYCLE AND MITOSIS

This part of the lesson elicits students' prior knowledge of the cell cycle, including events in mitosis. Students then watch a short video on the cell cycle and engage in discussion to confirm or revise their initial thoughts.

- To begin, ask students to read through the statements in the table on **Handout 3.7.A: What Do You Know About the Cell Cycle?** For each statement, they should write in the "Before the Video" column whether they believe the statement is true or false. Let students know that they will be able to revise their answers, if needed, later in the lesson.

Instructional Rationale

Many students were likely introduced to the cell cycle and mitosis in middle school. Therefore, the beginning of this lesson uses an anticipation guide strategy to elicit prior knowledge from students about these concepts. For students who do not recall much about these concepts, it is a good way to prime their thinking about important facets of the cell cycle prior to engaging in the rest of this lesson. Using anticipation guides also provides you with valuable feedback on students' level of knowledge regarding certain concepts; this allows you to better focus instructional time on the key areas where students show a lack of understanding or have developed misconceptions.

- Next, show the video on the cell cycle and cancer from the Amoeba Sisters (**https://www.youtube.com/watch?v=QVCjdNxJreE**). The video discusses uncontrolled cell growth (i.e., cancer) to help students to begin to appreciate why the cell cycle is so important. You can stop the video at 6:30 minutes since the discussion about apoptosis and the proteins involved in the regulation of cell cycle checkpoints that follows is beyond the scope of this course.

Classroom Ideas

It may be helpful to play the video several times to give students enough opportunities to capture key information needed to revise their answers and write appropriate rationales.

- As students watch the video, have them record once again whether they believe the statements in the table are true or false, this time using the "During the Video" column in the table. They may give the same answer they originally did, or it may be a different answer based on the information provided in the video. Then students should write their explanation of why they now believe it is true or false in the last column of the table.
- After the video, have students work with a partner and compare and discuss their responses on the anticipation guide. At this point, partners do not have to come

UNIT 3

to a consensus on whether the statements are true or false. Also, challenge student pairs to write a brief description of the G1, synthesis, and G2 phases of the cell cycle in the graph provided on their handout.

- Finally, lead a whole-class discussion about these statements and the cell cycle graph. Invite students to share their responses and encourage peer-to-peer dialogue to help the class confirm or revise their answers based on information from the video. Answers and sample responses are provided below for reference.

What Do You Know About the Cell Cycle?

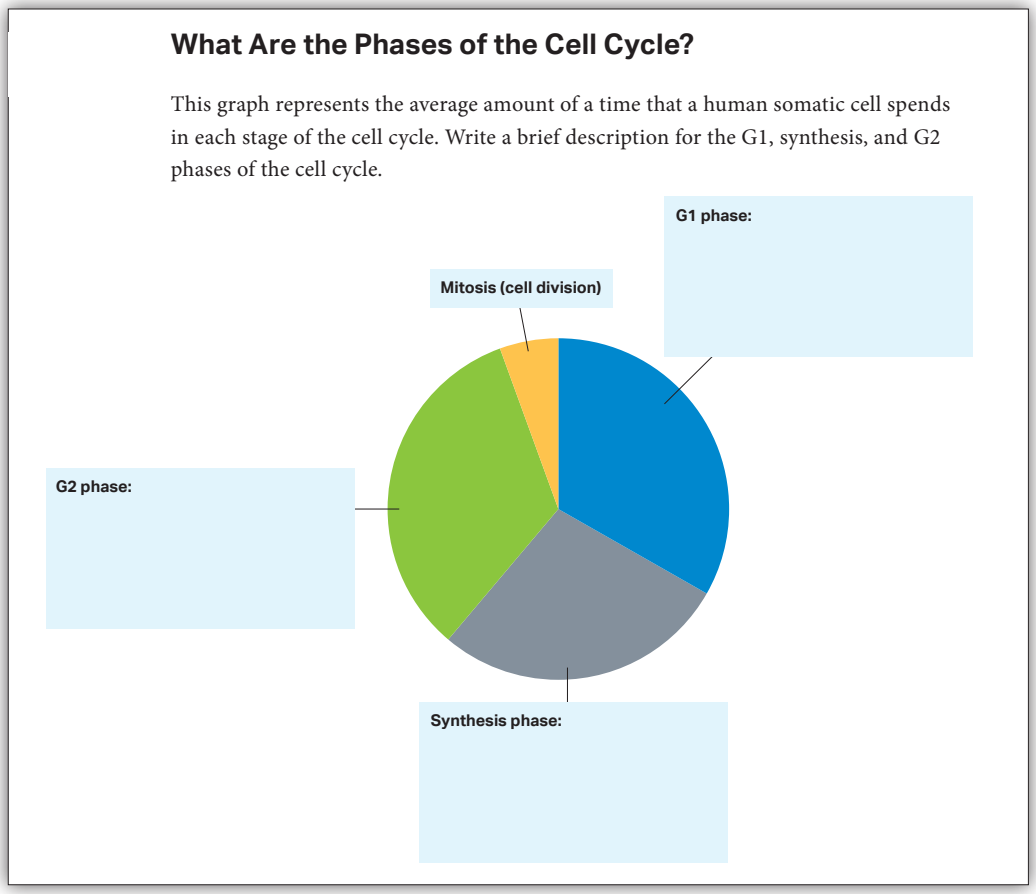
Cell Cycle Anticipation Guide

Before you watch the video, read each statement in the table below and determine whether it is true or false. Then, as you watch the video, reevaluate your responses and decide on a final answer for each statement. In the last column in the table, explain your final answer, listing information from the video that either supports or refutes each statement.

Statement	*Before the Video*: True or False?	*During the Video*: True or False?	Explain your final answer.
1 A cell only divides once during its lifetime.	Answers in this column will vary.	False	Cells divide multiple times throughout their lives.
2 Cells spend most of their time in mitosis (dividing).		False	The cell spends most of its time in interphase (G1, S, G2).
3 All cells divide (go through the cell cycle) at the same rate.		False	Some cells divide more often (e.g., hair cells), whereas others rarely divide (e.g., neurons).
4 Cancer cells are regular cells (such as skin or liver cells) that are dividing uncontrollably.		True	Cancer cells are regular cells that experience a disruption in the cell cycle and continue to divide without regulations and checkpoint controls on their growth.
5 A cell must replicate its DNA prior to cell division, during the G1 phase.		True	A cell needs a complete, identical copy of its DNA so that both cells have the right amount of DNA at the end of division.
6 All cells come from preexisting cells.		True	The cell theory states that all cells come from preexisting cells.
7 Mitosis results in gametes (sperm or egg cells).		False	Mitosis results in only somatic cells (e.g., skin, liver, or lung cells). Gametes are produced by meiosis.
8 Cells divide, but the cells themselves never increase in size or gain mass.		False	A cell doubles in size in G1 and continues to grow in G2 so that it has more cytoplasm and organelles to give to both cells by the end of mitosis.

Handout 3.7.A

UNIT 3



Handout 3.7.A

PART 2: VISUALIZING CELL DIVISION

In this next part of the lesson, students work with a partner to pair descriptions of the phases of mitosis with corresponding illustrations.

- First, have students work in pairs to cut out their mitosis cards (**Handout 3.7.B: Mitosis Cards**). Students should match each diagram with the appropriate phase name and description. Then they should try to place the phases in the correct sequence. *Note:* It is important to highlight for students that animal cells have centrioles and plant cells do not. Because the mitosis cards illustrate plant cells, centrioles will not be present in these diagrams.

Meeting Learners' Needs

Even though students are working with a partner, it might be beneficial to have each student spend a few minutes independently trying to match their own set of cards. This will provide valuable feedback about which students may need some additional instruction and support with these concepts. After the lesson, each student can glue the matched cards together to create study cards.

UNIT 3

- Once student pairs have finished matching and ordering the cards, have them partner with another group to compare results. Student groups should come to a consensus on the answers. If students have access to electronic devices, you may also want to have student groups confirm their conclusions by watching the Amoeba Sisters' video on mitosis (**https://www.youtube.com/watch?v=f-ldPgEfAHI**). Matching solutions are provided here for reference; the phases are listed in order.

Phase (in order of occurrence)	Diagram
Interphase	3
Prophase	4
Metaphase	5
Anaphase	1
Telophase	2
Cytokinesis	6

- Finally, lead a whole-class discussion that allows students to share their ideas about the process of mitosis. Help students summarize important information by asking these questions:
  - Why was interphase included in your cards when it is not a part of mitosis?

    Interphase is when the cell doubles in size and replicates its DNA so that it can become two separate cells. Therefore, interphase is critical to a cell's ability to undergo mitosis (division).

  - Describe why the cell doesn't spend most of its time in mitosis.

    If the cell spent most of its time dividing, it wouldn't be able to carry out its normal role as a part of another system. For example, a kidney cell is one of many cells that form kidney tissue, which makes up the kidney—the organ that is vital in helping us maintain homeostasis by excreting waste and regulating fluid balance.

Guiding Student Thinking

Many students develop the misconception that the cell may divide but it doesn't actually grow in size or mass. Therefore, it is important to emphasize that the cell almost doubles in size during the G1 phase of interphase to prepare for mitosis.

LESSON 3.8

UNIT 3

Modeling Mitosis

OVERVIEW

LESSON DESCRIPTION

Part 1: Modeling Mitosis

Students use pop beads and either lab desks or large pieces of paper to demonstrate their understanding of mitosis by modeling each stage.

Part 2: Peer Review of Mitosis Models

Students complete a handout in which they translate their models into sketches and summaries of each stage of mitosis. They then use that handout as a rubric to assess another group's model.

CONTENT FOCUS

In this lesson, students apply their understanding of the cell cycle and mitosis gained in the prior lesson (3.7: Launch Lesson – Modeling the Cell Cycle). They deepen their understanding of the key concepts of cell growth and division as they develop models of cell division and apply appropriate terminology to each phase of mitosis.

AREA OF FOCUS

- Attention to Modeling

SUGGESTED TIMING

~45–60 minutes

HANDOUTS

- 3.8.A: Modeling Mitosis
- 3.8.B: Sketch and Summarize Mitosis

MATERIALS

- neon dry-erase markers (for use on lab desks) or regular markers and large poster paper
- prepared set of pop beads (for each group)

COURSE FRAMEWORK CONNECTIONS

Enduring Understandings

- Biological systems have specialized structures that enable specific functions necessary to sustain life.
- In order to sustain complex processes, biological systems must have mechanisms for growth and repair.

UNIT 3

Learning Objectives	Essential Knowledge
CELLS 5.1(a) Describe the importance of the growth phases in the cell cycle.	**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.
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 5.2.1** 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.

SETUP AND PREPARATION NOTES

- Place at least 150 beads of two different colors (150 for the maternal chromosomes and 150 for the paternal chromosomes) and 50 yellow beads (for the centromeres) in a bag.

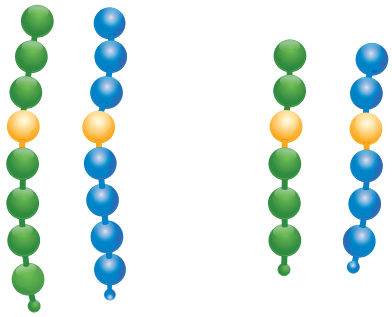
  Note: Bags should contain more beads than the students will need to save time in having to replace missing beads during the lesson.
- You can provide all student groups with the same color scheme (particularly for the two chromosomes) or create multiple color schemes (e.g., green/purple/yellow for some groups and blue/red/yellow for the others).

UNIT 3

PART 1: MODELING MITOSIS

This lesson is designed to deepen students' understanding of mitosis. Directions assume students will be working in pairs, but you may also choose to have students work individually.

- To begin, have student pairs collect their materials (i.e., sets of pop beads and markers), and record their bead colors in the key provided for them on **Handout 3.8.A: Modeling Mitosis**.
- Next, have students build homologous chromosomes for Chromosome 1 and Chromosome 2 using their pop beads. You may need to remind students to pay close attention to the details of the chromosomes since they are different sizes. When finished, students should have a model similar to the figure shown here, depending on what bead colors they were assigned.



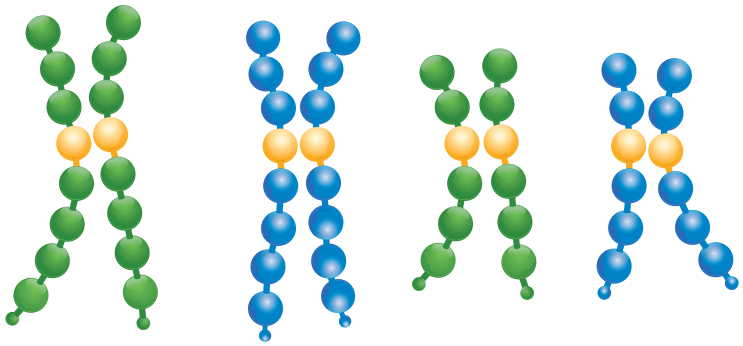
Model of homologous chromosomes for Chromosome 1 and Chromosome 2. In this particular example, paternal DNA is blue, and maternal DNA is green.

Guiding Student Thinking

Students often need explicit clarification on why we refer to homologous pairs of chromosomes as Chromosome 1 and Chromosome 2. It would be helpful to show students a human karyotype to help them visualize that humans have 23 pairs of homologous chromosomes, for 46 chromosomes in total, and that these chromosomes vary in size. For example, Chromosome 1 in humans is the largest chromosome and represents approximately 8% of all the DNA found in each cell. This will also help them visualize that each cell gets two copies of each chromosome. You can use the karyotype to show them that Chromosome 1 and Chromosome 2 in humans both have one chromosome from maternal DNA and one from paternal DNA.

- Once students have built their pairs of homologous chromosomes, have them model replication of the DNA to simulate the synthesis phase of the cell cycle. When finished, students should have a model similar to the one on the next page, depending on what bead colors they were assigned.

UNIT 3



Model of homologous chromosomes with sister chromatids for Chromosome 1 and Chromosome 2. In this particular example, paternal DNA is blue, and maternal DNA is green.

- Engage students in a short discussion about their model chromosomes before moving on to modeling the phases of mitosis. Some key questions to promote their thinking about cell division could include the following:
  - Why did you have to make a second set of chromosomes for Chromosome 1 and Chromosome 2?

    Humans have two copies of each chromosome. They receive one set of chromosomes from their mother and one from their father and are therefore referred to as *2N (diploid)*. Humans have 23 pairs of chromosomes for a total of 46.

  - How does making a simplified model of these chromosomes "hide" some of the chromosomes' characteristics?

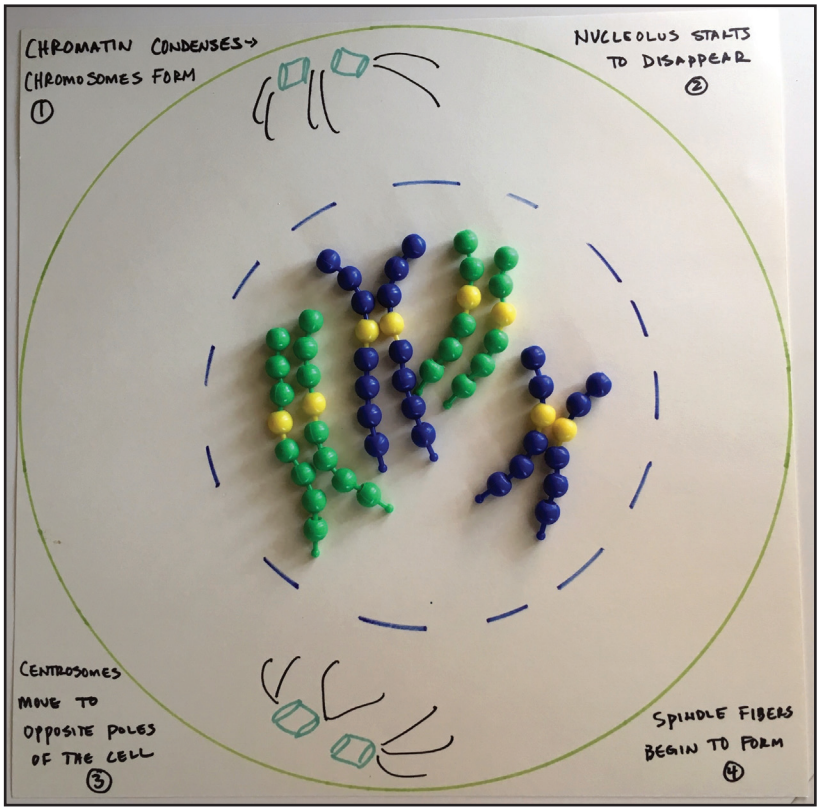
    Homologous chromosomes will likely carry different information from each other, which is not visible in this simplified model. Also, before sister chromatids are joined it appears there are two centromeres in the model, but in reality they share one *centromere* when they are joined.

  - Where in the cell are chromosomes located? At what stage in the cell cycle does the cell replicate its DNA?

    The chromosomes are located inside the nucleus of the cell.
    DNA replication occurs during interphase.

Meeting Learners' Needs
If you feel that some students need additional support during the modeling process, you can generate a list of key words they need to include by the end of their modeling process (e.g., spindle fibers, metaphase plate, centrosomes/centrioles). Post this list so that students can easily refer to it as they work on their models.

- Call students' attention to the question at the top of Handout 3.8.A, which their explanatory model of mitosis should answer: *How does the process of the cell cycle and mitosis ensure that both resulting daughter cells are genetically identical?*
- Now students are ready to begin modeling mitosis, using the following steps:
  - Students should use their markers (either on poster paper or lab tables) to make a large version of the blank diagram from **Handout 3.8.B: Sketch and Summarize Mitosis**; this will serve as a guide for their model.
  - Students should start their models with interphase and the two chromosomes they just "replicated." They will need to assemble more chromosomes as they continue to construct the model.
  - Challenge students to include as many components and key terms as they can for each phase. They should also include short descriptions of what is happening in their models for each phase.
- As students are constructing their models, move from group to group, checking for appropriate models and labeling. A sample model for prophase is shown here.



Example of student model for prophase during mitosis

UNIT 3

PART 2: PEER REVIEW OF MITOSIS MODELS

In Part 2 of this lesson, students work in pairs to translate their physical models into diagrams that include labels, numbers, and explanations for each event in mitosis. Groups then pair up to compare and critique their models and determine what revisions are needed.

- Now that student groups have developed a physical model of mitosis, they can use it as a guide in completing the mitosis diagram on Handout 3.8.B. They can continue to work in groups on this part of the lesson. However, each student should complete their own sketches and summaries of each phase, as this is extremely helpful in reinforcing the key concepts and terminology associated with mitosis.

Instructional Rationale

Often, students are given a model of mitosis and asked to simply fill in the diagrams based on their textbook or notes. This lesson is designed to challenge students to apply the understanding of mitosis they developed during the prior lesson in order to develop accurate models for each phase of cell division. Having students translate their physical models into their own personal explanatory models, through sketches and descriptions of each phase will reinforce these concepts and make their understanding more durable.

- Once students have finished sketching and summarizing mitosis, have them take their handouts as they switch tables with another student group. Each group will use their own sketches and summaries as rubrics for assessing the other group's physical pop-bead model. Students should record any differences they see between their handouts and the other group's physical model. They may see changes they need to make to their own handouts (and models) or elements that may be missing from the model they are assessing.
- After both student groups have finished their assessment of the other group's model, they should engage in a peer-to-peer discussion and come to a consensus on what changes should be made to both models. Students should then make revisions to their models and handouts based on this discussion.

Classroom Ideas

This lesson may extend past one class period. To save time and avoid requiring students to rebuild their models in the next class, they could take pictures of their models on their phones to be used for peer-to-peer assessment. If laptops are available, students can then put all their phases together into a Word or Google document and record their thoughts about their modeling next to each phase.

- Finally, lead a whole-class discussion about the main question: *How does the process of the cell cycle and mitosis ensure that both resulting daughter cells are genetically identical?* Invite students to share the final versions of their models to explain their answers. It may be helpful to display a completed representation of mitosis near the end of the discussion to ensure students have captured all the appropriate terms and concepts on their handouts. Some final questions may be helpful to ensure that students have a solid understanding of the process and importance of mitosis. Questions could include:
  - How does interphase help prepare the cell for division?

    Interphase includes stages that allow the cell to double in size (G1 stage), produce new organelles and proteins (G2 stage), and replicate its DNA (S stage) so that both daughter cells have what they need to function appropriately.

  - Use your model to help describe how and why both daughter cells are genetically identical.

    Each chromosome has a sister chromatid that is created when the DNA is replicated in the synthesis stage of the cell cycle. The sister chromatids align along the metaphase plate, and the cell checks that everything is aligned correctly so that the sister chromatids will split evenly when they pull apart during anaphase, thus providing each daughter cell with identical DNA.

  - Why is mitosis important to living systems?

    Mitosis is vital to living systems as it is a way for organisms to grow and repair. Mitosis makes new cells in order for organisms to develop and replace old or damaged cells.

UNIT 3

LESSON 3.9

Launch Lesson – Exploring Photosynthesis Through Atmospheric Carbon Dioxide Concentrations

OVERVIEW

LESSON DESCRIPTION

Part 1: Examining Global Vegetation

Students begin by exploring ideas about local vegetation and the chemical and energetic needs of plants. Then, they consider variations in global vegetation by exploring the plant life characteristic of different biomes.

Part 2: Analyzing Concentrations of Atmospheric Carbon Dioxide

Students work in pairs to analyze multiple pieces of data and examine how photosynthesis influences global carbon dioxide concentrations in the atmosphere.

CONTENT FOCUS

In this introductory lesson, students do not need to have detailed knowledge of photosynthesis. The lesson helps students make big picture connections between photosynthesis and concepts from Unit 1: Ecological Systems. Students should be familiar with differences in vegetation across global biomes, the carbon cycle, and how humans can influence the carbon cycle. Students should complete this lesson before moving on to Lesson 3.10: Model-Based Guided Inquiry – Introduction to Photosynthesis and Light Energy.

AREA OF FOCUS

- Strategic Use of Mathematics

SUGGESTED TIMING

~45–60 minutes

HANDOUT

- 3.9: Investigating Seasonal Changes in Atmospheric Carbon Dioxide

MATERIALS

- LCD projector, electronic whiteboard, or other technology for showing a website and online video
- internet access to **http://satellites.pro**
- green and brown colored pencils, crayons, or multicolored highlighters

UNIT 3

COURSE FRAMEWORK CONNECTIONS

Enduring Understandings	
▪ Biological systems have specialized structures that enable specific functions necessary to sustain life. ▪ In order to sustain complex processes, biological systems must have mechanisms for growth and repair.	
Learning Objectives	**Essential Knowledge**
CELLS 6.1(a) Explain why the products of photosynthesis are ecologically important. **CELLS 6.1(c)** Use data to describe what factors affect rates of photosynthesis.	**CELLS 6.2.1** 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. **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.

PART 1: EXAMINING GLOBAL VEGETATION

This first part of the lesson is designed to elicit students' prior knowledge about photosynthesis and characteristics of vegetation in specific biomes.

- To begin, lead a whole-class discussion to prompt student thinking about when local vegetation is most abundant. This line of thinking will foreshadow how the presence or abundance of vegetation may influence photosynthesis rates. Use some of these questions to spark student thinking:
  - Try to visualize what the vegetation in our local region looks like throughout the year. When is the vegetation the greenest? When is it the brownest?

    Student answers will vary based on your geographic location.
  - What do you already know about what plants require from their environment to produce energy (photosynthesize), grow, and develop?

    Plants need carbon dioxide, water, and nutrients to grow. They also need sunlight.
  - Why do you think some plants lose their leaves during certain times of the year?

    Plants shed their leaves during harsh conditions to conserve water, nutrients, and energy.
  - Do all plants lose their leaves? Provide examples to justify your answer.

    No; unlike deciduous trees, which lose their leaves in the fall, evergreens do not lose their needles.
- Now display the Google satellite image of the world found at **http://satellites.pro** for the whole class to see. Have students use the image and work with a partner to complete Part 1 on **Handout 3.9: Investigating Seasonal Changes in Atmospheric Carbon Dioxide**.
- Finally, invite students to share their findings in a whole-class discussion. Included on the next page is a portion of the student handout with sample student responses.

Meeting Learners' Needs

If students need more guidance, try asking some of these questions:

- What is the current color of vegetation in your neighborhood?
- What color was vegetation last month? What color do you think it will be next month?
- What color is vegetation in each of the four seasons?

Classroom Ideas

To extend this class discussion, you can bring in various types of leaves or plants for students to examine (e.g., leaves from any deciduous tree, needles from evergreens, or succulents such as aloe plants or cacti). This can lead to a valuable discussion about plant adaptation as students will notice the difference in leaf structure. You can then ask students to think about natural selection and environmental pressures that may have led to the differences we see in plant leaves.

UNIT 3

Guiding Student Thinking

This discussion can go in many directions; however, it is important that the seasonal color variations in a temperate biome be discussed here, if they have not yet been discussed. Again, winter is typically brown, spring begins brown and gets greener as the season goes on, summer is mostly green, and fall begins green and becomes browner as the season goes on. The last discussion question on the Southern Hemisphere may lead to deeper and more complex student questions later in this lesson. This may lead to a payoff at the end of the lesson; have students think back to the global map and predict why the annual drop in average atmospheric carbon dioxide levels coincides with summer in the Northern Hemisphere. Potential conclusions could involve the relative landmasses of the hemispheres (about 68 percent of Earth's land is north of the equator, providing more space for vegetation) and the distribution of biomes/vegetation between the two hemispheres (particularly the vast forests of Siberia and North America).

Investigating Seasonal Changes in Atmospheric Carbon Dioxide

PART 1: EXAMINING GLOBAL VEGETATION

Closely observe the colors in different regions on the global satellite image of Earth. Work with a partner to answer the following questions based on information from the map and your knowledge about global biomes and their vegetation.

1. What major areas of the world are green? Do you think they stay green year-round? Why or why not? (Use your knowledge of biomes to justify your answers.)

   Student answers will vary depending on the time of the year when the lesson is completed. However, students should see that much of the Northern Hemisphere is green due to the large coverage of forests—temperate deciduous forests and boreal forests. In North America and Europe, where there are large tracts of temperate deciduous forest, they are only green for parts of the year but become brown in autumn as the trees drop their leaves. Boreal forests, which are generally found at northern latitudes, stay green year-round, as conifers keep their needles.

2. What major areas of the world are brown? Do you think they stay brown year-round? Why or why not? (Use your knowledge of biomes to justify your answers.)

   Student answers will vary depending on the time of the year when the lesson is completed. However, they should be able to see areas of the world that stay "brown" year-round (such as desert regions) and predict the areas that will remain green.

3. What time of the year do deciduous trees lose their leaves in the Northern Hemisphere? Do you think this is the same in the Southern Hemisphere? Explain your answers.

   Deciduous trees typically drop their leaves during the fall. They have no leaves through the winter and grow new leaves during the spring. In the summer, they have all their leaves. This is also true of deciduous trees in the Southern Hemisphere, though the seasons there occur at different times than in the Northern Hemisphere.

Handout 3.9

Meeting Learners' Needs

While most students were introduced to the concept of Earth's axial tilt driving our seasonal differences in middle school earth science, it is a complex topic that may need to be quickly reinforced for some students. It is often useful to show a visual of how the tilt of Earth's axis, combined with our orbit around the sun, creates warmer months during spring and summer (May through August) in the Northern Hemisphere, which is tilted toward the sun during this portion of the year. For a helpful interactive visual, see the following PBS Learning Media resource: **gpb.pbslearningmedia.org/resource/npls13.sci.ess.seasons/why-seasons/#.WutgNqQvzX4**.

UNIT 3

PART 2: ANALYZING CONCENTRATIONS OF ATMOSPHERIC CARBON DIOXIDE

In this part of the lesson, students work with a partner to examine data on atmospheric carbon dioxide at several levels (i.e., months, years, and decades) and draw conclusions about how variations in photosynthesis rates influence atmospheric carbon dioxide levels around the globe.

- To begin, have student pairs complete the first section of Part 2 on the handout. In this part of the lesson, students reflect on their own experiences and observations to estimate the actual months when they think vegetation would be the most robust (greenest) or the least (brownest). A portion of the handout with sample student responses is included below and on the next page.

Instructional Rationale

Student answers will vary up to this point in the lesson, which is fine. This part of the lesson is just meant to help students think more specifically about when plants do and do not have leaves so they can leverage these ideas later as they think about the connections between leaves, photosynthesis rates, and atmospheric carbon dioxide concentrations.

PART 2: ANALYZING CONCENTRATIONS OF ATMOSPHERIC CARBON DIOXIDE

Examine the following claim about plants and atmospheric carbon dioxide and predict whether this claim is true or false:

> Plants' use of carbon dioxide in photosynthesis influences the atmospheric concentration of carbon dioxide.

Next, gather evidence to support or refute this claim by completing the questions below.

RECORDING INITIAL OBSERVATIONS

Reflect on your experiences and observations about the local vegetation in your area to record information for the following questions:

4. List the three months during which you recall the landscape being greenest.

   Student answers will vary but should be around the summer months.

Handout 3.9

5. List the three months during which you recall the landscape being brownest.

   Student answers will vary but should be around the winter months.

6. List three months during which you recall the trees having many leaves.

   Student answers will vary but should be spring to summer months.

7. List three months during which you recall the trees losing their leaves.

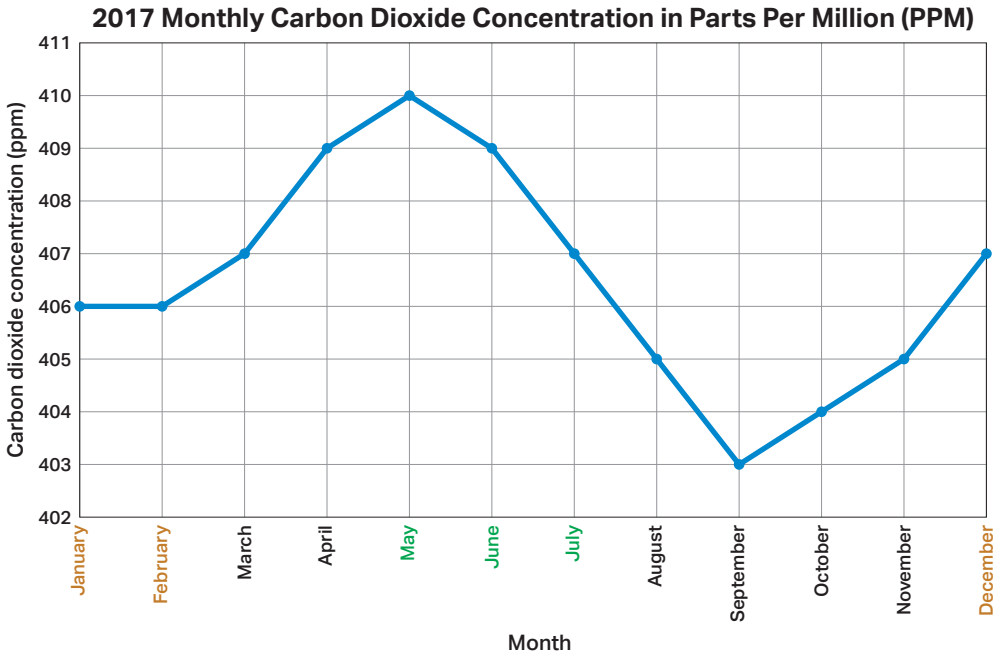
   Student answers will vary but should be fall months.

8. Describe one advantage of trees that lose their leaves compared to trees that don't lose their leaves.

   There are a few possible answers, including protection from damage to branches due to the weight of snow and ice collected on leaves and protection from damage to branches due to high winds. Answers referring to the inefficiency of photosynthesis during the winter are beyond the scope of this lesson; however, they give good insight into those students' prior knowledge.

Handout 3.9

- Next, students are asked to examine a table of monthly values for carbon dioxide concentration measured at Mauna Loa Observatory in Hawaii in 2017. Students are asked to find the months with the highest (May) and lowest (September) concentrations of CO_2.
- To analyze changes of CO_2 over the course of 2017, students are asked to graph the data from the table using the grid provided on their handout. When they are done, they should highlight in green the names of the three months they predicted to be the greenest and do the same in brown for those they predicted to be the brownest. A sample student graph is shown on the next page.



Students will also answer a series of questions about their graph. Sample responses are shown on the next page.

Instructional Rationale

Question 11 on Handout 3.9 asks students to think about any trends they see in the data from the table before graphing that data. Because differences between CO_2 concentrations are so small at this scale, students will likely have difficulty spotting trends. After students have graphed the data, they should begin to see that there are some valuable trends to isolate in the graph (e.g., an almost linear decline in concentrations from the peak in May down to the lowest point in September, before it begins to rise again). It is important to remind students that graphs are analytical reasoning tools that help us use mathematics (such as examining relationships with linear functions) to better reveal the relationships that may exist between two variables.

13. Do you think the graph will follow the same pattern (have the same shape) every year?

    Although it may vary slightly, the basic pattern of the data should be the same from year to year.

14. Explain the shape of the graph by describing what you think was happening with plants when carbon dioxide concentrations reached their high and low points.

    Plants are emerging and peaking in greenness as the carbon dioxide concentration reaches its high point. This could be explained by reasoning that carbon dioxide levels are highest as plants are greening and will fall as those now-green plants begin to use carbon dioxide.

    Plants are beginning to lose their leaves as the carbon dioxide concentration reaches its low point. This could be explained by reasoning that carbon dioxide levels are lowest as plants begin to brown, and the levels will rise as plants slow the rate at which they use carbon dioxide.

15. Propose an explanation for the shape of the graph.

    Carbon dioxide levels are not constant. The concentrations vary during the year, reaching their peak in the early summer and their lows in the late summer and early fall.

16. The data were obtained at Mauna Loa Observatory in Hawaii, which is at an altitude of 3,400 meters. Why do you think scientists use data from this location as a primary representation of global atmospheric carbon dioxide concentration?

    Mauna Loa is a remote location far from major population and industrial centers. The surrounding area is also devoid of plant life. These factors, in addition to its altitude, mean it is not as susceptible to local variations in carbon dioxide levels as is the case with locations closer to cities or at lower altitudes.

Handout 3.9

UNIT 3

- After all students have completed their graphs and corresponding questions, lead a whole-class debrief on what trends they see in the data so far. Student pairs can share their answers to the questions. Some additional questions to help spark student discussion could include the following:
  - How did your predictions of when trees would be the greenest correspond to when carbon dioxide concentrations were lowest?
  - How did your predictions of when trees would be the least green correspond to when carbon dioxide concentrations were highest?

Guiding Student Thinking

A key takeaway for this lesson is for students to see that concentrations of atmospheric carbon dioxide fluctuate in relation to photosynthesis rates, which in the Northern Hemisphere are highest in the spring to summer months. Be sure students understand that when photosynthesis rates are high, concentrations of carbon dioxide decrease because plants are using it to make chemical energy. Connect the prior conversations about global distribution of forests to this discussion to help students see that because most forest biomes are in the Northern Hemisphere, the fluctuation of average global atmospheric carbon dioxide corresponds to the seasons in the Northern Hemisphere. (*Note:* Mauna Loa measurements are not global carbon dioxide measurements, but they do mirror the global trends: **https://www.esrl.noaa.gov/gmd/ccgg/trends/global.html#global**.)

- Now students will examine concentrations of carbon dioxide over the course of four complete years (2014–2017). Using the "Recent Monthly Mean CO_2 at Mauna Loa" graph, students are asked to draw a box around the data that represents what they just graphed—the 2017 data. They should also work to identify any trends they see, such as the yearly cyclic pattern already revealed in their graph of the 2017 data and the year-over-year increase in carbon dioxide levels.
- One final graph, "Atmospheric CO_2 at Mauna Loa Observatory," asks student pairs to examine concentrations of carbon dioxide over several decades (1958–2017). They are asked to draw a box around the parts of the graph representing the data they graphed (from 2017) and a circle around the part representing the last graph they analyzed (2014–2017).
- Lead a whole-class discussion on the trends they notice in this last graph. Some questions for discussion may include the following:
  - What overall trends do you see in the data?

    Trends include the cyclic, annual variation in carbon dioxide concentrations, and the year-over-year increase in carbon dioxide levels.

- What is the percent change in carbon dioxide concentration from 1960 to 2015 (using estimates of whole numbers)?

  $$\frac{400 \text{ ppm} - 320 \text{ ppm}}{320 \text{ ppm}} = 0.25 = 25\%$$

  Note: Student answers may vary slightly but should be close to this value.

- Think back to our ecology unit. What may be causing the consistent increase in atmospheric carbon dioxide levels?

  Use of carbon-based fossil fuels, such as coal, oil, and natural gas, to produce energy (generating electricity, driving cars, etc.).

- Now direct students' attention back to the claim they were introduced to at the beginning of Part 2 of their handout: "Plants' use of carbon dioxide in photosynthesis influences the atmospheric concentration of carbon dioxide."
- Have students work in pairs or individually to craft evidence and reasoning to either support or refute this claim. Remind them that they must use data and scientific principles learned throughout this lesson.

  Students' evidence and reasoning will vary, but one correct *support* claim could be as follows:

Evidence	Reasoning
In 2017, concentrations of CO_2 decreased in the spring and summer months (to 403 ppm at the lowest) and increased in the fall and winter months, reaching 410 ppm. This fluctuation of carbon dioxide concentration across the seasons can be seen in data covering four years, as well as in data collected over several decades.	Atmospheric CO_2 concentrations fluctuate due to plant photosynthesis. When plants lose their leaves (the site of photosynthesis) in the fall, atmospheric carbon dioxide levels begin to rise because fewer plants are photosynthesizing. When plants grow new leaves in the spring and early summer, carbon dioxide rates go down as plants utilize it as part of photosynthesis.

- Finally, have students work in groups of three or four to share the evidence and reasoning they used to support or refute the claim. Allow students to use this peer-to-peer dialogue to help them revise their stance, evidence, and reasoning.
- If time allows, invite students to share their reasoning in a whole-class discussion.

UNIT 3

LESSON 3.10

Model-Based Guided Inquiry – Introduction to Photosynthesis and Light Energy

OVERVIEW

LESSON DESCRIPTION

Part 1: Leaf Structures

In this part of the lesson, students explore two models of leaf structures and their role in photosynthesis.

Part 2: Visible Light and Pigments

Students examine three different models that introduce the role of visible light and plant pigments in photosynthesis.

CONTENT FOCUS

This model-based inquiry lesson asks students to examine various 2D models and apply previous knowledge and critical thinking skills to learn about the basics of photosynthesis. The lesson investigates how the structure of the leaf fits its primary function of photosynthesis, as well as what wavelengths of light are used in photosynthesis. Specific processes of light-dependent and light-independent reactions are not addressed.

AREAS OF FOCUS

- Attention to Modeling
- Emphasis on Analytical Reading and Writing

SUGGESTED TIMING

~60 minutes

HANDOUTS

- 3.10.A: Photosynthesis Overview
- 3.10.B: Leaf Structure
- 3.10.C: Investigating Plant Pigments

UNIT 3

COURSE FRAMEWORK CONNECTIONS

Enduring Understandings	
▪ Biological systems have specialized structures that enable specific functions necessary to sustain life. ▪ In order to sustain complex processes, biological systems must have mechanisms for growth and repair.	
Learning Objectives	**Essential Knowledge**
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 6.1.1** 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.

UNIT 3

INSTRUCTIONAL INTRODUCTION TO FACILITATING MODELING-BASED GUIDED INQUIRY

- This modeling-based inquiry lesson is intended to be collaborative and student-driven and is best accomplished when students work in small groups of three or four. However, **this lesson is not intended as a worksheet to be completed individually or as homework**. The role of the teacher as facilitator throughout each section of this guided, modeling-based inquiry is critical in helping students develop appropriate conceptual understanding of photosynthesis.
- Throughout the investigation, students work together while examining the models provided to learn about different aspects of photosynthesis. The questions in this lesson are designed to challenge students to engage in self-led sense-making about the initial processes of photosynthesis.
- Your first role as the teacher in this type of lesson is to listen to student conversations and step in to help guide their learning when you find that groups need some guidance. When possible, avoid giving answers; instead, try to ask questions that help students arrive at their own understandings.
- Second, check in with each group as they complete the questions at the end of each model. Check the work of one student in the group (vary which student you check with at each stopping point). Ask questions such as "How did you arrive at this answer?" or "What did you mean when you said that?" to gauge students' understanding. When possible, engage with each group member during group check-ins in order to avoid one confident student acting as the group spokesperson.

Classroom Ideas

You can number each seat at the table and use a random number generator on your phone as you approach a group to determine which student's work will be checked. A set of cards they randomly draw can also be used.

Instructional Rationale

A guided, modeling-based inquiry lesson such as this one forces students to use their critical thinking skills while analyzing models and figuring out complex ideas for themselves. By using this approach instead of a traditional lecture or reading assignment, you encourage students to wrestle with ideas instead of memorizing conceptual content. Thus, your role shifts from providing information to helping students deepen their ideas through questioning. Teaching this way also allows you to learn more about individual students' thinking and find ways to improve individual understanding.

- This type of lesson also depends on a lot of collaboration and peer-to-peer dialogue. Instruct groups to examine and discuss each question, to come to a consensus through peer instruction, and to each record the consensus answers on their own handout. If a group is unable to reach a consensus, students may write their own ideas on the handout, but they should mark those items for review during teacher–student group discussions.
- Again, it is very important that this lesson not be provided as a worksheet task for homework or individual completion: it is intended to enable students to learn **through collaboration with their peers and through conversation with you**. At the end of the lesson, each student needs to be confident that their answers are correct and that their misconceptions have been clarified. Likewise, you will have a sense of what topics individuals in the class understand and what topics they may still be struggling with.
- Do not let groups leave the "What are your questions?" prompts blank. In general, asking good questions is difficult for novice science learners, so this skill needs to be pushed. If these prompts are optional, most students will opt out. This is the one exception to having each group determine a consensus for each response—students should be encouraged to write their own questions. Student questions in this part of the lesson are an excellent way to address the differing needs of learners. Some need simple clarifications; others may ask questions that allow them to deepen their learning.

Meeting Learners' Needs
While consulting with student groups, if it becomes apparent that multiple groups are facing a common struggle, bring the class together for a brief clarifying discussion. This can save time, which makes it easier for you to have conversations with individual groups.

UNIT 3

PART 1: LEAF STRUCTURES

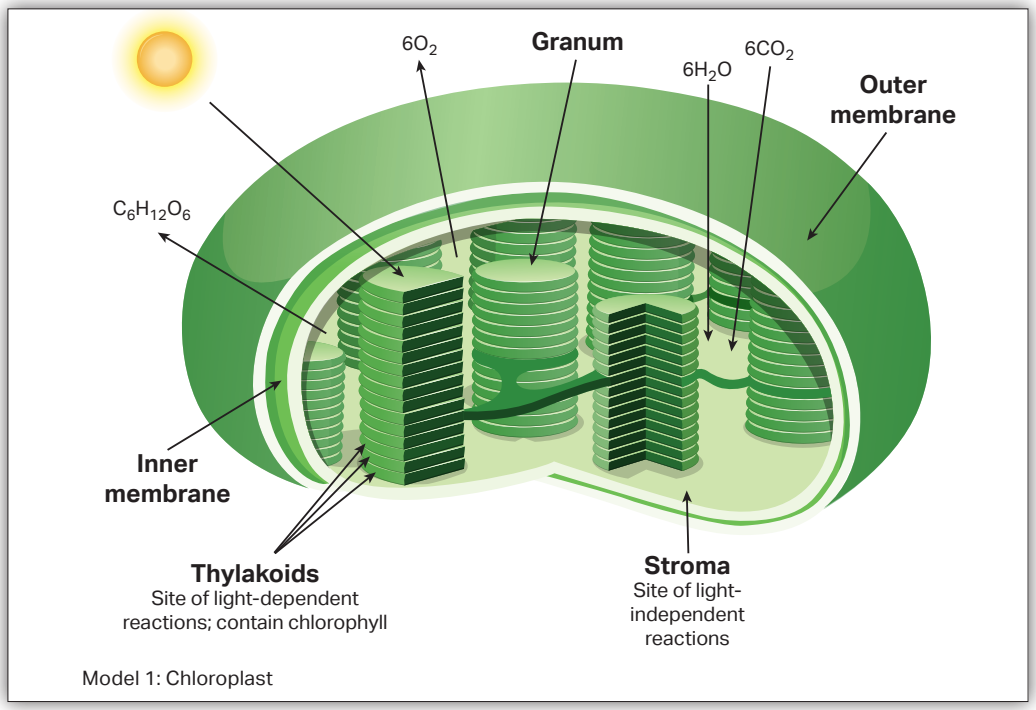
In this part of the lesson, students explore two models involving leaf structures and their role in photosynthesis.

- To begin, establish collaborative teams of three or four students. Then, have students begin working on **Handout 3.10.A: Photosynthesis Overview**. Circulate through the room to listen to student conversations and monitor progress as they work. Avoid jumping in too quickly; students should wrestle with the ideas as a group before you provide them with guidance. When a group indicates that they are ready for your consultation, check answers based on the sample student responses below.

Classroom Ideas

Two nested, colored plastic cups stacked upside down can be used to signal group progress. For example, students can place a green (for "go") cup on the outside so you can see easily that their group does not need assistance. A red cup can be placed on the outside to indicate that they have reached a stopping point or need teacher consultation. This way, groups do not need to keep their hands raised while waiting.

GUIDING STUDENT THINKING AND SOLUTIONS FOR MODEL 1 – EXAMINING THE CHLOROPLAST AND PHOTOSYNTHESIS



Model 1: Chloroplast

Handout 3.10.A

UNIT 3

1. The reactants for the chemical reaction known as photosynthesis enter the chloroplast. What are these reactants?

   CO_2 and H_2O (carbon dioxide and water). Student answers may include that there are six of each. Students should *not* include sunlight here. Sunlight may be an important part of photosynthesis, but it is not a reactant in the equation.

2. After photosynthesis is complete, its products can leave the chloroplast. What are these products?

   O_2 and $C_6H_{12}O_6$ (oxygen and glucose).

3. Write the balanced chemical equation for photosynthesis.

   $6CO_2 + 6H_2O \rightarrow 6O_2 + C_6H_{12}O_6$

4. What is the energy source that allows photosynthesis to occur?

   Sunlight. While many textbooks and references put sunlight in the equation as a reactant, this is technically incorrect and may increase the likelihood that students will develop the common misconception that sunlight adds mass to the plant.

5. What questions do you have?

   Student questions will vary.

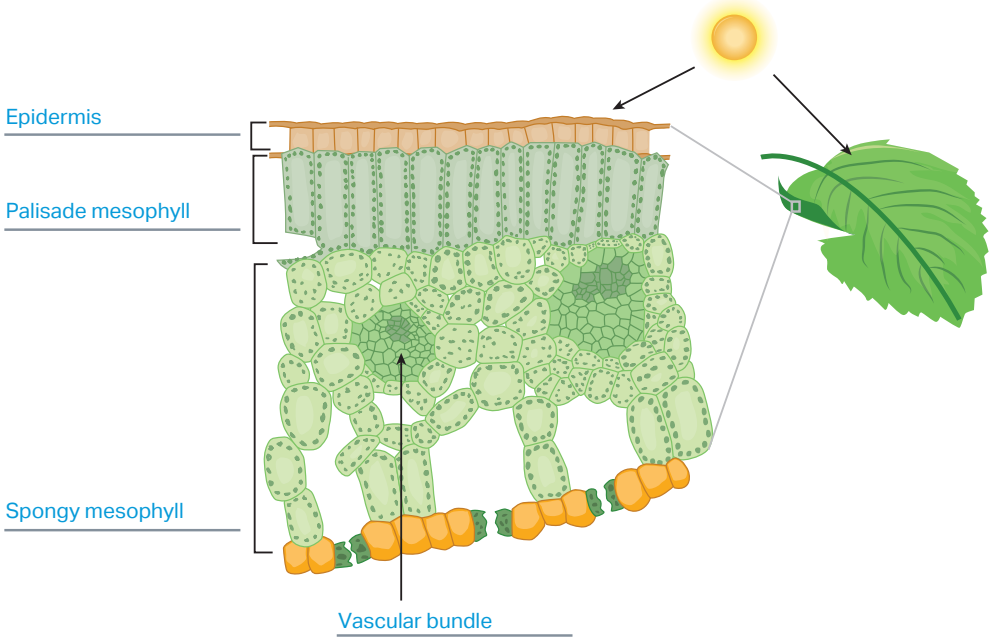
Handout 3.10.A

Guiding Student Thinking

This first model is not very complex, and students may feel confident that they have no questions. However, encourage them to consider asking open questions that could further their investigation such as "How does photosynthesis happen?" or "Why is it important?" Do not let students opt out of asking questions that can deepen their inquiry skills.

- Prior to providing students with the next model, lead a brief whole-class discussion in which they can share some of the questions they have written.
- Once you feel students are ready to move on, provide them with **Handout 3.10.B: Leaf Structure** so they can begin the next investigation.

GUIDING STUDENT THINKING AND SOLUTIONS FOR MODEL 2 – EXAMINING A CROSS SECTION OF A LEAF



Model 2: Cross section of a leaf

1. Label the following parts of the leaf on Model 2:
   - Spongy mesophyll
   - Palisade mesophyll
   - Epidermis
   - Vascular bundle

Handout 3.10.B

UNIT 3

2. Most photosynthesis occurs in the cells of the palisade mesophyll and the spongy mesophyll. For photosynthesis to occur, these cells must receive the reactants needed for photosynthesis and be able to allow the products to exit.

   (a) Draw an arrow indicating the pathway you think CO_2 follows to enter the leaf.

   Students should draw an arrow with CO_2 entering through a stoma.

   (b) Through the process of transpiration, water is brought into a plant through its roots and carried to the leaves, from which it evaporates. What structure brings water into the leaf from the roots?

   Vascular bundle (specifically, xylem)

   (c) Draw and label an arrow showing the path you think water takes when it evaporates out of the leaf.

   Students should draw an arrow with H_2O exiting through a stoma.

   (d) Draw and label an arrow indicating the pathway O_2 would follow out of the leaf.

   Students should draw an arrow with O_2 exiting through a stoma.

Handout 3.10.B

Guiding Student Thinking

Students may initially have difficulty thinking of appropriate answers for some parts of question 2 on Handout 3.10.B. Student thinking such as "How am I supposed to know this?" are not uncommon. When students need to be coached, simple guiding questions such as "Do you see any holes or passageways that molecules can fit through?" can help to get them back on track.

3. If the guard cells closed the stomata, what molecules would be unable to enter the leaf? What molecules would be unable to leave the leaf?

   CO_2 would not be able to enter. H_2O and O_2 would not be able to leave.

4. What would happen to the rate of photosynthesis if the stomata were closed?

   Photosynthesis would slow, because there would not be CO_2 available for it.

Handout 3.10.B

UNIT 3

5. Under what conditions would a plant close the stomata?

   Plants close their stomata (using guard cells) to prevent excessive water loss. Thus, they would do so when it is too hot or too dry.

6. What does the statement "Structure fits function" mean? Provide an example to illustrate your answer.

   This means that the form and shape of something suits the job it performs. Student examples will vary. One example could be the fact that some leaves are very flat. This flat shape allows the leaves to capture a lot of sunlight.

Handout 3.10.B

Guiding Student Thinking

You may need to remind students that they cannot answer question 6 by reusing the same words as the question. If they are struggling, remind them that this idea was introduced in Unit 2: Evolution and was recently revisited in the prior lesson on modeling the cell. They should be specific about the concept by providing an illustrative example.

7. What is the main function of leaves?

   Leaves are the main location for photosynthesis in plants.

8. Describe how the structure of a leaf fits its function.

   The leaf is well suited for photosynthesis. First of all, it has pathways for all the ingredients of photosynthesis to reach each of the cells in the leaf. CO_2 can enter through stomata and move through air spaces in the spongy mesophyll to reach every photosynthetic cell. H_2O enters the leaf through the vascular bundle, and light enters through the top of the leaf. Oxygen can exit the leaf through the stomata. Sugars that are produced can leave the leaf through the phloem in the vascular bundle.

9. Describe how the shape of a leaf (broad and flat) fits its function.

   The leaf has a large surface area; this feature allows it to capture a lot of sunlight.

Handout 3.10.B

10. Do you think all plant cells have chloroplasts? Explain your reasoning.

    Only plant cells that are photosynthetic have chloroplasts. The cells deep in the trunk of a tree or in roots, for example, do not receive sunlight and do not have chloroplasts. Students may need hints to answer this question. It is not intended to be a question that requires prior knowledge but instead one that they should think through.

11. What questions do you have?

    Student questions will vary.

Handout 3.10.B

Guiding Student Thinking

For question 10, a common response might be that some of the cells on the leaf diagram show no chloroplasts. This is good use of the model to answer a question. However, when you check with groups at the stop sign, this is a great question to explore further. Ask questions such as "Why do cells have chloroplasts?" and then "Can all cells receive the necessary inputs for photosynthesis?" Specifically, students should be able to arrive at the idea that only cells with sun exposure should have chloroplasts. Cells deep within the stem of a plant or underground do not.

PART 2: VISIBLE LIGHT AND PIGMENTS

Students examine three different models that introduce the role of visible light and plant pigments in photosynthesis, using **Handout 3.10.C: Investigating Plant Pigments** for this part of the investigation.

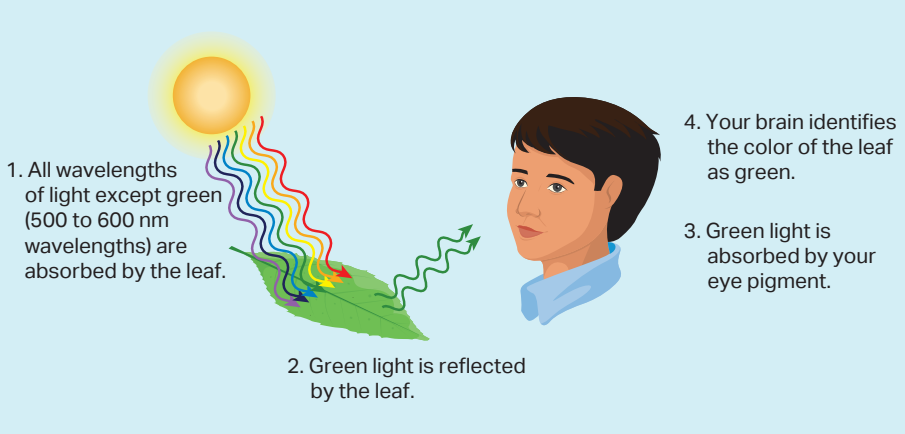
It is not expected that most students will be able to complete this lesson in one class period. However, it is best to not assign any unfinished parts as homework since the in-class peer discussion and teacher guidance is key to the success of this lesson. It is best for students to finish it during another class period as teacher guidance during this lesson is essential to preventing the development or consolidation of student misconceptions.

Guiding Student Thinking

As students study this set of models, they must pay attention to whether each one represents light *absorbed* or light *reflected*. Light that is absorbed can be used as energy by plant cells; light that is reflected cannot be used by the plant but can be perceived by human eyes. By flipping between questions that consider both situations, this part of the lesson forces students to think more critically about what they are learning.

UNIT 3

GUIDING STUDENT THINKING AND SOLUTIONS FOR MODEL 3 – INTRODUCTION TO PLANT PIGMENTS AND VISIBLE LIGHT



Model 3: Introduction to plant pigments and visible light

1. What colors are in visible light?

   Red, orange, yellow, green, blue, violet

2. Consider Model 3 and your experiences with plants. What color of light do you think plants are **least likely** to absorb? What is your evidence for this prediction?

   Green. Leaves appear green to our eyes, which means they are not absorbing the green light and are instead reflecting it.

3. Not all leaves are green. Some plants have leaves that appear purple. What do you know about the pigments in plants whose leaves appear purple?

   Purple-leaved plants must have different pigments in their leaves than green-leaved plants. These pigments must absorb all wavelengths of light except purple (violet).

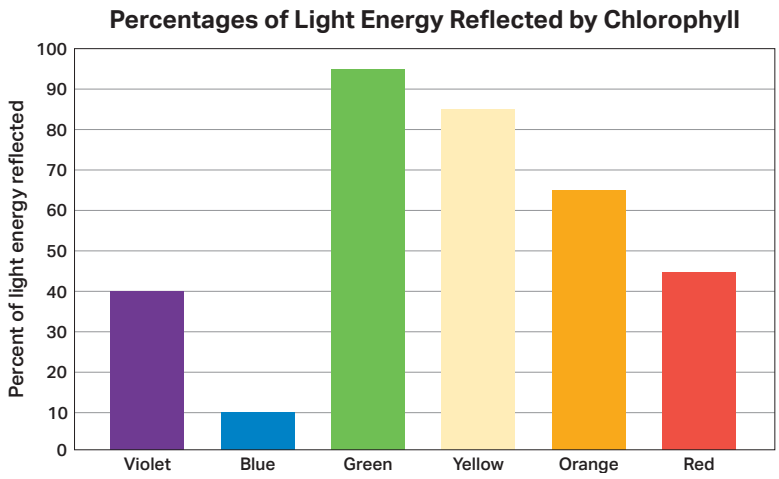
4. What questions do you have?

   Student questions will vary. Many students might ask about why leaves change color in the fall. The answer is that leaves have many different kinds of pigment in them, but chlorophyll is most abundant, giving leaves their green color. Chlorophyll is unstable and has to be made by the plant continuously—which it does throughout the summer—for the leaves to stay green. As fall approaches, the plant stops making chlorophyll, which breaks down and disappears. Thus, the other pigments, which were there all the time but were masked by the abundance of chlorophyll, become more visible.

Handout 3.10.C

UNIT 3

GUIDING STUDENT THINKING AND SOLUTIONS FOR MODEL 4 – PERCENTAGE OF LIGHT ENERGY REFLECTED BY CHLOROPHYLL



Model 4: Graph showing the percentages of light energy reflected by chlorophyll

5. Which color in this spectrum would be most visible to you?

   Green

6. What is the approximate percentage of energy reflected for that color of light?

   About 95 percent

7. What percentage of energy from that color of light is absorbed?

   About 5 percent

8. If every color with more than 50 percent of light energy reflected is visible to the human eye, is red light part of the mixture of visible colors in light reflected by chlorophyll? Explain.

   No. Less than 50 percent of the red light is reflected.

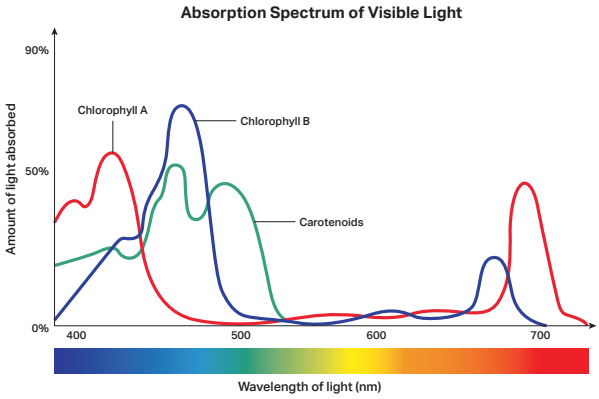
Handout 3.10.C

Guiding Student Thinking

Students may ask about indigo, which is represented on the previous model but not on this graph. Let them know that indigo is not typically included in graphs of absorption and reflection for chlorophyll because its location (wavelength range) is disputed and the human eye cannot detect the subtle differences between blue and violet to be a pure indigo color.

UNIT 3

GUIDING STUDENT THINKING AND SOLUTIONS FOR MODEL 5 – VISIBLE LIGHT AND PLANT PIGMENT LIGHT ABSORPTION



Model 5: Graph showing the absorption spectrum of visible light

9. (a) Which color are you least likely to be able to see reflected from chlorophyll A?
   Blue
   (b) At what approximate wavelength does chlorophyll A absorb the most light?
   430 nm
   (c) How much of this color is being absorbed?
   About 60–70 percent
   (d) What color of visible light has the least percentage of absorption by chlorophyll A?
   Green
10. What is the maximum percentage of orange light that chlorophyll B absorbs?
    About 20 percent
11. List the colors in the absorption spectrum of both chlorophylls in order of their visibility. The most visible color should be first.
    Students must focus on the two chlorophyll curves (and ignore the carotenoid curve) to get this question correct. The correct order is: green, yellow, orange, red, violet, blue.
12. Consider the line labeled "carotenoids." This represents the absorption spectrum of another type of pigment.
    (a) What color of light is absorbed by carotenoids but not by chlorophylls?
    Green
    (b) What is the advantage to having carotenoids in addition to chlorophylls?
    Having carotenoids allows the plant to absorb more green light than it can with chlorophyll.
13. What questions do you have?
    Student questions will vary.

Handout 3.10.C

Classroom Ideas

If students finish this investigation before the end of the class, a nice follow-up would be to have them create a concept map of the ideas they have just learned. This will help to solidify their learning by representing it in an organized way using their own words and ideas. A follow-up laboratory investigation would be a plant pigment paper chromatography lab, such as the one found at the Biology Corner (**www.biologycorner.com/worksheets/plant_pigments.html**).

LESSON 3.11

UNIT 3

Model-Based Guided Inquiry Activity – Comparing Cellular Respiration and Photosynthesis

OVERVIEW

LESSON DESCRIPTION

Part 1: Exploring Three Models of Respiration
This is the core focus of the lesson as it allows students to investigate three separate models that help develop their understanding of cellular respiration.

Part 2: Applying Understanding
Students use their prior knowledge of photosynthesis to make connections and apply their understanding of cellular respiration as they engage with one final model.

CONTENT FOCUS

This lesson does not attempt to address the specific steps of cellular respiration but instead focuses on the ideas of energy conversion, ATP, and the interdependence of cellular respiration and photosynthesis. Students explore the concept that energy conversions power life processes. Students then examine the reactants and products of cellular respiration, and the relationship between cellular respiration and photosynthesis. Students should already be familiar with photosynthesis before attempting this activity.

AREA OF FOCUS

- Attention to Modeling

SUGGESTED TIMING

~45–60 minutes

HANDOUTS

- 3.11.A: Model 1 – Power Conversion from Coal to Electricity
- 3.11.B: Model 2 – The ATP Cycle
- 3.11.C: Model 3 – Cellular Respiration in the Mitochondrion
- 3.11.D: Model 4 – The Relationship Between Photosynthesis and Cellular Respiration in Eukaryotic Cells

UNIT 3

COURSE FRAMEWORK CONNECTIONS

Enduring Understandings	
▪ Biological systems have specialized structures that enable specific functions necessary to sustain life. ▪ In order to sustain complex processes, biological systems must have mechanisms for growth and repair.	
Learning Objectives	**Essential Knowledge**
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.

INSTRUCTIONAL INTRODUCTION TO FACILITATING A MODELING-BASED INQUIRY ACTIVITY

- This modeling-based inquiry lesson is intended to be collaborative and student-driven and is best accomplished when students work in small groups of three or four.
- Throughout the lesson, students work together while examining the models provided to learn about different aspects of cellular respiration. The questions in this lesson are designed to challenge students to engage in self-led sense-making about the beginning processes for cellular respiration.
- Your first role as the teacher in this type of lesson is to listen to student conversations and step in to help guide their learning when you find that groups need some guidance. When possible, avoid giving answers, but instead try to ask questions to help students arrive at their own understandings.
- Second, check in with each group as they arrive at the end of each model. Check the work of one student in the group (vary which student you check with at each stopping point). You can check student understanding by asking questions such as "How did you arrive at this answer?" or "What did you mean when you said that?" When possible, engage with each group member during group check-ins in order to avoid one confident student acting as the group spokesperson.

Classroom Ideas

You can number each seat at the table and use a random number generator on your phone as you approach a group to determine which student's work will be checked. A set of cards they randomly draw can also be used.

Instructional Rationale

Using a guided inquiry lesson such as this one forces students to use their critical thinking skills while analyzing models and figuring out complex ideas for themselves. By using this approach instead of a traditional lecture or reading assignment, you encourage students to wrestle with ideas instead of memorizing conceptual content. Thus, your role shifts from providing information to helping students deepen their ideas through questioning. Teaching this way also allows you to learn more about individual students' thinking and find ways to improve individual understanding.

UNIT 3

- This type of lesson also depends on a lot of collaboration and peer-to-peer dialogue. Instruct collaborative groups to examine and discuss each question, to come to a consensus through peer-to-peer instruction, and to record the consensus answers on each of their documents. In the case that a group does not reach a consensus, students may write their own ideas down, but they should mark those items for review during teacher–student group discussions.
- It is very important that this lesson not be provided as a worksheet task for homework or individual completion: students are learning **through collaboration with their peers and through conversation with you**. At the end of the lesson, each student should be confident that their answers are correct and that their misconceptions have been clarified. Likewise, you will have a sense of what topics students understand and what topics they may still be struggling with.
- Do not let students leave the "What are your questions?" prompts blank. In general, asking good questions is difficult for novice science learners, so this skill needs to be practiced. If these prompts are optional, most students will opt out. This is the one exception to having the group determine a consensus for each response—students should be encouraged to write their own questions. Student questions here are an excellent way to address the needs of different learners. Some need simple clarifications, while others may ask questions that allow them to deepen their learning.

Meeting Learners' Needs
While consulting with student groups, if it becomes apparent that multiple groups are struggling in similar ways, it is appropriate to bring the class together for a brief clarifying discussion. This can save time, which makes it easier for you to have conversations with individual groups.

Classroom Ideas
Groups can signal their progress to you using two nested colored plastic cups, placed upside down. For instance, students can put a green cup on the outside so you can see that their group doesn't need assistance. They can put a red cup on the outside to indicate they have reached a stopping point and/or need teacher consultation. This way, groups do not need to keep hands raised while waiting.

PART 1: EXPLORING THREE MODELS OF RESPIRATION

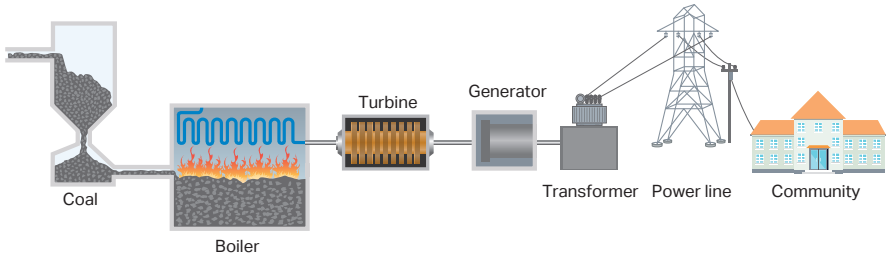
This is the core part of this lesson. Students investigate three separate models that help develop their understanding of cellular respiration.

- To begin, establish collaborative teams of three or four students. Then, allow students to start this part of the lesson, beginning with the investigation of

Handout 3.11.A: Model 1 – Power Conversion from Coal to Electricity. Circulate around the room to listen to student conversations and gauge their progress as they get to work. Avoid jumping in too quickly; groups should wrestle with the ideas together before you offer guidance. When each group indicates they are ready for your consultation, check answers based on the sample student responses below.

GUIDING STUDENT THINKING AND SOLUTIONS FOR MODEL 1 – POWER CONVERSION FROM COAL TO ELECTRICITY

In this investigation, students will use a model of electrical production from coal to think about the process of acquiring energy through cellular respiration.



Model 1: Power conversion from coal to electricity

Similarly, the energy stored in *glucose* from your diet requires a long series of complex steps to be released and converted to usable energy for our cells. Just as you can't plug your phone into coal and make it work, your cells can't use glucose directly to power their work. Thus, the energy in glucose is released and converted—through a process known as *cellular respiration*—into forms of energy that charge the cell's "battery." You will learn about ATP, the cell's charged battery, from Model 2.

1. Glucose is the basic unit of stored energy for cells. How do plant cells get glucose?

   Plant cells make their glucose through the process of photosynthesis.

2. How do animal cells get glucose?

   Animals must obtain energy-rich molecules such as glucose from their diet. In particular, animals consume glucose from plant sources.

Handout 3.11.A

3. In your own words, describe how the process of cellular respiration is similar to the process of converting fossil fuels such as coal to electricity.

   Student answers will vary. Sample response: Fossil fuels such as coal contain energy, but that energy is neither spontaneously released from the fuel nor is it directly usable by energy-consuming devices. Thus, energy from fossil fuels is released in a series of energy-harvesting reactions, and the energy released is converted to usable forms of energy such as electricity. Similarly, the energy stored in energy-rich molecules such as glucose is not directly usable by a cell. Therefore, a series of energy conversions must occur in order to release the energy in glucose and convert it into usable energy for the cell.

Handout 3.11.A

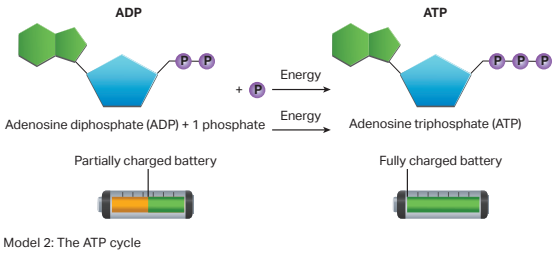
Guiding Student Thinking

Using analogies to think through complex concepts can be an effective way for students to deepen their understanding. Here, students are using electrical production from coal as an analogy for thinking about the process of acquiring energy through cellular respiration. If students struggle with this model, have them first recall prior knowledge about photosynthesis, such as the products of photosynthesis. Then, remind students of the series of energy conversions that must take place during photosynthesis in order for plants to produce those products.

- Prior to providing students with the next model, lead a brief whole-class discussion that allows students opportunities to share their written summaries of how the process of cellular respiration is similar to the process of electricity production from fossil fuels.
- Once you feel students are ready to move on, provide them with **Handout 3.11.B: Model 2 – The ATP Cycle** so they can begin the next investigation.

GUIDING STUDENT THINKING AND SOLUTIONS FOR MODEL 2 – THE ATP CYCLE

This model introduces more complex concepts as students start examining the specific chemical conversions that result in the production of energy during cellular respiration.



Model 2: The ATP cycle

1. Carefully study the two molecules in the model: ADP and ATP. What is the difference between them?

   ATP has one more *P*, or phosphate, attached to it than ADP.

2. Knowing what you know about how ATP is named, what do you think the letters in ADP stand for?

   Adenosine **di**phosphate

3. Think of ATP like a charged battery. If the cell uses some of the energy in this "battery," what must happen to the ATP molecule for it to be converted to a partially charged battery (ADP + P)?

   One of the Ps breaks off from the ATP molecule when the energy in it is used.

4. Energy can be stored in (and released from) chemical bonds in molecules. Draw an arrow to indicate the bond that stores energy when ATP forms from ADP + P. (This is the same bond that releases energy when ATP is converted into ADP + P.)

   Students should draw an arrow indicating the bond between the second and third phosphate on the ATP.

5. For ADP + *P* to be converted to ATP, energy is needed, as shown in this model. Where does this energy come from? (*Hint:* Think back to Model 1.)

   The energy needed to recharge the ADP + P back to ATP comes from glucose.

6. How is the production of ATP similar to how you charge a phone or other electronic device with a battery built in?

   Rechargeable batteries need a source of energy added to them in order for them to be fully charged again.

7. What questions do you have?

   Student questions will vary. It is best not to allow students to skip this question; encourage them to think more deeply until they can formulate a good question. Often the questions they ask will naturally lead them into the next section.

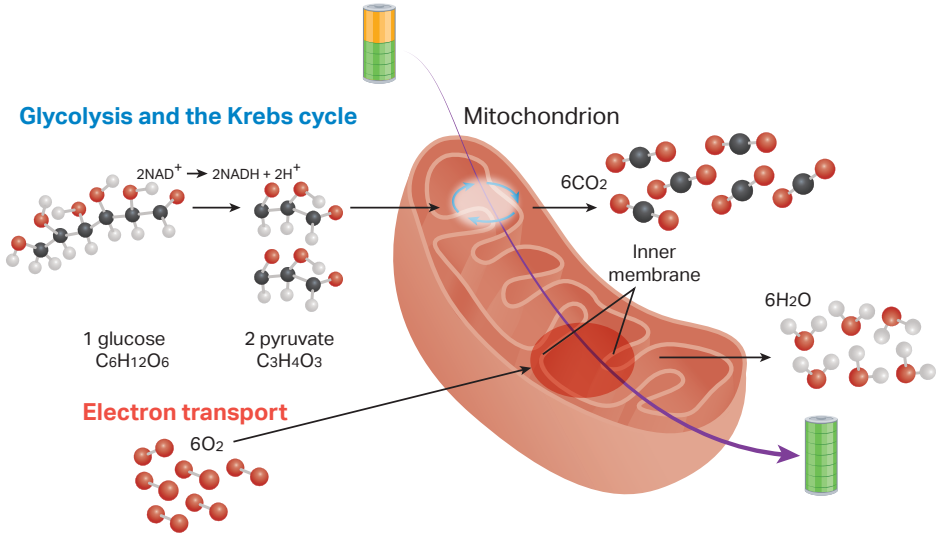
Handout 3.11.B

Meeting Learners' Needs

Some students may need additional support to feel confident in understanding the energy conversions in this model. If needed, stop the entire class and summarize key aspects of the model to make sure students are developing appropriate conceptual understanding of these conversions. For example, question 5 is a useful stopping point to regroup and review these conversions and the terminology being used before students move on to writing an analogy in question 6.

GUIDING STUDENT THINKING AND SOLUTIONS FOR MODEL 3 – CELLULAR RESPIRATION IN THE MITOCHONDRION

Handout 3.11.C: Model 3 – Cellular Respiration in the Mitochondrion guides students to begin to formalize their understanding of the chemical reactions that take place during cellular respiration. Before students engage with this model, it may be helpful to remind them of the basics for writing chemical equations.



Model 3: Cellular respiration in the mitochondrion

1. Using Model 3 as a guide, what are the reactants of cellular respiration? In other words, what molecules go into cellular respiration?

   The reactants of cellular respiration are glucose ($C_6H_{12}O_6$) and oxygen (O_2).

2. What are the molecular products of cellular respiration?

   The molecular products of cellular respiration are carbon dioxide (CO_2) and water (H_2O).

3. Write the full chemical equation for cellular respiration. (*Hint:* While the image shows cellular respiration as broken into two stages, the sum of these stages is one chemical reaction.)

   (a) The unbalanced chemical equation is $C_6H_{12}O_6 + O_2 \rightarrow CO_2 + H_2O$.

   (b) If your students are expected to balance chemical equations, the equation is $C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 6H_2O$

4. In cellular respiration, the energy stored in glucose molecules is released and stored in what energy-rich molecule (the cell's charged battery) that cells use to do work?

   The energy-rich molecule that stores the energy released from glucose is ATP.

Handout 3.11.C

5. Once ATP is used for cellular work, it breaks into the lower-energy ADP molecule and inorganic phosphate (P). Based on Model 2 and Model 3, what does the cell do with low-energy ADP + P?

   The cell will recycle ADP + P to re-form an ATP molecule through the process of cellular respiration.

6. Through the process of cellular respiration, 36–38 ADP + P are converted to 36–38 ATP. On Model 3, write "ADP + P" and "ATP" to correctly label the models of batteries on the diagram.

   Students should label the charged battery as "ATP" in order to designate that ATP is a product of cellular respiration. ADP + P should be used to label the partially charged battery.

7. Write the full equation for cellular respiration, including ADP + P and ATP.

   Sample response: 36 (ADP + P) + $C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 6H_2O$ + 36 ATP. *Note:* Students may or may not balance the equation, based on your expectations for your classroom. Also, they may write 36, 36–38, or 38 for the number of ADP + P and ATP molecules.

8. In your own words, describe (a) the process and (b) the function of cellular respiration.

   The process of cellular respiration breaks down glucose molecules, releasing their energy, and stores the energy released in molecules of ATP. The function of cellular respiration is to release energy from glucose and store it in ATP, since ATP is the only energy currency that the cell can directly use.

9. List at least two variables that might influence the rate of cellular respiration.

   Student answers will vary. Obvious choices would be that the availability of the reactants may influence the rate of reaction. Students may also say that variables such as temperature and pH would influence cellular respiration. The purpose of this question is to promote critical thinking. When checking with students on this question, ask questions such as "Why did you choose this variable?" to probe more deeply into their thinking.

10. CO_2 is toxic to your cells, yet cells produce it through the essential process of cellular respiration. Thus, the CO_2 that is produced must be removed from your cells. Considering what you know about your own body, what happens to the CO_2 that your cells produce?

    Students should identify that they breathe out CO_2. Depending on student content background, they may recognize that their bloodstream removes CO_2 from their cells, brings it to their lungs, and then they exhale it.

11. CHALLENGE! If you weigh yourself at night and again in the morning, you will find that you lose a small amount of weight every night. This is a direct result of cellular respiration. Use your understanding of cellular respiration to explain why you lose weight at night.

    The most common student misconception seen in this question is that the "loss" of energy from cellular work causes you to lose weight. But the answer to this question is about the atoms lost during sleep. Specifically, we exhale CO_2, resulting in a loss in mass overnight. All weight loss, in fact, is the result of losing atoms to our environment.

12. What questions do you have?

    Student questions will vary. It is best not to allow students to skip this question; encourage them to think more deeply until they can formulate a good question. If they "get it," they should ask questions to deepen their understanding.

Handout 3.11.C

Meeting Learners' Needs

Again, it may be useful to stop the entire class and summarize key aspects of this model to make sure students are developing an appropriate conceptual understanding of the chemical reactions. For example, question 7 is a useful stopping point to regroup and review before students are asked to summarize the process and purpose of cellular respiration in question 8.

UNIT 3

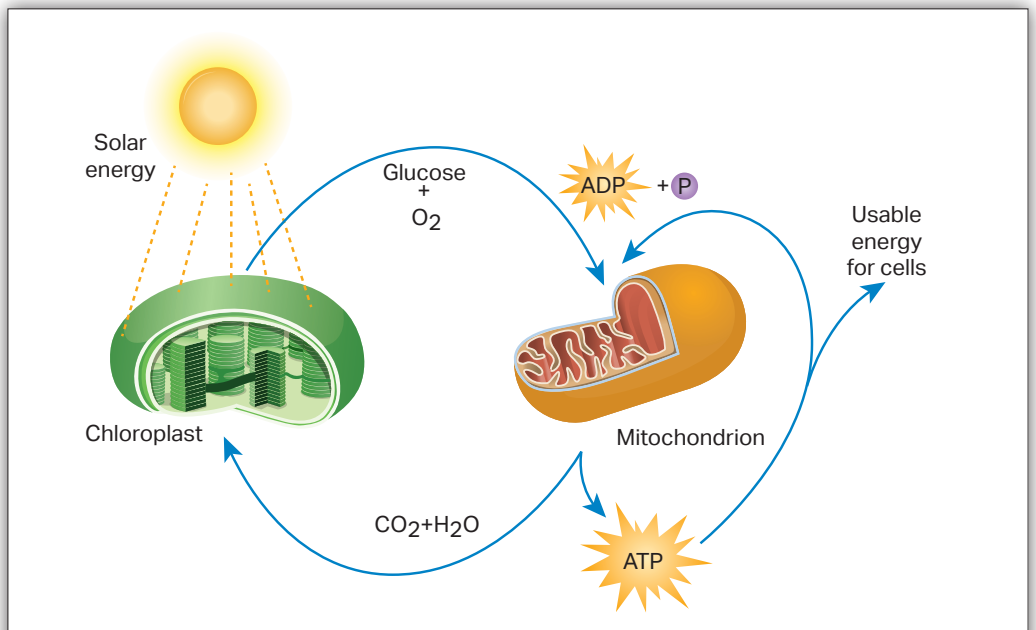
PART 2: APPLYING UNDERSTANDING

In the second part of this lesson, on **Handout 3.11.D: Model 4 – The Relationship Between Photosynthesis and Cellular Respiration in Eukaryotic Cells**, students apply what they learned from their introduction to photosynthesis in Lesson 3.10 and from their understanding of the first three models. The questions are designed to promote critical thinking, expand student understanding, and address common student misconceptions.

Before students engage with Model 4, it may be helpful to lead a whole-class discussion that elicits students' prior knowledge of photosynthesis. Or you may use this as a formative assessment opportunity to get feedback on their understanding of photosynthesis as you listen to and read their responses for this model.

GUIDING STUDENT THINKING AND SOLUTIONS FOR MODEL 4 – THE RELATIONSHIP BETWEEN PHOTOSYNTHESIS AND CELLULAR RESPIRATION IN EUKARYOTIC CELLS

The model in this investigation illustrates the relationship between photosynthesis and cellular respiration in eukaryotic cells.



Model 4: The relationship between photosynthesis and cellular respiration in eukaryotic cells

Handout 3.11.D

UNIT 3

1. On the diagram, write the phrase "site of photosynthesis" next to the organelle in which photosynthesis occurs.

   Students should label the green chloroplast on the left side of the diagram. (*Note:* Students should be able to answer this question by applying prior knowledge.)

2. On the diagram, write the phrase "site of cellular respiration" next to the organelle in which cellular respiration occurs.

   Students should label the mitochondrion on the right side of the diagram. (*Note:* Students should be able to answer this question by applying prior knowledge.)

3. What products from photosynthesis are used for cellular respiration?

   The answers for this are found on the model itself. The products from photosynthesis used in cellular respiration are glucose and oxygen.

   Note: In truth, glucose does not directly enter the mitochondrion for cellular respiration. Instead, the process known as glycolysis, which occurs in the cytoplasm, precedes cellular respiration in the mitochondrion. However, at this level the focus is on inputs and outputs of these processes, not on the detailed steps of cellular respiration or photosynthesis.

4. What products of cellular respiration are used by the chloroplast during photosynthesis?

   The answers for this are found on the model itself. The products from cellular respiration that enter the chloroplast for photosynthesis are carbon dioxide and water.

5. In the space below, write the equation for cellular respiration and the equation for photosynthesis.

   (a) Cellular respiration: $C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 6H_2O$

   (b) Photosynthesis: $6CO_2 + 6H_2O \rightarrow C_6H_{12}O_6 + 6O_2$

6. Below, rewrite the equations and add the energy input or output to the equations.

   (a) Cellular respiration: $C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 6H_2O$ + usable energy for cells

   (b) Photosynthesis: Light + $6CO_2 + 6H_2O \rightarrow C_6H_{12}O_6 + 6O_2$

Handout 3.11.D

UNIT 3

Guiding Student Thinking

While many textbooks show the reactions as shown in the sample responses to question 6 on the previous page, strictly speaking, energy should not be written as either a product or a reactant in a chemical equation, as this can lead to a misconception for students. To address this, you can rewrite the equation to show the light coming into the reaction (or energy released) by drawing it in on the arrow. The goal here is to reinforce student understanding that these reactions either consume or release energy, so you may coach the students toward that understanding in a way that best fits your expectations.

7. What is the relationship between the equations for photosynthesis and cellular respiration?

   The products of photosynthesis are the reactants of cellular respiration.

8. Is photosynthesis the exact opposite of cellular respiration? Explain.

   No, they are not exact opposites. This is a common misconception and is often stated to be true. While the products of one reaction are the reactants of the other, the energy inputs and outputs cannot be described as "opposite."

9. Circle the correct answer, and then explain your reasoning:

   (a) *Plants* / *Animals* / *Both* … have cells that can undergo photosynthesis.

   Explanation:

   Of the options given, only plants have the ability to photosynthesize, because they have chloroplasts. *Note:* There are some photosynthetic microbes, including bacteria, but the question doesn't offer that option. Outside the scope of this part of the lesson or the learning objectives of this unit, there are some photosynthetic ocean animals, specifically in the phyla Porifera and Cnidaria, and some mollusks. In all of these cases, however, the animals in question have formed endosymbiotic relationships with chloroplasts from algae or with photosynthetic bacteria.

   (b) *All* / *Some*… plant cells can photosynthesize.

   Explanation:

   Not all plant cells are exposed to light and therefore not all plant cells contain the chloroplasts required for photosynthesis. For instance, the cells in the roots of plants or inside the trunks of the trees would not be expected to photosynthesize.

Handout 3.11.D

(c) *Plants* / *Animals* / *Both*… use cellular respiration to harvest energy from glucose to "charge" the ATP battery for cellular work.

Explanation:

While plants can photosynthesize, they do so to store energy (and build structural molecules) so that they have energy-rich molecules for cellular respiration. Plants do not use energy directly from the sun for the work of plant cells. *Note:* A common misconception for students is that plants photosynthesize and animals respire.

10. What questions do you have?

This is an excellent opportunity to require every student to ask at least one question. Students who tend to quickly understand content often have the most difficulty asking a question. Prompting them to start a question with the phrases "I wonder …" or "What happens when …" can help them think more deeply and get around any insecurities about asking a question.

Handout 3.11.D

Unit 3

Performance Task

UNIT 3

PERFORMANCE TASK

Elodea Experiment

OVERVIEW

DESCRIPTION

This performance task engages students in analyzing an experimental setup designed to investigate energy production in an aquatic plant, *Elodea*. Students use the data from this experiment to apply their knowledge of energy production in plants.

CONTENT FOCUS

This performance task requires students to use knowledge about cellular systems and the structures and functions of those systems required to produce energy.

AREAS OF FOCUS

- Attention to Modeling
- Emphasis on Analytical Reading and Writing

SUGGESTED TIMING

~45 minutes

HANDOUT

- Unit 3 Performance Task: *Elodea* Experiment

MATERIALS

- colored pencils (optional)

COURSE FRAMEWORK CONNECTIONS

Enduring Understandings	
▪ Biological systems have specialized structures that enable specific functions necessary to sustain life. ▪ In order to sustain complex processes, biological systems must have mechanisms for growth and repair.	
Learning Objectives	**Essential Knowledge**
CELLS 2.2(a) Develop and/or use models to compare and contrast cell structures of different cells.	**CELLS 2.2.1** Cells have specialized structures that perform specific functions.
CELLS 2.3(a) Explain how cell structures indifferent types of organisms enable specialized cell functions.	**CELLS 2.3.2** Cell structures can differ across organisms and often give insight into an organism's ecological role.

UNIT 3

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.
CELLS 6.1(b) Create and/or use models to explain the process of converting solar energy into chemical energy through photosynthesis.	**CELLS 6.1.1** Photosynthetic organisms have the cellular structures to absorb solar radiation and convert it into chemical energy.

SCORING GUIDELINES

There are 12 possible points for this performance task.

Question 1(a)

Sample Solutions	Points Possible
The primary gas released by the plant is oxygen. The plant uses light energy to oxidize water, thereby releasing oxygen gas.	**2 points maximum** 1 point for identification of carbon dioxide gas 1 point for appropriate explanation *Scoring note:* Students do not need to use the term *oxidize* or *oxidation*, but they should be able to describe that light-dependent reactions require light energy and H_2O to transfer energy to ATP and NADPH and that a byproduct of this process is oxygen.
Targeted Feedback for Student Responses	
Students may confuse the byproducts of photosynthesis (oxygen) and cellular respiration (carbon dioxide). If so, have them return to Lesson 3.10: Model-Based Guided Inquiry – Introduction to Photosynthesis and Light Energy and review the models provided to correct their answers.	

TEACHER NOTES AND REFLECTIONS

UNIT 3

Question 1(b)

Sample Solutions	Points Possible
Light intensity influences photosynthesis rates. In this case, light intensity is greater in Setup A than in B, which is why more oxygen gas is released in A than B.	**1 point maximum** 1 point for appropriate description of the connection between light intensity and photosynthesis rates
Targeted Feedback for Student Responses	
Students may correctly explain the relationship between light intensity and photosynthesis rates but fail to provide any evidence. Ask students to use the experimental setup to provide evidence for their claims.	

TEACHER NOTES AND REFLECTIONS

Question 2

Sample Solutions	Points Possible
The primary gas released by the plant is carbon dioxide. Plants perform cellular respiration 24 hours a day and do not require light for this process. In cellular respiration, glucose is broken down to acquire cellular energy (ATP); a product of cellular respiration is carbon dioxide gas.	**2 points maximum** 1 point for identification of carbon dioxide gas 1 point for appropriate explanation
Targeted Feedback for Student Responses	
Many students may have a misconception that plants do not utilize cellular respiration to produce energy. Encourage students to create a list of all the shared organelles between plants and animals to help elicit their understanding that both have mitochondria. From there students should be able to reason through plants' ability to produce energy through cellular respiration.	

TEACHER NOTES AND REFLECTIONS

Question 3(a)

Sample Solutions	Points Possible
Movement of Water Students should provide an appropriate modeling of the movement of water up the stem and out of the leaf with appropriate labels (which could include capillary action, adhesion/cohesion) and/or a correct depiction of the diffusion of water across the cell membrane into the cell and large central vacuole. Storage of Water Students should provide an appropriate drawing and labeling of the large central vacuole in the center of the plant (and may also include nutrients/ions). Release of Water Students should provide an appropriate drawing of the release of water vapor from the leaf including correct labeling of stomata and guard cells.	**3 points maximum** 1 point for appropriate modeling of the movement of water *Scoring note:* The maximum for this part of the question is only 1 point, so if students accurately model both processes they will still only receive 1 point. 1 point for appropriate modeling of the storage of water in the plant cell 1 point for appropriate modeling of the release of water vapor from the leaf
Targeted Feedback for Student Responses	
Some students may create models that are partially accurate but not complete. Pair these students together to compare their models and work to make them complete. To help, give these student pairs guidance on where to focus based on what is missing from their models, such as differences between plant and animal cells if they didn't include the large central vacuole.	

TEACHER NOTES AND REFLECTIONS

Question 3(b)

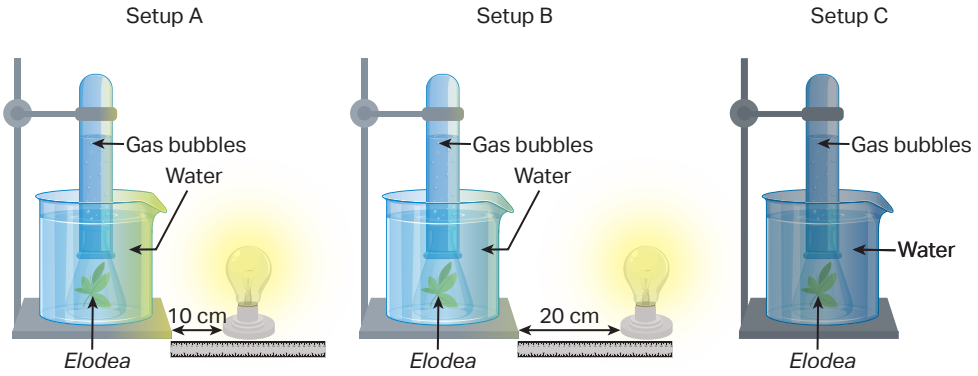
Sample Solutions	Points Possible
Photosynthesis Drawings of chloroplasts in the cell should show stacks of thylakoids (e.g., stacks of lines labeled as thylakoids). Drawings should also include the correct written equation for photosynthesis ($6CO_2 + 6H_2O \rightarrow 6O_2 + 6C_6H_{12}O_6$) near a chloroplast. Cellular Respiration Drawings of the mitochondria should show a folded membrane in the internal space. Drawings should also include the correct written equation for cellular respiration ($6C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 6H_2O$) near mitochondria.	**4 points maximum** 2 points for appropriate drawings of organelles and the correct equation for photosynthesis 2 points for appropriate drawings of organelles and the correct equation for cellular respiration *Scoring note:* Students do not receive points for labeling glycolysis in the cytoplasm. Students should still earn points for showing accurate but unbalanced equations for photosynthesis and cellular respirations.
Targeted Feedback for Student Responses	
Again, if students are missing key components in their models, have them work with another student to compare their two models and come to a consensus on what is missing in order to guide their revisions. Give constructive feedback, such as guiding students to include organelle details that help highlight their role in acquiring energy.	

TEACHER NOTES AND REFLECTIONS

PERFORMANCE TASK

Elodea Experiment

A biology class conducted an experiment to investigate how light intensity influences energy production in *Elodea* plants. *Elodea* is an aquatic plant commonly used in freshwater aquariums. The class used three different experimental setups, shown in the diagram below. Each setup contained a similarly sized *Elodea* plant in a beaker of water. The *Elodea* plants were each under a funnel that led directly to a test tube that was used to measure how much gas was released.



Three experimental setups for the *Elodea* experiment

Students counted the number of gas bubbles that were released by the plants over a set period to determine the average number of gas bubbles produced per minute for each setup. Their findings are shown in the table below.

Setup	Light Treatment	Gas Production (bubbles/min)
A	10 cm away	40
B	20 cm away	25
C	No light	10

1. (a) For Setups A and B, identify what type of gas is being released by the plant as a result of exposure to light and collected in the test tube. Explain your answer.

PERFORMANCE TASK

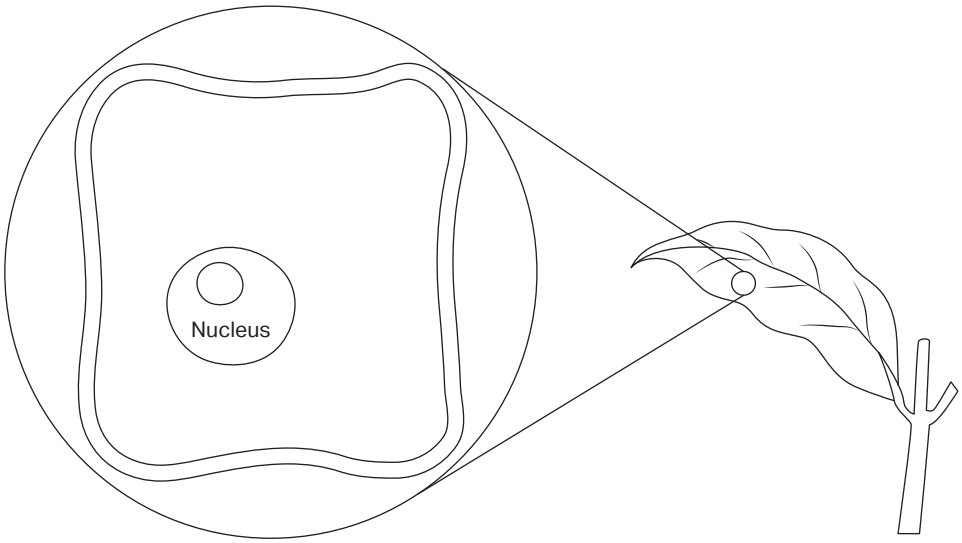
(b) Describe what could account for the difference in gas production between Setup A and Setup B.

2. Explain how the plant in Setup C produces gas in the absence of light. Identify the gas that is being released.

3. Use the diagram below to model the following processes that occur in the plants (include all necessary cell structures, chemical equations, arrows, and descriptions):

   (a) How water moves, is stored, and is released in the plant

   (b) How plants acquire energy (consider all three experimental setups)



Unit 4

Unit 4
Genetics

Overview

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

This unit focuses on the following enduring understandings:

- 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

This unit addresses the following key concepts:

- GEN 1: Structure of DNA
- GEN 2: DNA Synthesis

UNIT 4

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

UNIT RESOURCES

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

Lessons for Key Concept GEN 1: Structure of DNA				
Lesson Title	**Learning Objectives Addressed**	**Essential Knowledge Addressed**	**Suggested Timing**	**Areas of Focus**
4.1: Launch Lesson – Investigating the Building Blocks of DNA	GEN 1.1(a), GEN 1.2(b)	GEN 1.1.1a, GEN 1.2.1a	Less than 45 minutes	Strategic Use of Mathematics, Emphasis on Analytical Reading and Writing
	The following Key Concept GEN 1 learning objectives and essential knowledge statements are not addressed in Pre-AP lessons. Address these in teacher-developed materials. ▪ Learning Objectives: GEN 1.2(a) ▪ Essential Knowledge Statements: GEN 1.1.1b, GEN 1.1.1c, GEN 1.2.1b, GEN 1.2.2c 1–2			

Lessons for Key Concept GEN 2: DNA Synthesis				
Lesson Title	**Learning Objectives Addressed**	**Essential Knowledge Addressed**	**Suggested Timing**	**Areas of Focus**
4.2: Launch Lesson – Introduction to DNA Synthesis	GEN 2.1(a), GEN 2.1(b), GEN 2.1(c)	GEN 2.1.1a, GEN 2.1.1b	Less than 45 minutes	Emphasis on Analytical Reading and Writing

4.3: DNA Extraction Lab	GEN 2.1(a), GEN 2.1(c)	GEN 2.1.1a, GEN 2.1.1b	~120 minutes	Emphasis on Analytical Reading and Writing
	All learning objectives and essential knowledge statements for this key concept are addressed with the provided materials.			

Lessons for Key Concept GEN 3: Protein Synthesis				
Lesson Title	**Learning Objectives Addressed**	**Essential Knowledge Addressed**	**Suggested Timing**	**Areas of Focus**
4.4: Launch Lesson – Introduction to Gene Expression—Sickle Cell Anemia Case Study	GEN 3.3(a), GEN 3.3(b), GEN 3.4(a)	GEN 3.3.1a, GEN 3.3.1b, GEN 3.3.1c, GEN 3.4.1a, GEN 3.4.1b, GEN 3.4.1c	~60 minutes	Emphasis on Analytical Reading and Writing
	The following Key Concept GEN 3 learning objectives and essential knowledge statements are not addressed in Pre-AP lessons. Address these in teacher-developed materials. ▪ Learning Objectives: GEN 3.1(a), GEN 3.2(a), GEN 3.3(c), GEN 3.3(d), GEN 3.4(b), GEN 3.4(c) ▪ Essential Knowledge Statements: GEN 3.1.1a 1–3, GEN 3.2.1a, GEN 3.2.1b, GEN 3.2.1c, GEN 3.3.1c 1–3			

Learning Checkpoint 1: Key Concepts GEN 1–3 (~45 minutes)
This learning checkpoint assesses learning objectives and essential knowledge statements from Key Concepts GEN 1 through 3. For sample questions and learning checkpoint details, visit Pre-AP Classroom.

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Lessons for Key Concept GEN 4: Asexual and Sexual Passing of Traits				
Lesson Title	**Learning Objectives Addressed**	**Essential Knowledge Addressed**	**Suggested Timing**	**Areas of Focus**
4.5: Launch Lesson – Introduction to Meiosis Through Modeling	GEN 4.2(a), GEN 4.2(b), GEN 4.2(c)	GEN 4.2.1a 1–3, GEN 4.2.1b	~60 minutes	Attention to Modeling
4.6: Analyzing Shark Reproduction Strategies	GEN 4.1(a), GEN 4.1(b)	GEN 4.1.1c, GEN 4.1.1d	~90 minutes	Emphasis on Analytical Reading and Writing
	The following Key Concept GEN 4 learning objectives and essential knowledge statements are not addressed in Pre-AP lessons. Address these in teacher-developed materials. ▪ Learning Objectives: GEN 4.3(a), GEN 4.3(b) ▪ Essential Knowledge Statements: GEN 4.1.1a, GEN 4.1.1b, GEN 4.3.1a, GEN 4.3.1b			

Lessons for Key Concept GEN 5: Inheritance Patterns				
Lesson Title	**Learning Objectives Addressed**	**Essential Knowledge Addressed**	**Suggested Timing**	**Areas of Focus**
4.7: Launch Lesson – Exploring Mendelian Inheritance Patterns	GEN 5.1(a), GEN 5.1(b)	GEN 5.1.1a, GEN 5.1.1b, GEN 5.1.1c, GEN 5.1.1d	60 minutes	Attention to Modeling, Emphasis on Analytical Reading and Writing

4.8: Exploring Inheritance Patterns – Albinism	GEN 5.1(a), GEN 5.1(b), GEN 5.2(a), GEN 5.2(b), GEN 5.2(c)	GEN 5.1.1a, GEN 5.1.1b, GEN 5.1.1c, GEN 5.1.1d, GEN 5.1.2a, GEN 5.1.2b 1–2, GEN 5.2.1a, GEN 5.2.1b	~90 minutes	Emphasis on Analytical Reading and Writing, Attention to Modeling
4.9: Albinism Investigation	GEN 5.1(a), GEN 3.4(a), GEN 3.4(c)	GEN 5.1.1a, GEN 3.4.1a, GEN 3.4.1b, GEN 3.4.1c	~90 minutes	Emphasis on Analytical Reading and Writing
	All learning objectives and essential knowledge statements for this key concept are addressed with the provided materials.			

Practice Performance Task for Unit 4 (~45 minutes)

This practice performance task draws on learning objectives and essential knowledge statements addressed up to this point in the unit.

Lessons for Key Concept GEN 6: Biotechnology

Lesson Title	Learning Objectives Addressed	Essential Knowledge Addressed	Suggested Timing	Areas of Focus
4.10: Launch Lesson – Ethics and Decision Making in Science—Biotechnology	GEN 6.1(c)	GEN 6.1.1b, GEN 6.1.1c	~45 minutes	Emphasis on Analytical Reading and Writing
4.11: Gene Editing	GEN 6.1(b), GEN 6.1(c)	GEN 6.1.1a, GEN 6.1.1b, GEN 6.1.1c	~75 minutes	Emphasis on Analytical Reading and Writing
	The following Key Concept GEN 6 learning objective is not addressed in Pre-AP lessons. Address it in teacher-developed materials. ▪ Learning Objective: GEN 6.1(a)			

UNIT 4

Learning Checkpoint 2: Key Concepts GEN 4–6 (~45 minutes)

This learning checkpoint assesses learning objectives and essential knowledge statements from Key Concepts GEN 4 through 6. For sample questions and learning checkpoint details, visit Pre-AP Classroom.

Performance Task for Unit 4 (~60–70 minutes)

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

LESSON 4.1

Launch Lesson – Investigating the Building Blocks of DNA

OVERVIEW

LESSON DESCRIPTION

Part 1: Analyzing Nitrogenous Base Ratios
Students use some of Chargaff's data to develop their own inferences about base pairing.

Part 2: Making Claims About DNA's Structure
Students work in groups to develop predictions about base ratios in additional example species. They watch a video and revise or confirm their claims accordingly.

CONTENT FOCUS

This lesson asks students to closely observe and analyze Chargaff's data in order to make their own predictions and claims about nitrogenous base pairs in DNA. By the end of this launch lesson, students should have a deep understanding of Chargaff's ratios (A:T and C:G), which is an important foundation for subsequent lessons that more deeply investigate DNA's structure.

AREAS OF FOCUS

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

SUGGESTED TIMING

Less than 45 minutes

HANDOUT

- 4.1: Investigating the Building Blocks of DNA

MATERIALS

- LCD projector, electronic whiteboard, or other technology to show an online video
- internet access to the following 47-second video clip from the DNA Learning Center: **https://www.dnalc.org/resources/3d/21-chargaff-ratios.html**
- large poster paper and markers (optional)

UNIT 4

COURSE FRAMEWORK CONNECTIONS

Enduring Understandings	
▪ The molecular structure of DNA enables its function of storing life's genetic information.	
Learning Objectives	**Essential Knowledge**
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).
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.

UNIT 4

PART 1: ANALYZING NITROGENOUS BASE RATIOS

This launch lesson introduces students to the idea of base-pair rules, as defined by Erwin Chargaff. Students should not have prior knowledge of this concept. Rather than simply being given the rules for how the monomers (specifically the nitrogenous bases) in DNA pair, students craft their own inferences about base pairing. In the first part of this lesson, students independently observe and analyze some of Chargaff's data.

- To familiarize students with the background information, have them read a brief introduction on Chargaff and how his thoughts about DNA were influenced by the earlier work of Oswald Avery. See the top of **Handout 4.1: Investigating the Building Blocks of DNA** for this text.
- Now that students have some background on Chargaff's work, they should analyze the data table in Part 1 of the handout (shown below) that shows relative proportions of nitrogenous bases in four organisms. This initial analysis is simply to help students recall some prior knowledge about how organisms acquire the building blocks for DNA synthesis.

Relative Proportions (%) of Bases in DNA

Organism	Nitrogenous Bases			
	A	T	G	C
Human	30.9	29.4	19.9	19.8
Chicken	28.8	29.2	20.9	21.3
Grasshopper	29.3	29.2	20.5	20.7
Sea Urchin	32.8	32.1	17.7	17.3

Handout 4.1

- To elicit students' prior knowledge about how organisms acquire the building blocks for DNA, lead a whole-class discussion, and consider using the following prompts to spark their thinking:
  - How do you acquire the building blocks to make these nitrogenous bases?
  - Do you think plants have these same bases?
  - How do plants acquire the building blocks to make nitrogenous bases? Is this different from how consumers acquire them?

UNIT 4

Guiding Student Thinking

From Unit 1, students should understand that consumers must eat other organisms to acquire the nitrogen necessary to make DNA. It is a good opportunity to remind or review with students how plants instead rely on the nitrogen cycle to provide a usable form of nitrogen that they then take up through roots in the soil.

- Next, students should work individually to closely observe and analyze the data in order to look for trends and relationships. As instructed on their handout, students should record their observations in the space provided.
- Students then use the provided grid to graph the data from the table. The graph will help illustrate the base-pair patterns that emerge from the different species' DNA. Students will need to consider what type of graph is most appropriate (i.e., bar graph or line graph). They should quickly see that a bar graph will be best at helping them compare these ratios. If not, this is a good time to review types of data displays (e.g., bar graphs, scatterplots, or line graphs) and what types of data they are most useful for analyzing.
- Finally, students use the completed graph to make at least one or two inferences about base pairing in DNA. They should record these ideas on their handout.

PART 2: MAKING CLAIMS ABOUT DNA'S STRUCTURE

In the second part of this lesson, students work in groups to develop predictions about nitrogenous base ratios in additional example species. They watch a video and revise or confirm their claims accordingly.

- Have students work in groups of three or four to share their inferences. As instructed on the handout, each group should generate a list of at least two or three claims that can be made based on the data in Part 1. Encourage students to use the data to support their claims.
- Using the claims they generate as a group, students will complete the data table in Part 2 of the handout by adding probable percentages for the missing nitrogenous bases. Answers are provided on the next page for reference.

Meeting Learners' Needs

If you feel that students are still struggling to see the patterns in the nitrogen base data, you could have student groups share their predictions and find the average predicted value for each base. Student groups do not need to be exact but they should be guessing within an appropriate range based on the patterns they observed in Part 1. Showing group results on the board and highlighting the trends may help students better see these patterns.

UNIT 4

Instructional Rationale

Having students use trends in data, as Chargaff did, to make predictions will make their understanding of base-pairing ratios more meaningful and lasting. Solutions shared below are from Chargaff's actual findings. It is important to share the actual data with students to have them think about how their predictions differ and what may account for these differences (e.g., mutations in the genome).

Relative Proportions (%) of Bases in DNA

Organism	Nitrogenous Bases			
	A	T	G	C
Wheat	27.3	27.1	22.7	22.9
Yeast	31.9	32.5	18.1	17.7
E. coli	24.1	23.6	26.0	25.7

Handout 4.1

Classroom Ideas

Student groups could record their final claims on large poster paper and conduct a gallery walk to examine claims. They can also use markers to put check marks next to claims they agree with (green), disagree with (red), or are unsure about (yellow). Then students can discuss their reasoning during the whole-class discussion.

- Now lead a whole-class discussion so students can synthesize their understanding by sharing their list of claims and their predicted percentages. At this point, all claims should be recorded regardless of their accuracy so all students can see them. It is also important not to confirm any of these claims at this point.
- Next, show the video clip from the DNA Learning Center (**www.dnalc.org/resources/3d/21-chargaff-ratios.html**). Have students assess whether the class claims are reasonable or need revision. You may need to show the video twice.
- To conclude, have students confirm what the missing proportions of bases in the data table should be, based on the revised claims.

UNIT 4

Guiding Student Thinking

As students predict percentages, it is not important that they are exactly accurate since the percentages are not precisely 1:1. Instead, you want to see if students can make generalizations about the ratios. They should see that there are only four repeating nitrogenous bases (adenine, guanine, thymine, and cytosine) that make up the DNA of all living organisms. The ratios of A to T and of G to C are both 1:1 in all organisms' DNA. However, the proportion of A-T pairs and G-C pairs in DNA does vary between species (e.g., human DNA contains significantly more A-T pairs than G-C pairs, but there is still one adenine base for every thymine base, and one guanine for every cytosine). As students engage in subsequent lessons on DNA, you can remind them how Chargaff's ratios contributed to the discovery of the true structure of DNA.

LESSON 4.2

UNIT 4

Launch Lesson – Introduction to DNA Synthesis

OVERVIEW

LESSON DESCRIPTION

Part 1: Exploring DNA Replication

Students first preview the questions they will be answering as they watch the animation of DNA replication. Then, they watch the animation and respond to the open questions.

Part 2: Summarizing How DNA Is Copied

Students write paragraphs explaining how DNA is copied, summarizing the ideas they formed while watching the animation.

CONTENT FOCUS

This lesson is designed to spark student thinking about how organisms use the building blocks of DNA to make more DNA through replication. This allows students to make connections to key concepts in prior lessons, such as nitrogen cycling (Unit 1: Ecological Systems) and the synthesis phase of the cell cycle (Unit 3: Cellular Systems).

AREA OF FOCUS

- Emphasis on Analytical Reading and Writing

SUGGESTED TIMING

Less than 45 minutes

HANDOUT

- 4.2: Introduction to DNA Synthesis

MATERIALS

- LCD projector, electronic whiteboard, or other technology to show an online video
- internet access to the HHMI BioInteractive video "DNA Replication" (1:06), available at **www.hhmi.org/biointeractive/dna-replication-basic-detail**

UNIT 4

COURSE FRAMEWORK CONNECTIONS

Enduring Understandings	
▪ The molecular structure of DNA enables its function of storing life's genetic information.	
Learning Objectives	**Essential Knowledge**
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.

UNIT 4

PART 1: EXPLORING DNA REPLICATION

In Unit 3: Cellular Systems, students were introduced to the need for organisms to replicate their DNA in the synthesis phase of the cell cycle. This launch lesson is meant to deepen students' understanding as they explore how DNA is copied in cells. In Part 1 of the lesson, students watch a video animation of DNA synthesis and speculate on what is happening.

- To begin the lesson, give students some brief introductory information before they watch an animation of DNA synthesis. Explain that they will see a representation of a single strand of DNA being replicated to produce two strands of DNA and that the various structures they see in the animation play specialized roles in the replication process.
- To help guide students as they watch the video, ask them to preview the four questions about the animation in Part 1 of **Handout 4.2: Introduction to DNA Synthesis**:

    1. Why do you think the strand of DNA coming in from the left side of the screen is becoming two thinner strands?
    2. Does it look like the same process is taking place with both strands?
    3. How many distinct entities or structures do you see participating in the process?
    4. Come up with a descriptive name to identify each structure and explain what you think it is doing.

Let students know that they will have the opportunity to watch the video again while answering the questions.

- Now show the following video from HHMI BioInteractive with the sound turned off: **http://www.hhmi.org/biointeractive/dna-replication-basic-detail**.
- After students have seen the animation once, stop the video and instruct them to start developing answers to the questions. Remind students that the video will be replayed several times as they are working. Recommend that they focus on each individual entity, structure, or area one at a time as the video is replayed.
- Replay the video continuously (still with the sound turned off) for 5–10 minutes or until all the students have completed questions 1–4 on the handout. This will allow students to focus on each individual entity, structure, or area participating in the replication process and to formulate their ideas of what each one is doing. During one or two of the replays, pause the video approximately every 10 seconds to allow students to make additional observations.

Classroom Ideas
You can download this video file onto your computer prior to the lesson to avoid being interrupted by slow or spotty internet service.

UNIT 4

Guiding Student Thinking

Encourage students to use appropriate terminology from their prior lessons on the structure of DNA. For example, they know that DNA is double-stranded, made up of nitrogenous bases, and has a sugar–phosphate backbone. Therefore, they should include these concepts as they write descriptions of the structures and processes they are viewing in the replication video. Additionally, you can challenge students to make key connections to prior units by describing how cells get the building blocks for DNA and in what phase of the cell cycle this process would occur.

PART 2: SUMMARIZING HOW DNA IS COPIED

In this part of the lesson, students use their analytical writing skills to summarize their ideas from Part 1 into one coherent paragraph.

- As instructed on the handout, students should write a paragraph titled "My Explanation of How DNA Is Copied." Emphasize to students that this is an evidence-based writing task. Their paragraphs should be consistent with the evidence they have gathered from watching the video.
- Once the entire class is finished writing, ask for volunteers to read their paragraphs aloud. Support students in challenging or critiquing summaries that are not consistent with the evidence in the video. As students share their summaries, record the ideas on the board that accurately represent appropriate parts of DNA replication (e.g., helicase enzymes unwind the two strands). Have students continue to share their paragraphs until a complete outline of the replication process emerges for students to see on the board.
- Finally, have students complete the handout by writing three questions that they would like answered about DNA synthesis.

Meeting Learners' Needs

If you find that many students have written inaccurate summaries or are missing key steps to DNA synthesis, show the video again, this time stopping at key moments to have the class summarize together and then translate into their own words.

Instructional Rationale

This lesson is designed to have students extract relevant information in an inquiry-based manner in order to construct a process by which DNA is synthesized. They may not know all the relevant terminology to use during their summaries, such as names for enzymes like helicase. Introducing these terms in the moment of use for students to finish constructing the process of DNA synthesis will increase their understanding and retention.

LESSON 4.3

DNA Extraction Lab

OVERVIEW

LESSON DESCRIPTION

Part 1: Introduction to the Strawberry Lab
Students answer a series of guiding questions to better understand how DNA extraction is applied in the everyday world.

Part 2: Performing the Lab
Students carry out a procedure for extracting DNA from strawberries. Teacher prompting throughout this part of the lab helps students begin to consider the purpose of each step in the process.

Part 3: Post-Lab Questions
Students answer post-lab questions to develop and expand their thinking about the purpose of each part of the DNA extraction procedure.

Part 4: Guided Inquiry
Students build on what they learned in the previous parts of the lab to develop and carry out a modified version of the DNA extraction procedure.

CONTENT FOCUS

For this investigation, students should have basic knowledge of the facts that cell membranes are layers of lipids (or fat molecules), that DNA is found in the nucleus of a cell, and that enzymes speed up chemical reactions. The lesson focuses on students learning a simple method of DNA extraction, applying prior knowledge to explain the rationale for each step in the extraction process, and explaining why DNA extraction is important to the scientific community. This

AREA OF FOCUS

- Emphasis on Analytical Reading and Writing

SUGGESTED TIMING

~120 minutes

HANDOUT

- 4.3: Extracting DNA from Strawberries

MATERIALS

For each student group:

- plastic zip-top sandwich bag
- cold water
- beaker or plastic cup
- coffee filter
- rubber band
- ice bath (bottom of large Petri dish or flat-bottomed bowl, filled with crushed ice)
- liquid detergent (dish soap)
- table salt
- teaspoon
- meat tenderizer (or pineapple juice)
- test tube
- test tube rack
- glass stirring rod (or wooden stick or straw)
- ice-cold alcohol (ethanol or 70%–95% isopropyl alcohol), kept in an ice bath

UNIT 4

investigation prompts students to make connections to prior topics from Unit 3 (macromolecule structure and function, the role of enzymes in cells, the effects of temperature and pH on macromolecule stability, and the structure and function of cell membranes) and earlier lessons in this unit (structure of the nucleotide monomer and DNA's double helix structure). It also is intended to prime their thinking about biotechnology techniques used to manipulate DNA and the potential benefits and/or consequences of manipulating the DNA of organisms.

- strawberries (fresh, or frozen and thawed)
- timer
- Eppendorf tubes (optional)
- other organic materials such as banana, apple, chicken liver, green split peas, etc. (optional, for Part 4 only)

COURSE FRAMEWORK CONNECTIONS

Enduring Understandings	
▪ The molecular structure of DNA enables its function of storing life's genetic information.	
Learning Objectives	**Essential Knowledge**
GEN 2.1(a) Describe the importance of DNA synthesis. **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.

SETUP AND PREPARATION NOTES

- It is critical that the alcohol is **ice cold**. It should be placed in the freezer at least 24 hours in advance; 48–72 hours is preferable. An ice bath needs to be used to store the alcohol in between class periods if it is being left out of the freezer.
- An alternative to using plastic sandwich bags (for mashing strawberries by hand) is using a mortar and pestle or a blender. An advantage of using plastic bags is that almost the entire lab procedure can be carried out in the bag itself.

- Instead of meat tenderizer, you can use 1–2 drops of pineapple juice or an enzymatic cleaning solution for contact lenses. (Enzymatic cleaning solutions for contact lenses contain proteases to remove protein buildup.)
- If you do not have access to glass stirring rods, you can also use wooden skewers, straws, or coffee stirrers. Glass rods typically work the best at getting DNA to "stick," but these substitutes do work.
- If you'd like students to take home the DNA they have spooled, you can provide them each with an Eppendorf tube.

SAFETY NOTES

All general safety guidelines should be followed.

UNIT 4

PART 1: INTRODUCTION TO THE STRAWBERRY LAB

Most students will not intuitively understand why someone would have any practical reasons for extracting DNA from cells. Therefore, Part 1 of this lesson begins the lab investigation by establishing a context and purpose for conducting a DNA extraction.

- To prepare students for the investigation, use guiding questions such as the ones provided below to help them understand why they will be conducting a DNA extraction. You may wish to present the questions in a whole-class discussion or assign them for homework or a bell-ringer activity.
  - What does it mean to extract DNA?

    It means isolating the DNA from the rest of the cell's components.
  - Where is the DNA located in a plant or animal cell?

    DNA is located in the nucleus of plant and animal cells.
  - What might you have to do to isolate the DNA from the rest of the cell?

    You would have to "break through" the cell membrane and the nuclear membrane to be able to isolate the DNA from the rest of the cell.
  - Why might someone want to extract DNA from a cell? What applications does DNA extraction have in the real world?

    Some possible answers include to test a person for a genetic disease, to analyze forensic evidence, to study a gene involved in cancer, or to mass-produce a gene or protein important for treating a disease.

PART 2: PERFORMING THE LAB

In this part of the lesson, students carry out a procedure for extracting DNA from strawberries. Teacher prompting throughout this part of the lab helps students begin to consider the purpose of each step in the process.

- Once students understand why a scientist would want to extract DNA, allow them time to review the introduction, materials, and procedure on **Handout 4.3: Extracting DNA from Strawberries**. Invite any questions before students get started.
- To prompt students to start thinking about *how* and *why* this procedure works, ask them to recall information from the introduction about some of the materials they will use in the lab. For instance, ask, "What macromolecules does meat tenderizer (or pineapple juice) contain? What are some features of detergent molecules?"
- Next, have students work in small groups to carry out the procedure. Circulate around the room while they are working and gauge students' thinking to ensure they are connecting their knowledge of DNA structure gained in prior lessons to

the techniques and materials used in this lab. Some relevant questions for each step of the procedure are provided below.

Instructional Rationale

This is a common lab that many biology students have a chance to experience. However, often this investigation is done with little attention paid to why the procedure isolates DNA from the rest of the plant cell. By focusing on *why* these materials are needed, we yield 1) key prior connections for students about the structure and location of DNA, and 2) an engaging way for students see and understand that DNA is in every cell—even in the strawberries they eat!

STEP 1: EXTRACTING THE DNA FROM THE CELL'S NUCLEUS

In this step, students mash the strawberries and add water, salt, detergent, and meat tenderizer.

Some questions you might discuss with students for this step include the following:

Classroom Ideas

A discussion of these questions can take place in small groups or as a class while students are carrying out the 10–15 minutes of swishing the strawberries, salt, detergent, etc. mixture.

- Why mash the strawberries?

  This begins the physical breakdown of the cell walls. The cells must be broken open in order to extract the DNA.

- Why is salt added?

  Salty water helps the DNA precipitate (solidify and appear) when alcohol is added. In addition, sodium chloride helps remove proteins that are bound to the DNA. It also helps keep the proteins dissolved in the aqueous layer so they don't precipitate in the alcohol along with the DNA.

- Why is cold water better than warm water?

  Cold water helps keep the DNA intact during the extraction process. Cooling slows down enzymatic reactions. This protects the DNA from enzymes in the solution that can destroy it.

- Why would a cell contain enzymes that destroy DNA?

  These enzymes are present in the cell cytoplasm (not the nucleus) to destroy the DNA of viruses that may enter the cell. A cell's DNA is usually protected from such enzymes (called DNases) by the nuclear membrane, but adding detergent destroys that membrane.

UNIT 4

- Why is liquid detergent added?

  The detergent breaks open the cells by destroying the fatty membranes that enclose the cells, as well as the nuclear membranes within the cells. This allows the DNA to be released into the solution. Detergent and salt also help strip away proteins that are associated with the DNA molecules.

- What is the purpose of adding meat tenderizer?

  The meat tenderizer is a source of enzymes that break down proteins. DNA is attached and wrapped around proteins known as *histones*. The use of enzymes may help free the DNA from the histone proteins.

There is not a consensus on whether the addition of meat tenderizer improves the extraction of DNA. There are a number of successful procedures that do not include the use of meat tenderizer. However, it is useful to add to students' thinking about the need to uncoil the DNA by breaking down proteins, specifically histones.

Guiding Student Thinking

The questions provided here are examples of questions you might ask each group. Some of the questions review students' conceptual understanding of what influences enzymatic activity, from Unit 3: Cellular Systems. However, students may not fully understand why salt is added or why cells would contain enzymes that destroy DNA. Therefore, it may be useful to post these questions on the board as students work through this portion of the lab, and find a moment to stop all student groups and discuss before moving on to the next part of the laboratory procedure.

STEP 2: SEPARATING OUT THE SMALLER MOLECULES

In this next step, students construct and use an apparatus to separate the smaller molecules, including DNA, from the larger cellular components of the strawberry mixture. They collect some of the filtrate in a test tube.

Some questions you might discuss with students for this step include the following:

- Why filter the mashed up or blended strawberries?

  This helps separate the smaller molecules, such as DNA, from the large organic chunks in the mixture. This will usually improve your ability to isolate the DNA and increase your yield of DNA when spooling.

- Why is it suggested to keep the filtrate on ice?

  (1) At room temperature, enzymes that may be present in the filtrate are more likely to become active and degrade the DNA. (2) The warmer the environmental temperature, the closer you get to the melting temperature, which means the

more likely the DNA will denature. (The melting temperature, T_m, is defined as the temperature at which half of the DNA strands are in the random coil or single-stranded [ssDNA] state.)

STEP 3: ISOLATING THE DNA

Students isolate the DNA as a precipitate and then use a spooling technique to examine the DNA strands.

Some questions you might discuss with students for this step include the following:

- Why is cold alcohol added to the filtrate?

  DNA precipitates in the presence of alcohol, which means it doesn't dissolve in alcohol. This causes the DNA to clump together when there is a lot of it. And, usually, cells contain a lot of it! For example, each human body cell contains 46 chromosomes (or 46 DNA molecules). If you lined up those DNA molecules end to end, a single cell would contain six feet of DNA. The human body is made up of about 40 trillion cells, each of which contains six feet of DNA; our bodies contain more than a billion miles of DNA.

- Is the white, stringy stuff *only* DNA?

  No, this procedure actually produces a mixture of both DNA and RNA. The procedure for DNA extraction is really a procedure for nucleic acid extraction.

Classroom Ideas

If you have the resources, you can allow students to take the DNA home in an Eppendorf tube. Instruct them to transfer the spooled DNA into an Eppendorf tube with some alcohol. The tube should be kept tightly closed to avoid evaporation of the alcohol. The DNA is stable in this form for many years. If it is shaken, the DNA strands will break into smaller pieces, making the DNA harder to see. If it disappears, it is likely because enzymes are still present that are breaking apart the DNA in the sample.

PART 3: POST-LAB QUESTIONS

After completing the DNA extraction, students answer post-lab questions to develop and expand their thinking about the purpose of each part of the procedure.

- Students may work on the post-lab questions from the handout individually, in pairs, or in small groups. Encourage members of different lab groups to help one another, as each lab group is likely to have different insights to contribute, based on their own experience with the procedure and teacher-led prompting.
- Once students have finished, review the post-lab questions in a whole-class discussion. Sample responses are provided on the next page for reference. Ensure that students connect their understanding of the structure of DNA to specific techniques and materials used in the extraction of DNA.

UNIT 4

Post-Lab Questions

1. Explain why strawberries work better than human cells in this extraction lab.

   Strawberries are octoploid, which means they have 8 copies of each chromosome, compared to humans, who are diploid and have only 2 copies of each chromosome. Strawberry cells have a greater volume of DNA compared to human cells.

2. Explain why uneaten strawberries will eventually rot. What is the ecological advantage of the factors that cause this to happen?

   The pectinases and cellulases in the strawberries will eventually break down the cell walls, which provide most of the structural support for the cells. The ecological advantage is that animals will eat and more easily digest the fruit, and when they defecate later, they will disperse the seeds for the plant.

3. Why was it important to knead and mash the material used in this lab?

   This helps to physically break down the cell walls and membranes of the cells.

4. What barriers needed to be lysed in order to isolate the DNA from other cell components?

   The cell wall, cell membrane, and nuclear membrane need to be lysed.

5. Discuss why detergent was used in the lab. (Be very detailed, using macromolecule terminology and your knowledge of cell structure. *Hint:* What membranes would need to be broken down and what are they made of?)

   The detergent helps break down the cell and nuclear membranes. The cell and nuclear membranes are made up of phospholipids. The detergent, like phospholipids, is made of two parts—heads that are attracted to water and tails that repel water. When cell membranes are exposed to detergents, the detergent interacts with the membranes, causing them to disassemble.

6. Why was the meat tenderizer used during the lab? Predict what the result could have been if this was not used.

   The meat tenderizer was a source of enzymes that break down proteins. The DNA in the nucleus of the cell is molded, folded, and protected by proteins. The enzymes in the tenderizer help separate the DNA from the proteins (histones). Without the meat tenderizer, strands of DNA might not emerge from the precipitate.

Handout 4.3

7. Why was the coffee filter used for filtering the mashed-up material?

   The filter was used to separate the small molecules, particularly DNA, from the large molecules and chunks of organic matter in the strawberry mixture. This may increase the amount of DNA you can isolate in the final steps.

8. What was the role of the alcohol?

   DNA is not soluble in alcohol. The alcohol helps separate the strands of DNA from the soapy filtrate. Also, because the DNA is not soluble in alcohol, it will precipitate in the alcohol, causing it to clump together so we can isolate it.

9. Describe the appearance of the nucleic acids at the end of the lab exercise.

   The DNA (and RNA) is long, stringy, and sticky. It looks a bit like mucus.

10. The DNA in a human cell has a mass of approximately 6.0×10^{-12} grams. Calculate how many human cells you would need to use to extract 1 mg of DNA. Show your work.

    $1\text{ mg} = 0.001\text{g} = 1.0 \times 10^{-3}\text{ g}$

    $$\frac{1.0 \times 10^{-3}\text{ g} \times \text{cell}}{6.0 \times 10^{-12}\text{ g}} = 1.67 \times 10^{8}\text{ cells}\left(\text{or } 167\text{ million}\right)$$

Handout 4.3

PART 4: GUIDED INQUIRY

In this guided inquiry component of the lesson, students carry out the DNA extraction procedure again, this time modifying it based on a question of their choosing.

- Explain to students that they now have the opportunity to modify the procedure used in the strawberry lab to carry out their own version of the lab. You can direct students' attention to the sample ideas on the student handout shown on the next page. Students can also generate their own ideas for modifying the procedure.

UNIT 4

Taking It Further

Now that you've successfully extracted DNA, you're ready to experiment further by modifying the procedure we just used in the strawberry lab. Try these ideas or some of your own:

- Experiment with other DNA sources. Which source gives you the most DNA? How can you compare them?
- Experiment with different soaps and detergents. Do powdered soaps work as well as liquid detergents? How about shampoo or body scrub?
- Are there other effective ways of carrying out this experiment? Find out for yourself. Try leaving out a step or changing how much of a particular ingredient you use.

Working with a small group, write a few sentences to a paragraph describing how you plan to modify the procedure. Then get your teacher's approval before carrying out your procedure.

Handout 4.3

- Have students work in small groups to develop a plan for their lab. As instructed on the handout, students should present you with a written description of their plan for approval before they begin.
- If students wish to work with other DNA sources, the protocol provided for extracting DNA from strawberries can be used to extract DNA from other plant cells or animal cells. Some DNA sources that students could use for comparison to strawberries are bananas, apples, kiwifruit, or chicken liver. (*Note:* When working with other types of fruit, only the fleshy part of the fruit should be used. Students should discard any large seeds, skin, etc.)

EXTENDING THE LESSON

Once students have practiced the techniques and learned the rationales for the steps in a DNA extraction using strawberries, a great extension is to extract their own DNA from their cheek cells. For students, there is something powerful about being able to extract their own DNA and actually hold it and view it. There are many methods available online, such as the one at **https://www.biologycorner.com/worksheets/cheekcell.html**.

This extension does not necessarily need to be done directly after the strawberries lab; it could be done later as a good jumping-off point to the key concept of biotechnology at the end of this unit.

LESSON 4.4

Launch Lesson – Introduction to Gene Expression—Sickle Cell Anemia Case Study

OVERVIEW

LESSON DESCRIPTION

Part 1: Introduction to Sickle Cell Anemia and Gene Expression

In the first part of this lesson, students are introduced to the concepts and processes of transcription and translation as they explore the phenomenon of sickle cell anemia. A text, videos, and concept-mapping tools are used to help students begin to explore these topics.

Part 2: Decoding the Sickle Cell Mutation

Students connect the concepts introduced in Part 1. They revisit the topic of sickle cell disease by examining partial DNA sequences from a typical β-globin gene and a mutated β-globin gene. They then apply their understanding from Part 1 to transcribe the DNA into mRNA and translate the mRNA into the appropriate amino acid sequences.

CONTENT FOCUS

Students are introduced to the concepts of transcription and translation through a real-world context: sickle cell anemia. Students do not need any prior knowledge of gene expression before engaging in this lesson. They should make connections with prior knowledge about mutation and the importance of genetic variation from Unit 2: Evolution.

AREA OF FOCUS

- Emphasis on Analytical Reading and Writing

SUGGESTED TIMING

~60 minutes

HANDOUTS

- 4.4.A: Introduction to Gene Expression
- 4.4.B: Decoding the Sickle Cell Mutation

MATERIALS

- LCD projector, electronic whiteboard, or other technology to show online videos
- internet access to the following videos from the DNA Learning Center: "Sickle Cell" (0:58): **https://www.dnalc.org/resources/3d/17-sickle-cell.html**; "Transcription" (1:52): **https://www.dnalc.org/resources/3d/12-transcription-basic.html**; "Translation" (2:04): **https://www.dnalc.org/resources/3d/15-translation-basic.html**
- large poster paper and markers (optional)

UNIT 4

COURSE FRAMEWORK CONNECTIONS

Enduring Understandings	
▪ 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.	
Learning Objectives	**Essential Knowledge**
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 3.3.1** 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.
GEN 3.4(a) Describe how changes in DNA sequences may affect protein structure and function.	**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.

UNIT 4

PART 1: INTRODUCTION TO SICKLE CELL ANEMIA AND GENE EXPRESSION

In the first part of this launch lesson, students are introduced to the processes of transcription and translation through the phenomenon of the sickle cell anemia mutation in the *HBB* gene of Chromosome 11 in humans.

- First, have students read the short introductory text on sickle cell anemia at the top of **Handout 4.4.A: Introduction to Gene Expression**. After students have finished the reading, ask a few questions to motivate their thinking about this disease:
  - The text indicates that everyone has two copies of the gene for hemoglobin production. Where do these two copies come from?

    One copy comes from the biological mother and one from the biological father. Humans receive one set of chromosomes from each parent.

  - What is hemoglobin's role in the body?

    It is a critical component of red blood cells that binds oxygen so oxygen can be transported throughout the body.

  - What happens when an individual has two copies of the sickle cell mutation?

    The individual will have the disease; their red blood cells will have a distorted (sickled) shape and have trouble binding hemoglobin.

  - If the sickle cell mutation can be deadly, how has it survived for thousands of years?

    People with only one copy of the gene do not have sickle cell disease. And the sickle cell genotype tends to help protect people from another deadly disease, malaria. Therefore, malaria acts as a selective pressure in this environment that favors sickle cell genotypes.

Guiding Student Thinking

Students should recall from middle school life science that they have two copies of each gene—one from each biological parent. Be sure to highlight this reminder as it will help prime their understanding of homologous chromosomes later in this unit. This is also a good opportunity for students to connect the concept of natural selection (see Unit 2: Evolution) to the concept of selective pressures in the environment, such as malaria, that lead to genotype frequencies, such as heterozygosity for sickle cell.

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- Now that students have some background information on sickle cell anemia, show the DNA Learning Center's sickle cell video (**https://www.dnalc.org/resources/3d/17-sickle-cell.html**). This will not only help students visualize the physical deformity of the red blood cells but will also introduce the idea that just one simple mutation in the DNA sequence is responsible for this disease. This should leave students wondering how mutations in DNA result in changes in amino acids.
- Now show students two more videos from the DNA Learning Center. The first is "Transcription (Basic)" (**https://www.dnalc.org/resources/3d/12-transcription-basic.html),** followed by "Translation (Basic)" (**https://www.dnalc.org/resources/3d/15-translation-basic.html**). As students watch the videos, ask them to draw flow charts for each process, based on information from the video. You will most likely need to replay the videos at least twice in order for students to adequately diagram the steps. They can record their flow charts in the space provided on Handout 4.4.A.
- After both videos have been shown and students feel they have captured both processes, have them work in groups of three or four to share their flow charts and make revisions. As a group, they should work to generate a consensus about the appropriate flow charts for both transcription and translation. As you circulate from group to group, ensure that students are illustrating each step in these processes appropriately as well as using accurate terminology.
- Finally, lead a whole-class discussion in which the class collaboratively generates a flow chart for each process. Have different student groups contribute by sharing portions of their work.

Classroom Ideas

If time allows, you may wish to have students create flow charts collaboratively in groups. Student groups could record their flow charts on large poster paper and conduct a gallery walk to examine other groups' ideas. They should then have time to revise their work based on any new ideas they generate from their gallery walk.

Meeting Learners' Needs

If students seem to struggle with the concepts for these processes, after the whole-class development of the concept maps, you can do a follow-up interactive game at **https://learn.genetics.utah.edu/content/basics/txtl/**. This game has students construct an mRNA strand and then select the appropriate amino acids for each codon. This can be done as a whole class or individually with personal devices or laptops.

UNIT 4

Instructional Rationale

Students often struggle to connect to concepts of transcription and translation since these are abstract processes in the cell. Allowing students to connect these concepts to a phenomenon such as sickle cell anemia provides a more engaging reason for them to further explore how transcription and translation influence what traits we see every day.

PART 2: DECODING THE SICKLE CELL MUTATION

In this second part of the lesson, students return to the phenomenon of sickle cell anemia and apply what they have learned about transcription and translation.

- To engage students in this next part of the investigation, have them examine the first table, Partial Sequence of Typical β-Globin Gene on **Handout 4.4.B: Decoding the Sickle Cell Mutation**. Ask students to first transcribe the partial DNA sequence given for the β-globin gene. Once students have determined the mRNA sequence, they should use the amino acid chart provided to list the appropriate amino acid sequence. Highlight for students that this is just a partial DNA sequence and that genes are typically several hundred base pairs long.
- Now, students should analyze and transcribe the sickle cell β-globin partial DNA sequence provided in the second table and translate it into the appropriate amino acids. Have them circle any differences they find between this version of the gene and the version they decoded in the first table.

PARTIAL SEQUENCE OF TYPICAL β-GLOBIN GENE

Partial DNA Sequence	TGAGGACTCCTC
mRNA Sequence	ACUCCUGAGGAG
Amino Acid Sequence	Thy–Pro–Glu–Glu

PARTIAL SEQUENCE OF SICKLE CELL β-GLOBIN GENE

Partial DNA Sequence	TGAGGACACCTC
mRNA Sequence	ACUCCUGUGGAG
Amino Acid Sequence	Thy–Pro–Val–Glu

Handout 4.4.B

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- Finally, either have students work in groups or lead a whole-class discussion on the following questions:
  - What mutation can result in someone having sickle-shaped blood cells instead of normal ones?

    A single nucleotide mutation from T to A, which causes the glutamine amino acid to be replaced by valine.

  - Why do biologists study changes in amino acid sequence when trying to determine causes of genetic variation?

    Amino acids are the building blocks of proteins. Proteins are required for the structure, function, and regulation of the body's tissues and organs. Therefore, if the structure of the proteins change, as amino acid building blocks change, it can impact the function of the protein—leading to genetic variation.

  - Are mutations in DNA sequences beneficial, detrimental, or both? Justify your answer with examples.

    Students should remember from Unit 2: Evolution that mutations in DNA are the source of genetic variation. At times this can be beneficial; for example, a mutation in fur color that allows organisms to better blend in with their environment is likely to decrease predation. As this lesson indicates, it is also beneficial to have one copy of the sickle cell mutation, as it decreases the chance of illness or death from malaria. On the other hand, mutations can be detrimental when they reduce an organism's fitness in its environment. Again, if a human has two copies of the sickle cell mutation, then they will have numerous physical ailments and a shortened life expectancy.

Meeting Learners' Needs
The processes and concepts associated with gene expression are complex, and students may need additional support before engaging in subsequent lessons that explore these processes more deeply. A helpful overview video that reinforces all the ideas presented in this lesson can be found at **https://www.youtube.com/watch?v=oefAI2x2CQM&t=317s**.

LESSON 4.5

Launch Lesson – Introduction to Meiosis Through Modeling

OVERVIEW

LESSON DESCRIPTION

Part 1: Modeling Meiosis I

In the first part of this lesson, students use their understanding of mitosis and a familiar procedure from Unit 3 to model meiosis I.

Part 2: Differentiating Between Mitosis and Meiosis

Students study a short video to confirm and/or revise their ideas and models from Part 1 and continue building the model by adding the phases of meiosis II. They finish with a peer-to-peer discussion and critique of each other's models.

CONTENT FOCUS

This launch lesson is designed to introduce students to the concept of meiosis by first eliciting their prior understanding of mitotic cell division from Unit 3: Cellular Systems. The goal is to engage students in a guided-inquiry-based modeling lesson that helps them construct their own ideas about what happens during each phase of meiosis and why each phase is necessary to form haploid gametes.

AREA OF FOCUS

- Attention to Modeling

SUGGESTED TIMING

~60 minutes

HANDOUTS

- 4.5.A: Building Chromosomes for Modeling Meiosis
- 4.5.B: Sketch and Summarize Meiosis I
- 4.5.C: Sketch and Summarize Meiosis II

MATERIALS

- LCD projector, electronic whiteboard, or other technology to show an online video
- internet access to the Amoeba Sisters' video "Meiosis (Updated)" (7:43), available at **https://www.youtube.com/watch?v=VzDMG7ke69g**
- neon dry-erase markers (for use on lab desks) or regular markers and large poster paper
- prepared set of pop beads (for each group)

UNIT 4

COURSE FRAMEWORK CONNECTIONS

Enduring Understandings	
▪ 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.	
Learning Objectives	**Essential Knowledge**
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 (2*N*) 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.

SETUP AND PREPARATION NOTES

- In a bag, include at least 300 beads of two different colors (150 for the maternal chromosomes and 150 for the paternal chromosomes) and 50 yellow beads (for the centromeres).
  Note: Bags should contain more beads than the students will use to save time having to replace missing beads during the lesson.
- Based on the quantities and colors of pop beads you have available, you can provide all students with the same color scheme (particularly for the two chromosomes) or you can create multiple color schemes (e.g., green/purple/yellow for some groups and blue/red/yellow for the others).
- If you don't have pop beads, you could use 2–3 different colored pony beads strung on pipe cleaners. You could also use colored popsicle sticks: cut them to two different lengths and draw a centromere on each stick.

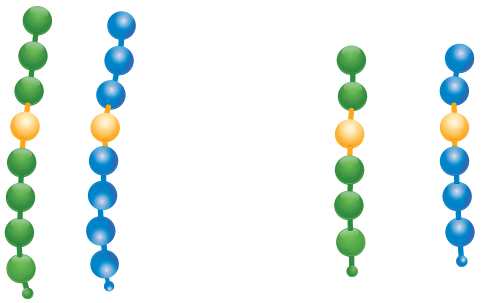
UNIT 4

PART 1: MODELING MEIOSIS I

In the first part of this launch lesson, students build on their prior knowledge of mitotic cell division from Unit 3: Cellular Systems to model the phases of meiosis I. This lesson mirrors Lesson 3.8: Modeling Mitosis, and students use knowledge only of mitosis phases to try to model and sketch meiosis I.

ELICITING PRIOR KNOWLEDGE OF CELL DIVISION

- To start, have students work in pairs and assign each pair a bead color for the paternal DNA and one for the maternal DNA. Ask students to record their bead colors in the key on **Handout 4.5.A: Building Chromosomes for Modeling Meiosis**.
- Students should then build homologous chromosomes for Chromosome 1 and Chromosome 2, as instructed on the handout. You may need to remind students to pay close attention to the details of the chromosomes since they are different sizes. When finished, students should have a model similar to the one below, depending on what bead colors they were assigned.



Example of a pop-bead model of homologous chromosomes prior to replication

- It is important to have students debrief about what the models represent. To do this, you can use the questions below, which revisit and build on topics discussed in Lesson 3.8.
  - The models of chromosomes represent just two human chromosomes. Why are there two chromosomes for each?

    Humans receive one set of chromosomes from their mother and one from their father. They are therefore referred to as 2*N* (*diploid*).

  - How does making a simplified model of these chromosomes "hide" some of the chromosomes' characteristics?

    These simplified models don't represent how the information these chromosomes are carrying could be different; that is, they may have different alleles.

- Human cells are referred to as diploid (2N), and the strawberries you used in the DNA extraction lab were octoploids (8N). Explain how these terms describe the differences in these organisms' genomes.

  This means that human somatic cells have two homologous chromosomes—one inherited from each parent. However, strawberry somatic cells have eight homologous chromosomes—four inherited from each parent.

- If potatoes are tetraploids (4N), what does that mean?

  They have sets of four chromosomes and receive two chromosomes from each parent plant.

- Prior to cellular division, what must happen to these homologous chromosomes? Why does this happen in mitosis?

  They are replicated during interphase so that at the end of mitosis each cell will have a complete set of chromosomes (46 chromosomes in each cell for humans).

- What would happen to cells if they simply split into two separate cells without any advance preparation for cellular division?

  There would not be a full set of genetic information (chromosomes) since the cell did not first replicate its DNA. Therefore, it would be missing vital genes necessary to carry out all the functions of the cell.

- Why is mitotic cellular division important?

  Mitotic division is important for cellular growth and repair. (Students do not yet have a formal understanding of mitotic division as a means of asexual reproduction.)

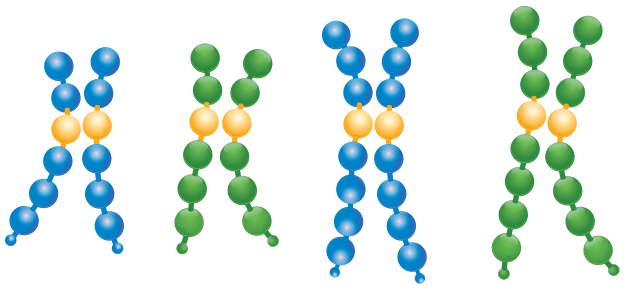
Meeting Learners' Needs
If students seem to struggle with the concepts they learned in Unit 3 for mitosis, you can do a quick review of the phases of mitosis on the board, with the students leading the discussion. You can also provide a terminology list on the board so students can see what should be included in their models as they move through each phase of division.

UNIT 4

Guiding Student Thinking

This is a good opportunity to have students think more deeply about homologous chromosomes since they often confuse them with sister chromatids. As students think through why human genomes are diploid, help them understand that a parent's two chromosomes carry alleles for the same genes, although the alleles may be different. You may want to contrast this with sister chromatids, which always have the same alleles since they are copies. Priming this understanding now helps students make connections to the importance of meiosis and gamete formation when they get to patterns of inheritance and work with Punnett squares and pedigrees later in this unit.

- Now that students have identified the need for replicating the cell's DNA, let the student pairs create the sister chromatids to their chromosome models. The results should look like the image below.



Example of a pop-bead model of homologous chromosomes with sister chromatids after replication

DEVELOPING A MODEL OF MEIOSIS I

Instructional Rationale

Often students are given the stages of meiosis and asked to simply fill in the diagrams based on their textbook or lecture notes. This lesson is designed to challenge students to first lean on their understanding of mitotic cell division stages to model meiosis I. It is okay that students will misrepresent some aspects of meiosis I at first. The process of comparing and then revising their model will provide a more lasting and deeper understanding of the differences between mitosis and meiosis. Having students translate their physical model (pop beads) into personal sketches helps them continue to visualize and reinforce the process of meiosis. This lesson is designed as an inquiry-based way to help students develop their own ideas about why meiosis is necessary and how it compares to the role of mitotic cell division. Engaging in critical thinking will help students develop more durable ideas about cellular division and its role in sustaining cellular systems and passing genetic material through sexual reproduction.

- Explain to students that they will be learning about a new type of cell division called meiosis, and that the first part of meiosis, meiosis I, is very similar to mitosis. Explain that they will use modeling to explore how meiosis I might work.
- Students will use their beads and additional provided materials (such as markers and large poster paper, or neon dry-erase markers and lab desks) to play with and revise a model. To guide students through this modeling process, use the following steps:
  - Students should start their models with interphase and the two chromosomes they just "replicated." They should use their markers to make a large version of the blank diagram from **Handout 4.5.B: Sketch and Summarize Meiosis I**; this will serve as a guide for their bead model.
  - To briefly introduce students to the concept of meiosis, play the Amoeba Sisters' "Meiosis (Updated)" video (**https://www.youtube.com/watch?v=VzDMG7ke69g**). Stop the video right after the end of the meiosis I explanation (5:22 minutes). At this point, show the video only once. Explain to students that they are not expected to have mastered the content yet.

Classroom Ideas
Students will be making a lot of revisions to their models during this lesson. Therefore, it is a good idea to have them work in pencil on their handouts and in neon dry-erase markers on lab tables for the actual modeling since both are easy to erase, allowing for revision as they gain new insights and understandings about meiosis.

  - Now allow students time to try to model the phases of meiosis I based on what they know of mitosis, what they recall from the video, and their own reasoning. Let students know that they will need to build more chromosomes to model the additional phases. (Keep in mind that at this point in the lesson students don't know meiosis well, so they will be largely basing their model on the phases of mitosis. They will revise their model in the next part of the lesson.)
  - Students should try to label the relevant parts of each cell on the diagram with the appropriate terminology as they move through each phase. This should include homologous chromosomes, sister chromatids, tetrad, centrioles, crossing-over, chiasma (optional), and spindle fibers.
  - As students are constructing their models, move from pair to pair checking for appropriate models and labeling of terminology.

Classroom Ideas
As students are developing their models, you can circulate around the room and help guide their thinking and development. For larger classes, it is often helpful to initial with your own marker next to the phases of the student models you have reviewed and provided feedback on. This will help you monitor what aspects of the model you've already seen for each group.

- Once students have completed their version of the model, they should sketch it on their handout. They should include the phase names and a brief description for each phase and label the sketches with the appropriate terminology from their models.
- It is important for students to synthesize their understanding at this point. Challenge student pairs to work together to answer the questions below or any additional questions you generate. They should use their models to support their answers.
  - Compare prophase 1 in meiosis to prophase in mitosis.

    In both processes sister chromatids form, but in meiosis homologous chromosomes align to form a tetrad where crossing-over can occur.
  - What is the benefit of crossing-over?

    Crossing-over increases the genetic diversity of the offspring produced, which is important for the long-term survival of a species.
  - Explain how the end products of meiosis 1 compare to the end products of mitosis.

    The end products of both have the same amount of DNA. But in mitosis, the sister chromatids separate and cell division is complete (2*n* daughter cells), whereas in meiosis the sister chromatids remain together and the tetrad of the homologous chromosomes separates in preparation for the next phase of the cell division process.

PART 2: DIFFERENTIATING BETWEEN MITOSIS AND MEIOSIS

Students continue to work in pairs for this next part of the lesson as they examine how mitosis and meiosis are different types of cellular division that serve different purposes. First, they work to answer some questions that should motivate their thinking about why meiosis is necessary. Then they watch a short video to confirm their understanding. Finally, they apply their understanding as they model meiosis II and make revisions to their meiosis I model based on their new information.

COMPARING MITOSIS AND MEIOSIS

- Before students launch into modeling meiosis II, it is a good idea to remind them of some of the concepts from the beginning of the video in Part 1 of the lesson. This will help drive their understanding of the need for meiosis II to occur. Have student pairs think about and answer the following questions:

- Humans are formed through the fusion of two gametes (sperm and egg). How many chromosomes should a sperm and an egg each have in order to form a healthy human zygote?

  Each gamete would need 23 chromosomes so the zygote that forms from fertilization has 46 total chromosomes.

- Meiosis is a type of cellular division that results in gametes (sperm or eggs, depending on the sex of the organism). Assuming your model is correct, does your model represent the complete process of meiosis from beginning to end? Explain your answer.

  No, the process in my model would not result in a reduction of chromosome number from 46 to 23. Therefore, this cannot be the complete process required for gamete formation.

Meeting Learners' Needs

If students struggle to answer these questions, replay the beginning of the video and challenge them again to answer these questions on their own. Then capture this information on the board for the whole class to see so that they can visualize human ploidy numbers for somatic cells and gametes.

Guiding Student Thinking

Students often have misconceptions about what percentage of their DNA is from each parent. This is a good opportunity to reinforce the idea that 50 percent of their chromosomes (23 of their 46 chromosomes) are from their biological father and 50 percent of their chromosomes (the remaining 23 chromosomes) are from their biological mother. Once students think through the fact that each gamete must have only half the DNA of a somatic cell, they should begin to reason that meiosis, as shown in their model, is not complete; another round of cell division is needed. However, students do not need to be rushed to this conclusion quite yet.

- Now students will watch the remaining part of the video (starting at 5:22 minutes) to confirm their reasoning about meiosis and check their original work from the Part 1 modeling activity. If you feel students could use a full review, you can show the video from the beginning.
- After they watch the rest of the video, allow students to use the chromosomes they modeled for meiosis I in the first part of the lesson to complete the model for meiosis II. Again, have them draw a guide for their model on the lab desk or poster paper; this time, they should use **Handout 4.5.C: Sketch and Summarize Meiosis II**.

UNIT 4

- Again, circulate around the room and provide feedback to students on their models and the labeling of each phase.
- Once student pairs finish their modeling of meiosis II, have them draw their model on the handout, with appropriate labeling and descriptions.

REVISING MEIOSIS MODELS

- Once all pairs are finished with their models and sketches, replay the entire video. As students watch the video, they should revise their sketches and labels for both meiosis I and meiosis II. Ask students to also add any new terms or ideas they hear in the video that they did not include in their original sketches.
- Finally, have each student pair partner with another pair to form a larger group. The groups should engage in a peer-to-peer critique of each other's models and labels. Have groups work together to reach a consensus on their sketches and the appropriate labeling. They should then work together to answer this final analysis question:
  - How do the end products of mitosis, as compared to the end products of meiosis, give insight into their role in biological systems (such as organisms and ecosystems)? Use your models to justify your answer.

Meeting Learners' Needs

While the video will confirm students' thoughts and labeling on their models and handouts or help with revising them, it will also introduce some new concepts and terminology. If students have trouble working with these new concepts and terms, you can stop the video at the moment they are introduced and keep a running list on the board. Students can then reference this list to make sure they have included each term.

Guiding Student Thinking

Students should see that the end products of mitosis, two diploid somatic cells, support an organism's need to grow and repair damaged or aging cells. The end products of meiosis—four haploid gamete cells—support an organism's ability to sexually reproduce. This is important, as it is a source of genetic variation in the ecosystem. Help students make connections to ideas from Unit 2: Evolution about how genetic variation is one of the underlying principles of the process of natural selection.

LESSON 4.6

UNIT 4

Analyzing Shark Reproduction Strategies

OVERVIEW

LESSON DESCRIPTION

Part 1: Investigating Shark Parentage
Students answer the question "How do we determine parentage?" by engaging in close observation and analysis of data about shark genotypes in F1 and F2 generations of a population.

Part 2: Analytical Reading on Parthenogenesis
Students analyze an extended passage to extract the necessary background information about parthenogenesis. They then use this information to revise their analysis from Part 1.

Part 3: Applying Understanding of Parthenogenesis
Students apply their understanding of reproductive strategies as they analyze a new data set of zebra shark genotypes for an F1 and F2 generation. They then use the data to make a claim about the parentage and the reproductive methods.

This lesson is based on "Did I Have a Daddy? A Parthenogenic Problem," from our partners at **https://www.xy-zoo.com/xy-zoo-parthenogenic**. Special thanks to Jason Crean and coauthors for use of these materials.

AREA OF FOCUS

- Emphasis on Analytical Reading and Writing

SUGGESTED TIMING

~90 minutes

HANDOUTS

- 4.6.A: Investigating Shark Parentage
- 4.6.B: Exploring Parthenogenesis
- 4.6.C: Applying Understanding of Parthenogenesis
- 4.6.D: Additional Copies of Data Tables for Analysis

MATERIALS

- markers or colored pencils (optional)
- large poster paper (optional)

CONTENT FOCUS

Students should have a basic understanding of the difference between sexual and asexual reproduction as well as the idea of "paired alleles" in diploid cells. This lesson reinforces concepts of cell division and meiosis to support students in thinking about the division of homologous chromosomes and random assortment in gametes. Students also use their understanding of evolutionary principles, such as adaptation, to examine how each reproductive strategy has costs and benefits to the population.

UNIT 4

COURSE FRAMEWORK CONNECTIONS

Enduring Understandings	
▪ Organisms have diverse strategies for passing their genetic material on to the next generation.	
Learning Objectives	**Essential Knowledge**
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. **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.

UNIT 4

PART 1: INVESTIGATING SHARK PARENTAGE

In the first part of this lesson, students are challenged to answer the question "How do we determine parentage?" To answer, they engage in close observation and analysis of data about shark genotypes in F1 and F2 generations of a population.

- To introduce the context of the investigation, have students read the brief introductory text on **Handout 4.6.A: Investigating Shark Parentage** describing the work of breeding programs at zoos and aquariums. After students have finished reading this opening text, introduce them to the question that will guide this initial part of the investigation: *How do we determine parentage*?
- Students then examine the context and data on the handout in preparation for their initial investigation. They will analyze data from shark offspring at the Shedd Aquarium and make a claim about the parentage of the F2 generation. Make sure students carefully read the context as it contains valuable information that will help orient them to the data.
- Have students individually spend some time closely observing the data. It is important that they are well oriented to the data set before getting into the deeper analysis questions about parentage. To help students get to know the data, use questions such as the following:
  - If we were looking at human data, where would each of the two alleles come from?

    One of the two alleles would come from the mother; the other would come from the father.
  - What does heterozygous mean?

    The individual possesses two different alleles for the gene.
  - What does homozygous mean?

    The individual possesses two of the same alleles for the gene.
  - Find an example of a gene where all the individuals in the F1 generation have a heterozygous genotype.

    Answers could include Gene 1, Gene 5, and Gene 7.
  - Find one example of a homozygous genotype for an individual in the F1 generation.

    Answers will vary, but some examples include Gene 2 for Pong and Gene 6 for Jaws.

Classroom Ideas

For some students, it may be difficult to work with the abundance of numbers in the table. Some students may find it easier to use different colored markers or pencils to circle potential alleles of the parents. If so, they may need several additional copies of the table. You can find these on **Handout 4.6.D: Additional Copies of Data Tables for Analysis**.

UNIT 4

Instructional Rationale

This lesson is designed to introduce students to the concept of parthenogenesis through an inquiry-based investigation. Therefore, it is important to give students time to deeply analyze the data on their own. Challenge student groups to work together to answer the questions based on the reading and data rather than providing the answers for them.

- Next, students work in small groups to begin the investigation on parentage under the "Making Sense of the Data" heading on Handout 4.6.A. They will work together to answer two questions about each new shark's parentage: "Who is the mother?" and "Is Jaws the father?" A table is provided for students to record their results and give evidence to support their claims. Students then briefly reflect on the data in follow-up questions. Sample responses are shown below.

F2 Individual	Mother	Evidence from Data	Is Jaws the Father? (Yes or No)	Evidence from Data
Quinn	SF97-02 Pong	She shares an allele for every gene with this shark pup. Also, for Gene 5, Pong is the only shark in the F1 generation with the 313 allele.	No	Jaws does not share alleles for every gene with Quinn. Alleles that he does not share with Quinn are those for Genes 2, 4, 5, and 7.
Grace	SF03-06 Yang	She shares an allele for every gene with this shark pup. Also, Yang is the only shark that shares alleles for Genes 5 and 7 with Grace.	No	Jaws does not share alleles for every gene with Grace. Specifically, he does not share allele matches for Genes 1 through 5.
Ariel	SF97-02 Pong	She shares an allele for every gene with this shark pup. Also, Pong is the only female to share the alleles Ariel has for Genes 1, 4, 5, and 7.	No	Jaws does not share alleles for every gene with Ariel. In fact, the two do not share any alleles for these genes.

1. Based on the data, for which F2 offspring was Jaws the father?

   None

2. Write two questions that came up in your group discussion regarding these shark data.

   Questions will vary, but students may wonder who the father is, why all the F2 offspring are female, or why all the F2 offspring are homozygous for each gene.

Handout 4.6.A

- Finally, as directed on the handout, students will construct a pairing of a scientific claim about the sharks' parentage with appropriate evidence from the data. Then they will share their work with their group. The group should then work together to revise their claims and evidence. Sample responses are shown below.

Claim: We determine parentage by looking at alleles. We compare alleles of offspring to those of possible parents to see which alleles they share. Individuals can be a parent–child match only if they share an allele for every gene.

Evidence: When examining the possible parents of each member of the F2 generation, we found one female shark that shared at least one allele for each of the seven genes. For example, Pong is the mother of Quinn because she is the only female in the F1 generation that shares at least one allele for each gene with Quinn. Jaws was not the father since he did not match at least one allele for each gene with any of the F2 offspring.

Handout 4.6.A

Guiding Student Thinking

The key takeaway for this part of the lesson is for students to see that we determine parentage by looking at alleles. We compare alleles of offspring to those of possible parents to see which alleles they share. Individuals can be a parent–child match only if they share an allele for every gene. Therefore, students should begin to wonder why there were no matches with Jaws for the F2 generation offspring.

- After groups have completed this first part of the investigation, lead a whole-class debrief on their findings. Be sure to allow plenty of time for students to share the data they used as evidence to support their claims of parentage.

  Also encourage students to share the questions their team had about the data. Students may have noticed and found it unusual that all the F2 individuals are female and homozygous for each gene. Validate students in asking these questions and encourage them to consider answers, but it is not necessary for students to draw conclusions at this point. Some students may correctly suggest that asexual reproduction is involved. You can explain to the class that these questions and ideas will be explored in Part 2.

UNIT 4

PART 2: ANALYTICAL READING ON PARTHENOGENESIS

In this part of the lesson, students engage with an extended passage that requires close analytical reading in order to extract relevant information about parthenogenesis. They then use this information to revise their analysis from Part 1.

- Before students begin the reading, remind them to use annotation strategies such as underlining key concepts, boxing key vocabulary words, and circling words they don't know to help them extract important information from the text. Students should rephrase key concepts in their own words in the My Notes section on the handout.
- You may want to lead a quick debrief on the reading to help define words students did not know and to ensure students captured the overall key concepts in their notes.
- Now have students begin the reading on **Handout 4.6.B: Exploring Parthenogenesis**. Once students have completed the reading, they should work in small groups to answer two question sets.
  - The "Check Your Understanding of Parthenogenesis" question set guides students to summarize and analyze what they learned from the reading about parthenogenesis.
  - Using the "Reexamining the Shark Data" question set, students will revisit the data from Part 1 through the lens of their new knowledge about parthenogenesis.
- Regroup with students once again and have individual group members report on their ideas and solutions to the question sets. Sample responses to both question sets are provided for reference, starting on the next page.

Meeting Learners' Needs
If students are likely to struggle with reading the text independently, you could break after each example in the reading to debrief with students about any words, phrases, or sentences they may have struggled with. This is also a good time to generate a list of key concepts as a class that students can then record in the My Notes section on the handout.

UNIT 4

Check Your Understanding of Parthenogenesis

1. Why is parthenogenesis considered an adaptation?

   It allows the species to survive when there are few or no males. The females that are able to reproduce without males are more likely to pass along their genes than those that cannot reproduce in this way, so their genes become more frequent in the gene pool.

2. What is a disadvantage to parthenogenesis?

   For some species, such as some sharks, it decreases the diversity of alleles in the gene pool. This can make the population more susceptible to disease and environmental changes. It also produces a population that is all female with no males.

3. Which species discussed above can reproduce through either sexual or asexual means? How does having those reproductive options benefit those species?

   Komodo dragons and sharks. If isolated for a period of time, they can produce offspring asexually without requiring a mate.

Reexamining the Shark Data

1. Look again at the F2 shark pups in the data table. What do all the F2 individuals have in common?

   They are all female and all of their genotypes are homozygous.

2. Now consider the following piece of information: at the Shedd Aquarium, Jaws was the only male in the F1 generation at the time the shark pups were produced.

   Based on this information and your answer to the previous question, what can you conclude about how the F2 generation was produced? Provide evidence to support your answer.

   The F2 generation was produced asexually, by parthenogenesis. Evidence for this is that there was no genetic input from the only male, all offspring are female, and each offspring has two copies of the same allele shared with the mother.

Handout 4.6.B

UNIT 4

3. Draw a flow chart on the left that shows the major reproductive steps in producing the F1 generation of sharks. Then, on the right, draw a flow chart showing the reproductive steps you think occurred in order to produce the F2 generation.

Reproductive Steps for F1 Generation	Reproductive Steps for F2 Generation
Female eggs and male sperm (gametes) are created as genetic material is divided in half by meiosis ↓ Male mates with female ↓ Female's eggs are fertilized with male sperm; fertilized eggs divide through mitosis ↓ The developing zygote has 50% of genetic material from the female parent and 50% from the male parent ↓ Eggs are laid ↓ Eggs develop into shark pups with 50% of their genes from the mom and 50% from the dad	Female eggs (gametes) are created as genetic material is divided in half by meiosis ↓ Female's eggs double their genetic material and divide ↓ Egg cells combine and divide through mitosis ↓ The developing zygote has 100% of genetic material from one female parent ↓ Eggs are laid ↓ Eggs develop into shark pups with 100% of their genes from the mom

4. If the reproductive trend seen in the F2 generation continues, what could this trend do to the gene pool over time?

   There will be fewer alleles in the gene pool and most individuals will be closely related to each other. Over time, this lack of genetic diversity can produce organisms that are more susceptible to disease and environmental change.

Handout 4.6.B

Guiding Student Thinking

The whole-class discussion is a great opportunity to revisit a common misconception students often hold about where organisms get their DNA. Many students might not fully understand that through the process of meiosis and sexual reproduction, they receive 50% of their DNA from a biological mother and 50% from a biological father. It is also a nice opportunity to revisit concepts from Unit 2: Evolution about how asexual reproductive strategies affect species: they may benefit species who do not come into contact with mates very often, but they also reduce the genetic variation of the gene pool, and therefore adaptation to any changes in the environment may be limited for offspring of asexual reproduction.

PART 3: APPLYING UNDERSTANDING OF PARTHENOGENESIS

Students now have an opportunity to apply their understanding of reproductive strategies as they analyze a new data set about zebra shark offspring from the Shedd Aquarium. See **Handout 4.6.C: Applying Understanding of Parthenogenesis** for the student task.

- Students should again work in groups to determine the parentage for each F2 offspring and predict whether the offspring was produced through sexual or asexual reproduction. Once the data table for parentage and reproductive methods is complete, students should work as a group to answer the final set of analysis questions.
- Once all groups are finished with their data analysis and the corresponding questions, they will merge with another student group. They should engage in peer-to-peer dialogue and review each other's analyses. Then they should work as a larger group to develop a consensus on their solution and revise their work based on this discussion.
- Finally, lead a whole-class discussion on the solutions to the data table and on the importance of and process for determining parentage, relatedness, and genetic diversity within a population.

Classroom Ideas

Students could record their populated data table from the analysis on large poster paper. Groups could then do a gallery walk to examine all groups' data prior to combining with another group to discuss and refine their own ideas and solutions.

UNIT 4

1. Use the data on the previous page to complete the table below. You will determine (1) what reproductive strategy produced each F2 offspring and (2) the parentage of each.

DETERMINING F2 GENERATION ZEBRA SHARK PARENTAGE

ID Number	Reproduction Strategy (Sexual or Asexual)	Mother ID Number	Father ID Number
SF-0419	Sexual	SF-0393	SF-0346
SF-0420	Sexual	SF-0393	SF-0254 & SF-0346
SF-0421	Sexual	SF-0393	SF-0254
SF-0425	Sexual	SF-0393	SF-0254 or SF-0346
SF-0277	Sexual	SF-0393	SF-0056
SF-0534	Sexual	SF-0393	SF-0254 or SF-0346
SF-0538	Sexual	SF-0394	SF-0254
SF-0951	Asexual	SF-0565	None

2. (a) What was the most common form of reproduction used to produce the F2 generation?

Sexual

(b) Use the data from the table on the previous page to explain how you arrived at your answer for part (a).

Most of the individuals have heterozygous genotypes, which means they most likely received alleles from two different parents.

(c) How could this form of reproduction be an advantage over parthenogenesis?

There is more genetic diversity in the population. Therefore, the population is less susceptible to environmental changes and disease.

Handout 4.6.C

(d) Propose a hypothesis for why some offspring may be produced through sexual reproduction and others may not.

Answers will vary. Students may state that females may produce offspring asexually in the absence of a male, especially for a long period of time, or when a male is unable to reproduce.

3. Which individual(s) was/were produced through asexual means? Justify your answer using evidence from the data.

SF-0951. All of the genes are homozygous and no males have allele 300 for Gene 5 or allele 160 for Gene 6.

4. (a) For which individuals was the paternity not able to be determined?

SF-0420, SF-0425, and SF-0534

(b) Explain why there is not clear paternity based on the data you analyzed.

There was more than one male that shared the alleles with the offspring and mother.

(c) For those with questionable paternity, what additional data would you need to make a reliable conclusion?

Additional alleles from other genes would need to be observed until one could be found that was different between the two possible fathers.

5. Shark pup SF-0951 died relatively shortly after birth. Write a claim that could explain this.

Shark pups that are produced through asexual reproduction may be less healthy than others due to decreased genetic diversity.

6. Explain why breeding programs, like the Shedd Aquarium's, are interested in determining if inbreeding and parthenogenesis are occurring in their shark populations.

Students should highlight that both inbreeding and parthenogenesis reduce genetic diversity and the gene pool. Therefore, breeding programs try to ensure that related organisms are not placed in the same tanks and that female sharks are not isolated from males for a long time.

Handout 4.6.C

UNIT 4

EXTENDING THE LESSON

As an optional extension to this lesson, or as a take-home homework assignment, students could design a plan to breed the F2 zebra sharks from their last data set in Part 3 of the lesson. Though sexes of the shark pups were unknown in the data table, they should list their top candidates for future breeding based on the available data. Challenge them to answer the following questions in their breeding plan:

- Which individuals would you breed?
- Who would you pair with whom?

Student answers will vary. However, SF-0538 should be selected as it is less related to all the others than they are to each other. Those with unknown paternity should not be bred. F2 offspring produced by male SF-0056 may be better choices to breed with SF-0538 to maintain genetic diversity in the next generation.

LESSON 4.7

Launch Lesson – Exploring Mendelian Inheritance Patterns

OVERVIEW

LESSON DESCRIPTION

Part 1: Investigating Pea Plants and Mendelian Genetics

Students gain important background information about Mendel's work and investigate key terms in genetics.

Part 2: Modeling Mendelian Inheritance Patterns in Pigeons

Students use pop beads to model two Mendelian traits seen in pigeons by first constructing the chromosomes using pop beads and then conducting two monohybrid crosses to determine the probability of each phenotype and genotype.

Part 3: Extension

To extend this lesson, student pairs could use their model to conduct a dihybrid cross.

This lesson is based on materials from the website "Pigeon Breeding: Genetics at Work," from the University of Utah's Genetic Science Learning Center. **http://learn.genetics.utah.edu/content/pigeons**.

CONTENT FOCUS

This launch lesson is designed to introduce students to the concept of Mendelian inheritance patterns. This should be a first exposure experience for students, so it is best if they have had no introduction to Mendel's work. Students may be familiar with concepts of phenotype and genotype, but this lesson deepens and extends their understanding as they use those concepts to model a real-world scenario (pigeon inheritance). First, students develop a working knowledge of the key

AREAS OF FOCUS

- Attention to Modeling
- Emphasis on Analytical Reading and Writing

SUGGESTED TIMING

~60 minutes

HANDOUTS

- 4.7.A: Exploring Mendelian Inheritance Patterns
- 4.7.B: Punnett Square Templates
- 4.7.C: Two-Factor Cross with Two Punnett Squares

MATERIALS

- LCD projector, electronic whiteboard, or other technology for displaying photos and an online video to students
- six different colors of pop beads
- internet access to the video at **https://ed.ted.com/lessons/how-mendel-s-pea-plants-helped-us-understand-genetics-hortensia-jimenez-diaz** and to visit **http://learn.genetics.utah.edu/content/pigeons/**

UNIT 4

terms associated with Mendel's principles of inheritance. Next, they apply these new concepts as they use pop beads to model two Mendelian traits seen in pigeons. This lesson prepares students for subsequent lessons on Mendel's laws of inheritance.

COURSE FRAMEWORK CONNECTIONS

Enduring Understandings	
▪ 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.	
Learning Objectives	**Essential Knowledge**
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.

SETUP AND PREPARATION NOTES

- Prepared sets of pop beads (for each student):
  - Include two different main colors of beads (11 beads of one color for the shorter chromosome and 15 beads of another color for the longer chromosome).
  - Include 2 secondary colors of beads to represent the *recessive red* or the *grouse* alleles.
  - Include 4 yellow beads to represent the centromere regions of the chromosomes.
- You can distribute the beads in the way that works best for your classroom. For example:
  - Give each student a bag with the exact number of pop beads they will need.
  - Give a group of two students a bag with more than enough pop beads of each color.
  - You can sort pop beads by color into large plastic bags and keep them in a central location for students to retrieve as needed.

UNIT 4

PART 1: INVESTIGATING PEA PLANTS AND MENDELIAN GENETICS

This launch lesson is designed to introduce students to Mendelian inheritance patterns. In Part 1 of the lesson, students gain important background information about Mendel's work and investigate key terms in Mendelian genetics.

- To begin, have students read the opening text on **Handout 4.7.A: Exploring Mendelian Inheritance Patterns**, which provides a brief introduction to Mendel and his work with pea plants. Students should also review the table of key terms, which they will need to fill in during the next part of the lesson. These terms are important for students to have in their working vocabulary to fully understand Mendel's three key principles: the law of dominance, the law of segregation, and the law of independent assortment.
- Next, have students watch the TedEd video on Mendelian inheritance (3:06 minutes), which can be accessed at the following link: **https://ed.ted.com/lessons/how-mendel-s-pea-plants-helped-us-understand-genetics-hortensia-jimenez-diaz**. Before you play the video, ask students to listen closely for information that they can use to fill in their table of key terms. You may need to play the video a few times for them to be able to write down all the important information.

Classroom Ideas
It is a good idea to recommend that students use pencils for this lesson because they will most likely need to revise their table of key terms throughout the lesson.

- After students have had ample opportunities to identify important information from the video, lead a whole-class discussion about the key terms and invite students to share what they learned.
- Next, display the table below for the whole class to see.

Type of Trait	Seed Shape	Seed Color
Dominant Trait	 Round	 Yellow
Recessive Trait	 Wrinkled	 Green

Meeting Learners' Needs
The chart of pea traits is a simplified list of traits Mendel examined. You may want to start with just one trait to support students in applying their terminology. Or, if you feel students have a grasp on the key terms, you can use a diagram with more of the traits he examined, such as flower height and position or pod color.

UNIT 4

Ask the following questions, referencing the table:

- If we use the letter *R* to represent seed shape, what is the genotype for a heterozygous individual? What is that individual's phenotype?

  Rr; round

- If we use the letter *Y* for seed color, what is the genotype of a green pea?

  yy (both lowercase)

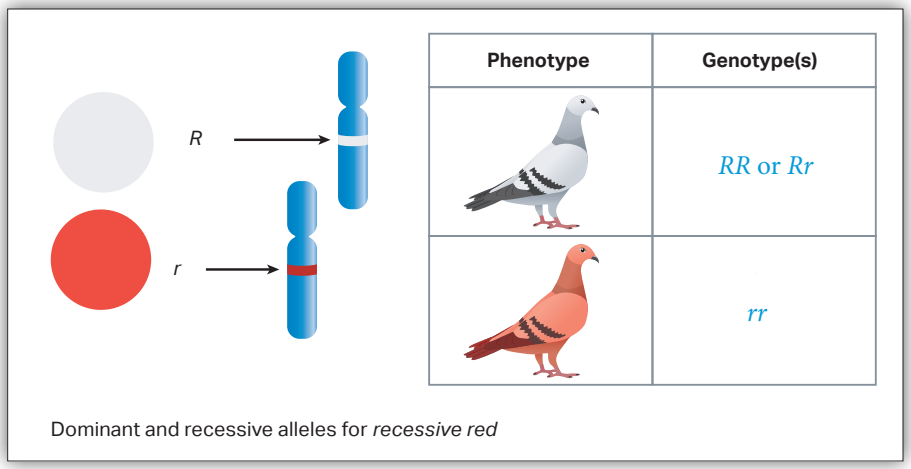
- What are all the possible genotypes for a round, yellow pea phenotype?

  RRYY, RRYy, RrYY, RrYy

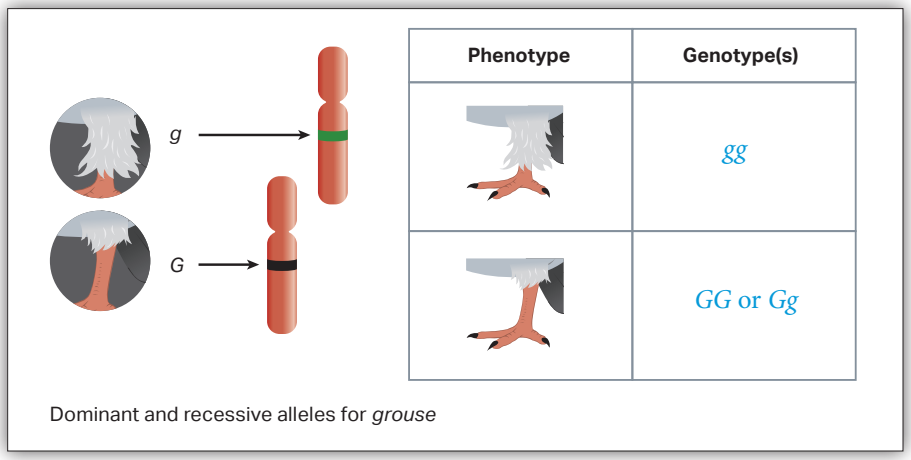
PART 2: MODELING MENDELIAN INHERITANCE PATTERNS IN PIGEONS

In this part of the lesson, students use pop beads to model two Mendelian traits seen in pigeons. Students first construct the chromosomes using pop beads and then conduct two monohybrid crosses to determine the probability of each phenotype and genotype. Students will likely need to reference the key terms they explored in Part 1 throughout Part 2.

- First, have students read the background information under Part 2 of Handout 4.7.A about the *recessive red* and *grouse* genes in pigeons. Students have most likely never seen these variations of pigeon traits, so it may be necessary to show them the *recessive red* and *grouse* genes from the University of Utah's Learn Genetics site (**http://learn.genetics.utah.edu/content/pigeons/**). Click on these traits, and any other interesting pigeon traits, under the "Inherited Characteristics in Pigeons" heading on the right-hand side of the page; these will give pictures and information about the traits.
- Once students have had time to observe and think about these variations, have them fill in the possible genotypes for the two examples. Then lead a brief class discussion to ensure students were able to use the correct symbols for each trait and identify all possibilities for the phenotypes. Portions of the student handout with answers are included on the next page for your reference.



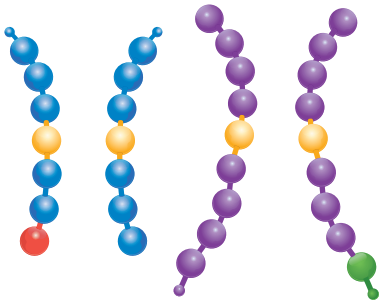
Dominant and recessive alleles for *recessive red*



Dominant and recessive alleles for *grouse*

Handout 4.7.A

- Have students work in pairs on Part 3 of Handout 4.7.A. Assign each student in the pair one of the two traits to be modeled.
- Next, identify the colors of pop beads that students should use and have them record this in the key on their handout. Students should then use the beads and the key to model chromosomes of a pigeon that is heterozygous for both traits (*RrGg*). An example of a student model is shown on the next page.



Examples of pop-bead model chromosomes

Guiding Student Thinking

Any time a student develops a model, they should be prompted to think through how choices and assumptions they make impact how they are representing the phenomenon under study. In this case, since students are not using a colored bead to represent the dominant alleles, it appears as though they don't exist on the chromosome. It is important to remind students that this simplified model is meant to highlight the presence of the recessive traits, but that the dominant alleles are still present on the chromosome. You can challenge students to think about other characteristics that are "hidden" in this model. For example, since they are using the same color beads for both homologous chromosomes, the model also hides what DNA is maternal versus what DNA is paternal.

- Once students have developed their chromosomes, have them work with a partner to conduct a monohybrid cross for each trait. (See step 2 at the top of the final page of Handout 4.7.A for the student instructions and **Handout 4.7.B: Punnett Square Templates** for the blank templates.) To help students visualize what the symbols used in Punnett squares represent, encourage them to line up their chromosomes along the Punnett square prior to filling it in.

Instructional Rationale

While students can learn how to do a monohybrid cross by simply filling in the letters, they often do not understand what those letters represent and why the Punnett square is an appropriate mathematical model to predict inheritance patterns in offspring. Creating the chromosomes can help remind students that those letters represent alleles, which are found on chromosomes, and that they are the products of meiosis. Modeling should help them visualize that chromosomes carry distinct versions of alleles that code for different genotypes and therefore phenotypes. Making these connections will prepare students to make sense of Mendel's three key principles of inheritance, rather than just memorizing them.

- Once all student pairs have completed their monohybrid crosses, have them develop a table that provides the expected outcomes for each phenotype and genotype (see step 3 at the top of the final page of Handout 4.7.A for the student instructions). Then they should work together to answer the analysis questions on the final page of Handout 4.7.A.
- Finally, after student pairs have completed the questions, lead a whole-class discussion to review the expected outcomes students reported in their tables as well as the key ideas of Mendelian inheritance represented in the analysis questions, shown below with sample responses.

ANALYSIS QUESTIONS

1. Examine the data in your Punnett squares. Write a ratio for the expected genotype outcomes (i.e., homozygous dominant : heterozygous : homozygous recessive) for both traits. Then, predict the percentage of offspring from this cross that can be expected to display the recessive red phenotype versus the wild type.

   Ratios are 1:2:1 with 75% of the offspring expected to be wild type and only 25% expected to be recessive red.

2. Describe how the Punnett square is a mathematical model for predicting outcomes of inheritance patterns. Use the results from your monohybrid crosses to support your answer.

   Punnett squares provide a way to represent the heritable combinations of alleles that are possible between two organisms. They predict mathematical probabilities for each genotype, and therefore phenotype.

3. Like humans, pigeons are diploid. Pigeons have 80 chromosomes ($2N = 80$). Explain why you had to create two chromosomes for each pigeon trait. Describe where these chromosomes come from and how many chromosomes each pigeon gamete would have.

   Like humans, pigeons carry two alleles for each of these traits since they are diploid. They inherit one allele from the female parent and one from the male parent. At the beginning of meiosis, homologous chromosomes pair up so that the process of meiosis ensures that each gamete receives only one copy of these chromosomes. Therefore, each gamete would have 40 chromosomes, so when fertilization occurs, the newly formed zygote has 80 chromosomes.

Handout 4.7.A

UNIT 4

PART 3: EXTENSION

Now that students have had an introduction to monohybrid crosses, a natural next step is to introduce a two-factor cross and Mendel's laws of independent assortment and segregation. Since students developed a model of a heterozygous individual for two traits in this lesson, they could then use that same genotype (and model chromosomes) to conduct a dihybrid cross with their student partner. Students can work through a two-factor cross using **Handout 4.7.C: Two-Factor Cross with Two Punnett Squares**.

UNIT 4

LESSON 4.8

Exploring Inheritance Patterns – Albinism

OVERVIEW

LESSON DESCRIPTION

Part 1: Exploring the Genetic Inheritance of Albinism

Students begin by discussing a short video clip that introduces the first case study: A Brazilian family in which some siblings show the albinism trait and others do not.

Part 2: Modeling Genetic Inheritance

Students read a second case study on albinism. Using information from the reading, they construct a pedigree and make claims about how the trait is inherited. Students also spend time engaging in peer review of their models.

Part 3: Investigating Claims About Genetic Inheritance

Students construct Punnett squares to investigate the validity of their claims about genetic inheritance of albinism.

This lesson is based on "Albinism: From Genotype to Phenotype" from our partners at **https://c7c25f2f-1385-421c-982b-00c5c52a4afc.filesusr.com/ugd/6f88e8_0a9e39bc1a4b4150946a926331060f72.pdf**. Special thanks to Jason Crean and coauthors for use of these materials.

AREAS OF FOCUS

- Emphasis on Analytical Reading and Writing
- Attention to Modeling

SUGGESTED TIMING

~90 minutes

HANDOUTS

- 4.8.A: Using Pedigrees to Model Albinism Inheritance
- 4.8.B: Using Punnett Squares to Predict Albinism Inheritance

MATERIALS

- LCD projector, electronic whiteboard, or other technology to show an online video
- internet access to the Barcroft TV video "My Albino Children" (4:26), available at **https://www.youtube.com/watch?v=awhQ6NT7LBAnandade-Andrade-Recife**
- large poster paper and sticky notes for feedback (optional)

CONTENT FOCUS

The focus of this lesson is on applying key concepts in genetics to real-world scenarios. Students will likely have some prior knowledge of genetic inheritance from middle school life science and should display a basic understanding of reproduction and processes of cellular division (i.e., mitosis and meiosis) from prior lessons. This lesson provides an opportunity for students to deepen their conceptual understanding of chromosomal genetics and mutations.

UNIT 4

COURSE FRAMEWORK CONNECTIONS

Enduring Understandings	
▪ Encoded in DNA is the heritable information responsible for synthesis of RNA, which makes gene expression possible. ▪ Models can be used to illustrate and predict the inheritance of traits.	
Learning Objectives	**Essential Knowledge**
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.

UNIT 4

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.

UNIT 4

PART 1: EXPLORING THE GENETIC INHERITANCE OF ALBINISM

In the first part of this lesson, students are introduced to a case study that investigates the inheritance of a rare trait called albinism. They watch a short video introducing a Brazilian family with six children, three of whom display albinism. Students then use their prior knowledge of genetic inheritance to engage in a whole-class analysis and discussion of this case.

- To begin, have students watch a short video introducing the first case study on the genetic inheritance of albinism (**https://www.youtube.com/watch?v=awhQ6NT7LBAnandade-Andrade-Recife**).
- Prompt students to think critically about the case by asking some of the following guiding questions:
  - Why might parents who do not show the trait of albinism have children who do?
  - Why might some siblings in a family show the trait of albinism while others do not?
  - How might we predict whether their next child will show the trait of albinism?
  - How might we predict whether one of the siblings will have children that show the trait of albinism?
  - How might we determine if albinism is an inherited or acquired trait?
  - How might we determine if the trait of albinism is dominant or recessive?
  - How might we determine if the trait of albinism is sex-linked?

Meeting Learners' Needs
You could also have students write individual questions on sticky notes about the following theme: *How can children with the same parents look so different?* You can then drive the whole-class discussion by identifying common themes in the student questions.

Guiding Student Thinking

As students share their answers to the guiding questions, it is a good opportunity to listen for continued misconceptions about inheritance of traits. Remind students that they get 50% of their chromosomes from their biological mothers and 50% from their biological fathers. While their siblings also receive those same percentages from their parents, they will not inherit the exact same chromosomes unless they are monozygotic (identical) twins.

UNIT 4

PART 2: MODELING GENETIC INHERITANCE

In this second part of the lesson, students read and analyze another case study on albinism. Using information from the case, they model the genetic inheritance of albinism over multiple generations by constructing a pedigree. To construct a pedigree for this case, students need to model family relationships, identify each person's phenotype for the trait of albinism, and predict each person's genotype for the trait of albinism. They then use this data to develop their understanding of autosomal traits that demonstrate Mendelian inheritance (dominant and recessive traits) and investigate how albinism may be passed to the next generation genetically even if it is not always displayed.

- To begin, have students pair up and read "Hidaya's Story" on **Handout 4.8.A: Using Pedigrees to Model Albinism Inheritance**. Encourage students to extract important information from the reading by recording their ideas about the potential genotype of individuals mentioned throughout the story.
- Next, student pairs should work together to construct a pedigree based on their notes. Some guidance for constructing the pedigree is provided on the handout. Students may want to draft their pedigree in pencil so it is easy to make changes.
- As you circulate among groups, you may want to prompt student thinking with the following questions:
  - Why is it important to identify each individual in the family and model their relationships?
  - Why is it helpful to track whether individuals in the family display the trait of albinism?
  - How might we predict the genotype of individuals in the family?
  - Why is it helpful to analyze multiple generations in one family when examining inheritance of a trait?

Meeting Learners' Needs
Some students may need a quick review of pedigrees and how to represent important information. If students are unfamiliar with pedigrees, you may want to do this part of the lesson as a class. You can have them write down all the family members that are mentioned in the story and how they are related to Hidaya and to each other. Students can then collaboratively construct a pedigree.

UNIT 4

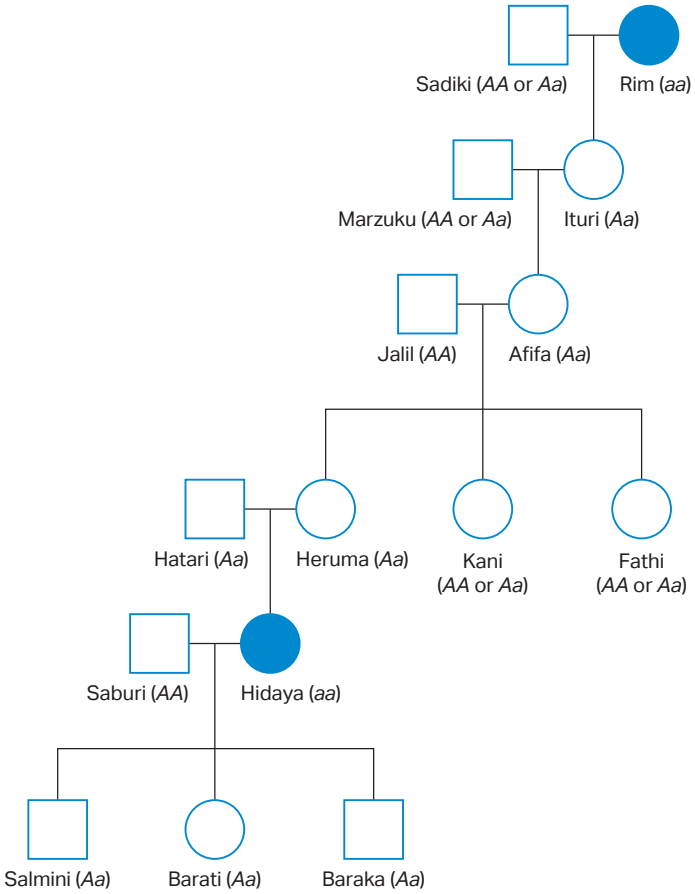
Guiding Student Thinking

Student will likely need help in making some assumptions so that they can build a model of inheritance from this story. For example, for individuals who indicate they have never had a case of albinism in their family, we will assume they are homozygous dominant. Therefore, it is important to remind students that every model is based on some assumptions that may be revised over time as new data emerge.

- After student pairs have had ample time to work, have them merge with another group (forming groups of four, if possible). Have groups compare their pedigrees and discuss possible patterns in the inheritance of albinism. Students should make any needed revisions to their own work based on their peer-to-peer critique and dialogue.
- Lead a whole-class discussion to construct a pedigree as a class. A sample pedigree is provided on the next page for reference. Then, invite student groups to share their observations about possible patterns in the inheritance of albinism. Ask students to consider how they might collect more evidence to support their observations. This will be the focus of the next part of this lesson.

Classroom Ideas

If appropriate, you may want your students to be more informed about the serious issue of violence against individuals with albinism. The CBS News story "African Children with Albinism Targeted by Poachers" introduces the dangers that African children with albinism commonly face and shows how some community leaders are working to help these children (**https://www.cbsnews.com/video/african-children-with-albinism-targeted-by-poachers/**).



Classroom Ideas

Instead of having student pairs merge to engage in peer review, you could also have students do a gallery walk and comment on all of the pedigrees. Students could transfer their pedigree to large poster paper so that it is easier to review. Assigning each group a different colored sticky note can be an easy way to keep track and assess how each group is completing the task of peer review.

PART 3: INVESTIGATING CLAIMS ABOUT GENETIC INHERITANCE

In Part 3 of the lesson, students analyze data using models (Punnett squares) to investigate their observations and claims about the possible patterns in inheritance of albinism in Hidaya's family. Students make scientific claims about whether albinism is a dominant or recessive trait and support their claims with evidence from their investigation.

- First, display the pedigree of Hidaya's family that the whole class generated in Part 2 of the lesson. Ask students the following guiding questions:
  - Based on the information in the pedigree, what possible claims can we make about the inheritance of albinism?

    The pedigree shows that this trait is recessive as the children can have the trait even if the parents do not (e.g., Hidaya has albinism but her parents do not). Pedigrees for autosomal traits typically show roughly equal percentages of males

and females with the trait. Hidaya's family pedigree only had two females with albinism. So, more data on either other families or additional generations would need to be collected.

- Why is it important to consider the genotypes of individuals in Hidaya's family and not just their phenotypes?

  Genotypes provide the most accurate information about what traits are available to pass on to the next generation. For example, in Mendelian traits, the phenotype doesn't reflect organisms that are heterozygous and are carriers of the recessive allele.

- Is there a way to investigate whether our predictions about genotypes are accurate?

  Using Punnett squares is a method for examining whether genotype predictions are accurate. Punnett square results can be compared to genotype data on the offspring of two individuals to help further support the conclusions about the genotype.

Meeting Learners' Needs
If your students do not come up with the idea of Punnett squares on their own, or if they have not seen Punnett squares, have them work on some practice problems together as a class or in small groups.

- Next, have students work in pairs to create Punnett squares and identify important information for each relationship in the pedigree. See **Handout 4.8.B: Using Punnett Squares to Predict Albinism Inheritance**.
- After students have had ample time to work, lead a whole-class discussion evaluating the possible claims about the inheritance of albinism based on evidence from their Punnett squares. The student handout with answers is shown on the next page for reference.

UNIT 4

Using Punnett Squares to Predict Albinism Inheritance

To gather evidence for your claims about the inheritance of albinism, use your understanding of Punnett squares to determine the following information about key relationships in Hidaya's family. (Use *A* to represent a dominant allele and *a* to represent a recessive allele. Circle any genotypes that produce the albinism phenotype.) Then, check that the results below are consistent with your pedigree and the text.

Gathering Evidence of Inheritance

1. **Heruma and Hatari:**

   Mother's genotype: *Aa* (heterozygous)

   Father's genotype: *Aa* (heterozygous)

   Offspring genotype %: 25% homozygous dominant, 50% heterozygous, 25% homozygous recessive (albinism)

   Offspring phenotype %: 75% no albinism, 25% albinism

	A	*a*
A	*AA*	*Aa*
a	*Aa*	*aa* (circled)

2. **Afifa and Jalil:**

   Mother's genotype: *Aa* (heterozygous)

   Father's genotype: *AA* (homozygous dominant)

   Offspring genotype %: 50% homozygous dominant, 50% heterozygous

   Offspring phenotype %: 100% no albinism

	A	*a*
A	*AA*	*Aa*
A	*AA*	*Aa*

3. **Rim and Sadiki:**

   Mother's genotype: *aa* (homozygous recessive)

   Father's genotype: *AA* (homozygous dominant)

   Offspring genotype %: 100% heterozygous

   Offspring phenotype %: 100% no albinism

	a	*a*
A	*Aa*	*Aa*
A	*Aa*	*Aa*

Handout 4.8.B

UNIT 4

4. **Hidaya and Saburi:**

Mother's genotype: aa (homozygous recessive)

Father's genotype: AA (homozygous dominant)

Offspring genotype %: 100% heterozygous

Offspring phenotype %: 100% no albinism

	a	a
A	Aa	Aa
A	Aa	Aa

Looking Ahead at Potential Inheritance

5. **Barati and her dark-skinned husband if he had no albinism in his family:**

Mother's genotype: Aa (heterozygous)

Father's genotype: AA (homozygous dominant)

Offspring genotype %: 50% homozygous dominant; 50% heterozygous

Offspring phenotype %: 100% no albinism

	A	a
A	AA	Aa
A	AA	Aa

6. **Baraka and his dark-skinned wife who had an albino father:**

Mother's genotype: Aa (heterozygous)

Father's genotype: Aa (heterozygous)

Offspring genotype %: 25% homozygous dominant, 50% heterozygous, 25% homozygous recessive (albinism)

Offspring phenotype %: 75% no albinism, 25% albinism

	A	a
A	AA	Aa
a	Aa	aa

Handout 4.8.B

- Finally, ask students to identify other questions they still have about the genetic cause and inheritance of albinism. Students may have difficulty constructing questions that reflect key concepts about genetic inheritance and that can be investigated. You can model this skill by constructing a few questions with the whole class to meet these criteria. Some questions could include:
  - What causes this condition to happen? Why/how are things passed to us from our parents?
  - Is albinism only genetic, or can it be caused by something else too?
  - Why/how does this condition affect hair and eyes too?
  - How are skin, hair, and eye color all related?

Instructional Rationale

By the end of this lesson, students should understand that albinism is an inherited autosomal recessive trait. They should also start to make connections to earlier topics on genetic mutations to help explain how this trait emerges in individuals. In the next lesson, students will take a closer look at specific mutations that result in different types of albinism.

LESSON 4.9

Albinism Investigation

OVERVIEW

LESSON DESCRIPTION

Part 1: Introduction to the Genetics of Albinism

Students are introduced to the importance of melanin and the genetics behind the mutations that lead to albinism.

Part 2: Analyzing DNA Sequences

Students analyze DNA sequences and mutations to make evidence-based claims about genetic causes of albinism.

This lesson is based on "Albinism: From Genotype to Phenotype" from our partners at **https://c7c25f2f-1385-421c-982b-00c5c52a4afc.filesusr.com/ugd/6f88e8_0a9e39bc1a4b4150946a926331060f72.pdf**. Special thanks to Jason Crean and coauthors for use of these materials.

CONTENT FOCUS

This investigation builds on the previous lesson, which introduced students to the type of inheritance pattern albinism demonstrates. This lesson extends their understanding by applying key concepts in genetics to an investigation of the relationship between genotype and phenotype of albinism. Students reinforce prior knowledge of transcribing and translating DNA sequences as they analyze DNA sequences of the four types of albinism. Students should already be familiar with different types of mutations (silent, missense, nonsense, and frameshift) from earlier in this unit.

AREA OF FOCUS

- Emphasis on Analytical Reading and Writing

SUGGESTED TIMING

~90 minutes

HANDOUTS

- 4.9.A: Albinism – From Genotype to Phenotype
- 4.9.B: Analyzing DNA Sequences
- 4.9.C: Phenotype and Amino Acid Sequence Cards, with cards cut out

MATERIALS

- LCD projector, electronic whiteboard, or other technology to show photos and an online video
- internet access to the TED-Ed video "The Science of Skin Color" (4:54), available at **https://www.ted.com/talks/angela_koine_flynn_the_science_of_skin_color**
- colored pencils or highlighters

UNIT 4

COURSE FRAMEWORK CONNECTIONS

Enduring Understandings	
▪ Encoded in DNA is the heritable information responsible for synthesis of RNA, which makes gene expression possible.	
Learning Objectives	**Essential Knowledge**
GEN 5.1(a) Explain the relationship between genotype and phenotype.	**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.
GEN 3.4(a) Describe how changes in DNA sequences may affect protein structure and function. **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.

UNIT 4

PART 1: INTRODUCTION TO THE GENETICS OF ALBINISM

In the first part of this lesson, students are introduced to the importance of melanin and the genetics behind the mutations that lead to the phenomenon of albinism introduced in Lesson 4.8: Exploring Inheritance Patterns – Albinism.

- Since students will be investigating the mutations that lead to albinism, it is first helpful to discuss what influences human skin color. To help students visualize and think about what influences skin color, they will watch the TED-Ed video "Science of Skin Color" (**www.ted.com/talks/angela_koine_flynn_the_science_of_skin_color**).
- Before watching the video, post the following questions on the board to guide students' note-taking as they watch the video.
  - What is responsible for the range of skin colors in humans?

    The type and amount of melanin in the skin.
  - What is the biological purpose of melanin?

    Melanin helps shield nuclear DNA from damage that can occur from UVB radiation, thereby preventing skin cancer.
  - How can melanin influence vitamin D production?

    Vitamin D synthesis is stimulated in the epidermis by UVB radiation from the sun. Therefore, melanin in the skin can reduce the amount of vitamin D that is synthesized.
  - How does natural selection influence the melanin in human populations?

    Populations that live close to the equator have high exposure to sunlight. Therefore, the greatest environmental pressure for skin color is on protection of nuclear DNA from UVB radiation. So, populations around the equator tend to be dark-skinned. In contrast, populations far from the equator receive very little sunlight. Therefore, the environmental pressure for synthesizing vitamin D leads to lighter-skinned populations.
- After the video, lead a whole-class debrief on the questions posed prior to the video. This short introduction to skin color helps students place the phenomenon of albinism in context. Later, students will use this initial information about the biological importance of melanin to revisit the topic of potential risks for people with albinism, discussed in the prior lesson.

UNIT 4

- Next, have students work together in groups of three or four. They should independently read the passage on **Handout 4.9.A: Albinism – From Genotype to Phenotype**, and then work with their group to fill in the table and answer the questions in Part 1 of the handout.
- After students have had ample time to work, invite them to share their findings in a whole-class discussion. Sample student responses are provided below for reference.

Meeting Learners' Needs
If students need more support with the reading, you could conduct this part of the lesson as a whole-class guided investigation. Or, if you have limited classroom time, you could have students complete Part 1 of the handout independently, outside of class.

Part 1: Introduction to the Genetics of Albinism

Fill in the table below using information from the reading.

Albinism Type	Skin Color	Hair Color	Iris Color	Gene Affected
OCA1	very pale	white	translucent	*TYR*
OCA2	creamy white	light-yellow, blond, or light-brown	light-colored	*OCA2; MC1R*
OCA3	reddish-brown	ginger or red	hazel or brown	*TYRP1*
OCA4	creamy white	light-yellow, blond, or light-brown	light-colored	*SLC45A2*

Use information from the video and the reading to answer the following questions.

1. What do all types of albinism have in common? Use the traits discussed in the reading as evidence.

   The mutation results in reduced amounts of melanin in the skin, hair, and eyes.

Handout 4.9.A

2. What is the function of the protein melanin? Explain its importance by citing evidence from the reading and the video.

   Melanin is a pigment in human skin and is responsible for variations in skin color. Melanin helps protect the nucleus of cells by blocking out harmful UVB radiation from the sun that can alter DNA (potentially leading to skin cancer).

3. Construct an explanation for why there are different variations of albinism and why it results in the same basic phenotype. Support your explanation with evidence from the text.

   Answers will vary, but they should indicate that all the mutations disrupt the natural production of melanin. For example, the text states, "These mutations disrupt the ability of cells to make melanin, which reduces pigmentation in the skin, hair, and eyes." Therefore, students should see that no matter what form of albinism is inherited, the resulting phenotype has reduced pigmentation.

4. Are any of the mutations more likely to be found in certain populations? Give an example.

   Yes, the type 3 form of albinism is primarily found in African populations.

Handout 4.9.A

Guiding Student Thinking

It might be helpful to extend the class discussion by having students recall other contexts in which pigment is important. In Unit 2: Evolution, students learned about Asian ladybug and California salamander populations that demonstrate pigment variations. This is a great opportunity to connect to students' prior knowledge about how variation in pigment affects chances of survival based on environmental conditions.

PART 2: ANALYZING DNA SEQUENCES

In this part of the lesson, students analyze DNA sequences and mutations to make evidence-based claims about genetic causes of albinism.

- To begin, each member of the group will investigate one of four sets of DNA sequences provided. See **Handout 4.9.B: Analyzing DNA Sequences** for the sets of sequences. Each set includes a DNA sequence from a gene associated with albinism and three mutated versions of that sequence. Students will transcribe and translate the DNA and identify types of mutations. See Part 2 of Handout 4.9.A for the student task and instructions.

UNIT 4

- After students have had ample time to work, encourage them to share their results with their group. Have students come to a consensus on what type of mutation is reflected by the codon and amino acid changes that lead to each type of albinism. For a key to the mutation types and the correct mRNA and amino acid sequences for each DNA strand, visit **https://bit.ly/32QGg7X**.
- Next, give each group a set of the eight cards from **Handout 4.9.C: Phenotype and Amino Acid Sequence Cards**. Each card has a picture of an individual with albinism (phenotype)—see the first page of the handout—that should be matched to the appropriate amino acid sequence on the second page of the handout.
- With their group, students will need to match each card with the mutated DNA sequence that corresponds to it on Handout 4.9.B. Students should use their knowledge about the traits associated with each type of albinism to help them isolate potential options for matching. (*Note:* Not all the mutated DNA sequences have matching cards. In some cases, the DNA mutation is silent, so the mutation does not result in albinism.)
- As the final step in this investigation, students work collaboratively to answer the three questions about developing evidence-based claims on the final page of Handout 4.9.A (below the table).
- When all groups have finished, have them combine into larger groups of six to eight students. Student groups should compare their results from their tables. If students are in disagreement about type of mutations and selection of individuals, have them reexamine the data in order to come to a consensus.

Classroom Ideas

The structure of the investigation can be modified. If you are short on time, you could assign each student group one of the four original DNA sequences, and have each student transcribe and translate one of the associated mutations. If you have a large class, you may have more than one group working on the same gene and have those groups then compare their answers for this part of the investigation.

For reference, the mutation types of the eight individuals are as follows:

Individual 1 = OCA2, mutation 1
Individual 2 = OCA1, mutation 1
Individual 3 = OCA4, mutation 3
Individual 4 = OCA3, mutation 1
Individual 5 = OCA2, mutation 2
Individual 6 = OCA1, mutation 2
Individual 7 = OCA3, mutation 3
Individual 8 = OCA4, mutation 2

- Finally, lead a whole-class review of the three key ideas from the lesson. Use the following prompts to spark discussion from students:
  - How do mutations in DNA influence the presence of the pigment melanin in humans?

    A change in a DNA sequence is a mutation, and there are different types of mutations (silent, missense, nonsense, and frameshift) that can occur. Some mutations cause a change in the amino acid sequence that is produced, and this can result in a reduction in the production of melanin in skin, hair, and eyes. However, not all mutations cause changes in phenotype; that is, it is possible for genotype to change without a resulting change in phenotype.

  - How are the four types of albinism similar? How are they different?

    All forms of albinism cause a change in the natural production of melanin in the skin, hair, and eyes. However, each type of albinism (phenotype) is associated with mutations in a different gene (genotype).

  - What type of health risks do individuals with albinism face?

    Since they have less pigment in the skin to shield the nuclear DNA from harmful UVB radiation from the sun, individuals with albinism may face increased risks of skin cancer.

Guiding Student Thinking

It is important to remind students that not all mutations are "bad." While some certainly do alter the function of a protein in a manner that results in negative consequences for an organism, most mutations are actually harmless to the organism and a few may be beneficial. Students should remember from prior lessons that genetic variation is actually beneficial for a population's gene pool.

UNIT 4

PRACTICE PERFORMANCE TASK

Thalassemia

OVERVIEW

DESCRIPTION

This task requires students to use concepts from prior lessons to demonstrate their understanding of transcription and translation as they analyze DNA sequences. They examine how a point mutation can impact the structure and function of a protein, thus leading to variation in populations' phenotypes. Students also apply their knowledge of natural selection to explain how the selective pressure of malaria drives phenotype frequency of thalassemia.

CONTENT FOCUS

This practice performance task is designed to be used after Lesson 4.9: Albinism Investigation. The task challenges students to transfer the knowledge gained thus far in the unit to a novel context—thalassemia disease. This task also elicits students' prior knowledge about natural selection as they examine how the frequency of this trait may increase in certain populations due to protection from malaria.

AREAS OF FOCUS

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

SUGGESTED TIMING

~45 minutes

HANDOUT

- Practice Performance Task: Thalassemia

MATERIALS

- copies of the scoring guidelines for student use (optional)

COURSE FRAMEWORK CONNECTIONS

Enduring Understandings	
▪ Encoded in DNA is the heritable information responsible for synthesis of RNA, which makes gene expression possible. ▪ Models can be used to illustrate and predict the inheritance of traits.	
Learning Objectives	**Essential Knowledge**
GEN 3.3(c) Create and/or use models to demonstrate how the information in genes is expressed as proteins.	**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.

UNIT 4

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. **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.

SUPPORTING STUDENTS

BEFORE THE TASK

- Prior to engaging students in this practice performance task, it may be helpful to have a whole-group discussion to review concepts developed during Lesson 4.4: Launch Lesson – Introduction to Gene Expression—Sickle Cell Anemia Case Study.
- Some students may need additional support unpacking the introductory text of this practice performance task due to the frequency of words they may not have encountered before. It may be helpful to read the introductory text aloud together as a class. Support students in using context clues within the passage to deduce the meaning of words they do not already know. Make sure all students have an understanding of what thalassemia is and of the words used in the passage before they engage in the practice performance task.
- Question 5 of this task asks students to engage in mathematical reasoning that requires the use of large numbers and changing whole-number percentages into decimals. It may be helpful to do a few review practice problems like these prior to having students complete this task. Remind students how to convert numbers to powers of 10 so they can more easily multiply or divide numbers by adding or subtracting exponents.

SCORING GUIDELINES

There are 15 possible points for this practice performance task.

Question 1

Sample Solutions	Points Possible
Typical *HBB* Gene Partial DNA sequence: A C C T G G G T C mRNA sequence: U G G A C C C A G Amino acid sequence: Trp-Thr-Gln **Thalassemia *HBB* Gene** Partial DNA sequence: A C C T G G A T C mRNA sequence: U G G A C C U A G Amino acid sequence: Trp-Thr-Stop	**4 points maximum** (a) 1 point for each correct mRNA sequence (2 points maximum) (b) 1 point for each correct amino acid sequence (2 points maximum)

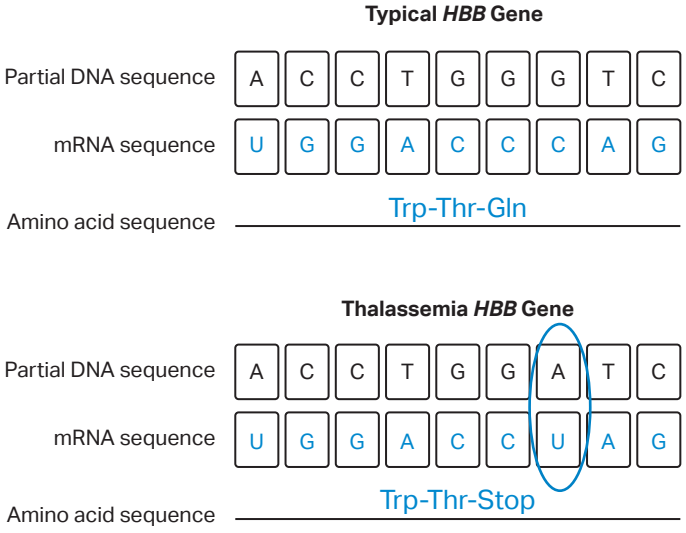
Targeted Feedback for Student Responses

Students may include only DNA bases in their transcription instead of RNA bases. Encourage students to review how DNA and RNA are structurally different and then revisit their mRNA sequences.

TEACHER NOTES AND REFLECTIONS

UNIT 4

Question 2

Sample Solutions	Points Possible
(a)  (b) The mutation is a point mutation.	**2 points maximum** (a) 1 point for a correct identification of the change in nitrogen bases in the thalassemia *HBB* DNA sequence from a guanine (G) to an adenine (A) (b) 1 point for identification of a point mutation *Scoring note:* Students may circle the original base in the typical *HBB* gene (G) that changed to the new base (A) as well as the mutation in the thalassemia *HBB* gene without penalty. However, they should not circle the resulting amino acid change as this may indicate a misconception about the process of how genetic mutations influence phenotypes.

Targeted Feedback for Student Responses

Some students may not remember the various types of mutations, and therefore cannot identify this as an example of a point mutation. Ask these students to review both point and frameshift mutations and write a comparison statement for the two types to be sure they understand the differences.

TEACHER NOTES AND REFLECTIONS

Question 3

Sample Solutions	Points Possible
Sample response 1: **Claim:** The mutation in the *HBB* gene causes a shorter amino acid chain than the normal *HBB* gene. **Evidence:** The mutation changes the original codon from CAG to UAG, which is a stop codon instead of a codon for the amino acid glutamine. **Sample response 2:** **Claim:** A point mutation occurred that caused a new codon sequence which results in changes to the protein. **Evidence:** A guanine base in the typical DNA sequence changed to an adenine base, producing a stop codon in the mRNA sequence. The stop codon will cause a change in the structure of the protein.	**2 points maximum** 1 point for a reasonable claim about how the point mutation causes the translation to stop sooner in the thalassemia *HBB* gene 1 point for appropriate evidence to support the claim. Evidence must cite specifics about the amino acid chain *Scoring note:* Students may use the abbreviations for the amino acids in their claims and evidence rather than full names.

Targeted Feedback for Student Responses

Some students may make an accurate claim but not support it with any evidence or appropriate evidence. Encourage these students to return to the DNA and mRNA sequences and the corresponding amino acids in order to support their claims.

UNIT 4

TEACHER NOTES AND REFLECTIONS

Question 4

Sample Solutions	Points Possible
Individual 4: *Tt* Individual 7: *Tt* Individual 10: *T*?	**3 points maximum** 1 point for each of the requested genotypes
Targeted Feedback for Student Responses	
If students struggle to come up with appropriate genotypes for all the individuals, pair students up and have them work as teams to review the pedigree and solve for the correct genotype for each individual.	

TEACHER NOTES AND REFLECTIONS

Question 5

Sample Solutions	Points Possible
(a) Sample response 1: $1\% \times 10 = 10\% = 0.1$ $1{,}200{,}000 \text{ people} \times (0.1) = 120{,}000 \text{ people}$ Sample response 2: $1.2 \times 10^6\left(1.0 \times 10^{-1}\right) = 1.2 \times 10^5 \text{ people}$	**4 points maximum** (a) 1 point for a correct answer, only if work is shown *Scoring notes:* ▪ Students may solve this problem with either approach. However, you may want to encourage students to make use of powers of 10, which can help them calculate large numbers more quickly. ▪ Do not penalize students if they use mental math and do not show work for finding the *percentage* of carriers on Cyprus.
(b) Sample response: Carriers of thalassemia are not as likely to die from malaria, so they have an opportunity to produce more children than individuals who are not carriers. Since the thalassemia allele is passed from parents to children, as carriers produce offspring, the frequency of thalassemia in areas with malaria could increase.	(b) 1 point for the selective pressure of malaria 1 point for the heritable nature of thalassemia 1 point for how differential reproduction leads to increased frequency of the trait

Targeted Feedback for Student Responses

While students had opportunities to learn the mathematical concepts used in part (a) in middle school, they may easily struggle with the math in this question. If you have many students who had difficulty with part (a), this is a great opportunity to provide a just-in-time review for the entire class of these critical mathematical concepts.

TEACHER NOTES AND REFLECTIONS

UNIT 4

LESSON 4.10

Launch Lesson – Ethics and Decision Making in Science—Biotechnology

OVERVIEW

LESSON DESCRIPTION

Part 1: Making a Case For or Against Regulating Biotechnologies
Students work in groups of four to make a case for or against potential uses of biotechnologies. First, each member constructs a written argument and shares it with the group. Then, each group summarizes the various positions discussed in their group for the whole class.

Part 2: Voting on Ethical Uses of Biotechnology
Students participate in a whole-class activity that elicits their opinions about the ethical uses of genetic engineering and facilitates reflection and discussion.

Part 3: Analyzing Decision Making Behavior
Students analyze and reflect on the decisions and reasoning in Part 2.

AREA OF FOCUS

- Emphasis on Analytical Reading and Writing

SUGGESTED TIMING

~45 minutes

MATERIALS

- 5 × 7 index cards (or half sheets of paper)
- LCD projector, electronic whiteboard, or other technology for displaying text
- large poster paper and markers

CONTENT FOCUS

To successfully participate in this lesson, students should be familiar with genetic engineering and genetic modification techniques. A key focus of the lesson is encouraging students to use what they have learned about biology and the process of science to make informed decisions and support their arguments. While the lesson may initially evoke responses based on personal opinions and beliefs, students should also begin to understand that it is important to consider multiple perspectives and outcomes when making decisions about the use of biotechnologies.

UNIT 4

COURSE FRAMEWORK CONNECTIONS

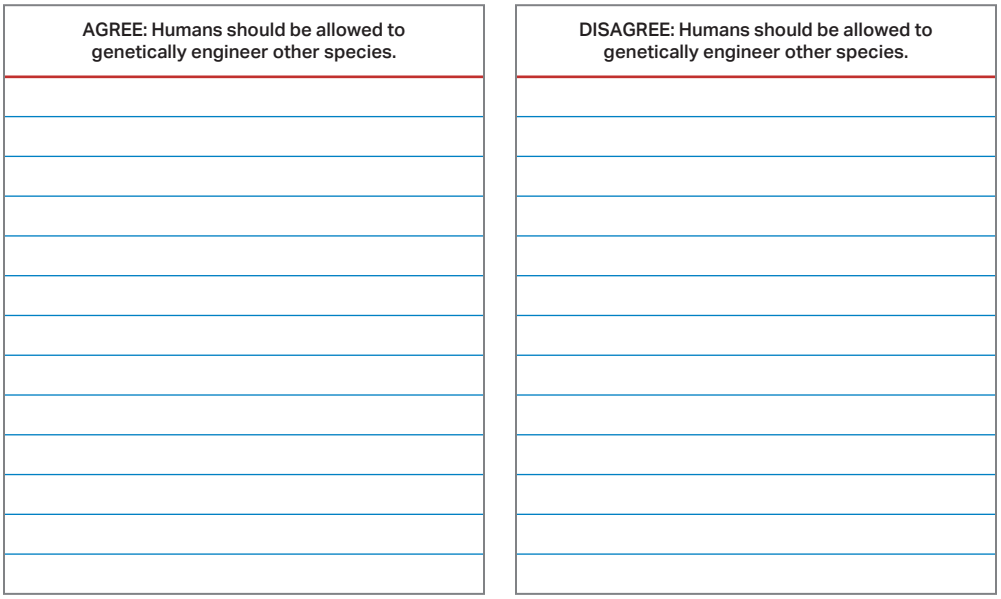
Enduring Understandings	
▪ The molecular structure of DNA enables its function of storing life's genetic information.	
Learning Objectives	**Essential Knowledge**
GEN 6.1(c) Explain potential benefits and/or consequences of manipulating DNA of organisms.	**GEN 6.1.1** Biotechnology enables scientists to study and engineer heritable traits of organisms. **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.

UNIT 4

PART 1: MAKING A CASE FOR OR AGAINST REGULATING BIOTECHNOLOGIES

The first part of this lesson is designed to stimulate critical thinking and argumentative writing as students explore the ethics of using genetic technologies. Students take on the role of policymaker and argue for or against the creation of proposed regulations on the use of genetic technology.

- To begin, assign students to groups of four and give each student a 5×7 index card. Then, display the first four policy proposals for the whole class to see:
  1. Humans should be allowed to genetically engineer other species.
  2. Humans should be allowed to genetically engineer other humans without their consent.
  3. Genetically modified food should be labeled.
  4. Research that involves the engineering of human organs should be allowed.
- Ask each group member to select one of the four proposals and write the statement at the top of their index card on both the front and back (so that each group has one card for each proposal). On the front they should include "Agree" and on the back they should include "Disagree," as shown below.



Front of card | Back of card

- Students should now engage in a timed collaborative writing session. Each member should start with their own card. Give students 1–2 minutes to write an argument on the appropriate side of the card explaining why they are either for or against the statement. After 2 minutes, have students pass their cards clockwise and spend 1–2 minutes writing an argument for the next card. Continue this process until students receive their original card.
- Next, have each group member read through the arguments written on their original card and summarize the arguments for the rest of the group. The group should agree on which arguments seem most persuasive; they will share these during the whole-class discussion. They may also want to revise these arguments based on their review and group discussion.
- Finally, lead a whole-class discussion about each of the four prompts. Ask student groups to summarize their most persuasive arguments for and against the first statement. Record all student responses for the class to see, and make sure to validate arguments and concerns for both positions. If there are no arguments for one side, encourage students to brainstorm some together. Repeat this process for the remaining three prompts.

Classroom Ideas

If 5 × 7 cards are not available, half sheets of paper could also be used; 3 × 5 index cards are a little too small to allow students enough room to respond. Also, if there are some groups of three, then have students respond to only the first three prompts.

Instructional Rationale

It is important for students to be able to engage in critical dialogue about current events. They should be able to form arguments for their opinions, understand arguments for opposing opinions, and respectfully raise questions or present other perspectives for the class to consider. It is important that students understand that there are valid arguments for each position and many perspectives to consider when public policy is created. While the goal is to teach students how to successfully participate in this type of critical dialogue, which may include personal opinions, they should still lean on scientific thinking and responses based on what they have learned in biology this year.

UNIT 4

PART 2: VOTING ON ETHICAL USES OF BIOTECHNOLOGY

In Part 2 of this lesson, students participate in a whole-group activity that elicits their opinions about the ethical uses of genetic engineering and facilitates reflection and discussion. This also generates the sample data on decision making behavior that they will analyze as a class in Part 3.

- Using large poster paper, label one side of the room "agree" and the other side of the room "disagree," so that students can clearly see the signs and know which side of the room is for which decision.
- Before the prompts are read, make sure students understand the rules: after each prompt is read, students will have 15 seconds to decide whether they agree or disagree with the statement and move to the appropriate side of the room; they may not choose to stand in the middle.
- Pose at least a few of the following policy proposals to students:
  - Humans should be allowed to voluntarily undergo genetic engineering.
  - Health insurance companies should be able to use my DNA sequences to determine the cost of my insurance.
  - Stem cell research that is focused on improving human health, and that involves the creation of embryos that will not be brought to term, should be allowed.
  - Humans should be able to select the gender of their child.
  - Humans should be able to select traits other than gender in their child.
  - Humans should be able to reproductively clone themselves.
- After all students have chosen a side in response to a proposal, record how many students agree and disagree and invite students to share some of their reasoning with the whole class. Record all reasoning for the class to see. (A template for recording student reasoning is provided at the end of this lesson.) Continue to invite students to share until at least 5–10 students on each side have shared their ideas.

Meeting Learners' Needs
Some students may benefit from seeing the prompts written out in addition to hearing them. Therefore, you could either have a printed list of prompts for students or display the prompts one at a time for the whole class to see.

UNIT 4

PART 3: ANALYZING DECISION MAKING BEHAVIOR

In Part 3, students reflect on the number of people who agreed and disagreed with the proposals in Part 2 and on the reasoning for each decision. After students have had a chance to review and reflect on their class's collective decision making behavior and experience, they are encouraged to make connections to broader voting behavior and consider the potential outcomes of their collective decisions.

- For each proposal from Part 2, display the number of people who agree or disagree and the recorded arguments. Ask students to reflect on their own experience:
  - How did you feel having to choose to argue for or against a proposal?
  - Would your choices be different if these proposals were about organisms other than humans?
  - What concepts that you learned in our biology class this year influenced your decisions and reasoning?

Guiding Student Thinking

The last question in this series should elicit students' thinking about prior knowledge from the other units. Challenge students to be specific about concepts that influenced their decisions and reasoning.

- After students have had a chance to review and reflect on their class's decision making behavior and experience, encourage them to make broader connections to voting behavior.
- Finally, invite students to identify some of the potential cultural and social outcomes of the class's collective decision making behavior.

TEMPLATE FOR RECORDING STUDENT RESPONSES

Humans should be allowed to voluntarily undergo genetic engineering.

Agree _____ Disagree _____

Health insurance companies should be able to use my DNA sequences to determine the cost of my insurance.

Agree _____ Disagree _____

Stem cell research that is focused on improving human health, and that involves the creation of embryos that will not be brought to term, should be allowed.

Agree _____ Disagree _____

UNIT 4

Humans should be able to select the gender of their child.

Agree _____ Disagree _____

Humans should be able to select traits other than gender in their child.

Agree _____ Disagree _____

Humans should be able to reproductively clone themselves.

Agree _____ Disagree _____

UNIT 4

LESSON 4.11

Gene Editing

OVERVIEW

LESSON DESCRIPTION

Part 1: Reading and Research

Students read a passage about the CRISPR-Cas9 gene-editing biotechnology. They then conduct their own background research to decide whether they think the potential benefits or consequences are more influential when determining continued funding for this type of research.

Part 2: Biotechnology Debate

Students engage in a peer-to-peer discussion of their stances on funding for research.

CONTENT FOCUS

This lesson is designed to get students thinking about the positive and negative impacts of biotechnology in regard to genetic engineering. Many of the previously addressed concepts in genetics can be incorporated into the discussion. In particular, it is a good opportunity to review the structure of DNA and RNA. Since Cas9 is a protein complex, this lesson also offers some opportunities to review macromolecules and the role of proteins.

AREA OF FOCUS

- Emphasis on Analytical Reading and Writing

SUGGESTED TIMING

~75 minutes

HANDOUTS

- 4.11.A: Understanding CRISPR-Cas9
- 4.11.B: Graphic Organizer for Gene-Editing Research

MATERIALS

- markers or colored pencils
- LCD projector, electronic whiteboard, or other technology to show an online video
- internet access to the UC Berkeley video "Gene Editing with CRISPR-Cas9" (2:20), available at **https://www.youtube.com/watch?v=avM1Yg5oEu0**
- devices for conducting online research (computer lab or library, laptop/iPad cart, or students' individual devices), or a collection of printed articles about CRISPR-Cas9

UNIT 4

COURSE FRAMEWORK CONNECTIONS

Enduring Understandings	
▪ 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.	
Learning Objectives	**Essential Knowledge**
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.

SETUP AND PREPARATION NOTES

- There are a number of ways to facilitate the research aspect of Part 2 of this lesson. You may have access to a computer lab, laptop/iPad cart, or library. Alternatively, you could provide articles and information printed ahead of time, or allow your students to use their own devices to find the research information. The important part is that students are able to research and find information on the potential benefits and consequences of gene editing.

UNIT 4

PART 1: READING AND RESEARCH

In the first part of this lesson, students engage with an analytical reading about the CRISPR-Cas9 gene-editing biotechnology. They then conduct their own background research to decide whether they think the potential benefits or consequences are more influential when determining continued funding for this type of research.

- To begin the lesson, introduce students to the topic of CRISPR-Cas9 and the rapid pace of innovations in biotechnology. Explain that they will be reading an article about recent advancements in the field of biotechnology that involve editing genes using the CRISPR-Cas9 complex. See the passage on **Handout 4.11.A: Understanding CRISPR-Cas9**.
- Next, students should work their way through the text using close reading strategies such as underlining or circling key terms and concepts and making notes alongside the article. Students may want to use colored pencils or markers to mark up their text.
- After students have had a chance to read the article, play the following video to help them visualize what they were reading about: **https://www.youtube.com/watch?v=avM1Yg5oEu0**. This video is narrated by Jennifer Doudna, from the University of California, Berkeley. She is one of the leading biochemists involved in CRISPR-Cas9 research. As students watch the video, encourage them to make any revisions to the original notes they took on the article. You may need to play the video more than once so that students can truly grasp what this gene-editing system does to a cell's DNA.
- Now explain to students that they will be conducting some background research on the potential benefits and consequences of gene editing. By the end of their research, they should decide whether they are for or against continued funding for gene-editing biotechnology research, including CRISPR-Cas9 projects.
- Give students at least 20–30 minutes to conduct their background research. They should use **Handout 4.11.B: Graphic Organizer for Gene-Editing Research** to record their findings and ideas. This includes listing their sources as well as drafting their stance, supported by the evidence they collected from their research.

Meeting Learners' Needs
If students need more support with the reading, you can have them work through it a section at a time. After each section, stop to discuss any words, phrases, or sentences that they may have struggled with. These stopping points are good opportunities to add to a class list of the article's key concepts. Students can then record these in their own words in the My Notes column beside the passage.

Instructional Rationale

The purpose of this lesson is for students to engage with current scientific technologies and think about possible benefits and challenges. This provides them with a valuable opportunity to practice their communication of scientific arguments based on evidence.

PART 2: BIOTECHNOLOGY DEBATE

In the second part of this lesson, students engage in a peer-to-peer discussion about their stances on funding for gene-editing biotechnology research.

Debate setup

- In order to encourage open dialogue, have students take their chairs and arrange them in two rows facing one another. Students who concluded they are "for" continued funding should sit in one row; students who are "against" it should sit in the other row. If the group sizes are uneven, you may wish to ask some students to change groups to balance the numbers. If there is not room for this setup in the classroom, you can do this outside or in the hallway or cafeteria.
- Set a timer for 1 minute and have each student in the "for" group explain to the student sitting directly across from them why gene-editing benefits outweigh the consequences and should continue to be funded. When the timer goes off, switch roles so that each student in the "against" group discusses their perspective for 1 minute.
- Now ask the "for" group of students to stand up and move three chairs to the right and have a seat so that each student has a new partner. This will mean that the students at the end will walk around to the beginning of the row.
- Repeat the discussion; then have the "for" group shift seats again so that each student has had a chance to debate their side of the issue with three different students.

UNIT 4

Guiding Student Thinking

This type of debate may lead some students to use personal beliefs rather than the scientific evidence they generated earlier in the lesson. This is a good time to remind students that they need evidence to back up any claims they are making. It is also a great time to remind students that not all sources are created equal in the eyes of scientific evidence.

- Finally, have students complete the following sentence stems:
  - "CRISPR-Cas9 is a system for gene editing that promises to change humankind's relationship with genetics because ..."
  - "CRISPR-Cas9 is a system for gene editing that promises to change humankind's relationship with genetics, but ..."
  - "CRISPR-Cas9 is a system for gene editing that promises to change humankind's relationship with genetics, so ..."

Unit 4

Performance Task

PERFORMANCE TASK

Modeling Pigeon Trait Inheritance

OVERVIEW

DESCRIPTION

Students use data from a real-world scenario to model the inheritance patterns of certain pigeon traits in order to make predictions. They also analyze gene sequences in order to explain the relationship between pigeon genotype and phenotype.

This performance task is based on materials from the website "Pigeon Breeding: Genetics at Work," from the University of Utah's Genetic Science Learning Center. **http://learn.genetics.utah.edu/content/pigeons**.

CONTENT FOCUS

This task is designed to assess students' understanding of gene expression and both Mendelian and non-Mendelian inheritance patterns.

AREAS OF FOCUS

- Attention to Modeling
- Strategic Use of Mathematics

SUGGESTED TIMING

~60–70 minutes

HANDOUT

- Unit 4 Performance Task: Modeling Pigeon Trait Inheritance

MATERIALS

- pop beads

COURSE FRAMEWORK CONNECTIONS

Enduring Understandings	
▪ Encoded in DNA is the heritable information responsible for synthesis of RNA, which makes gene expression possible. ▪ Models can be used to illustrate and predict the inheritance of traits.	
Learning Objectives	**Essential Knowledge**
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. **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).

Continues on next page.

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.
GEN 3.4(a) Describe how changes in DNA sequences may affect protein structure and function.	**GEN 3.4.1** Mutations are heritable changes to DNA sequences. **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.
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.

Continues on next page.

	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.

SUPPORTING STUDENTS

BEFORE THE TASK

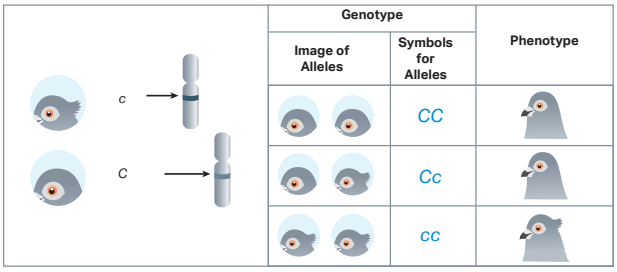
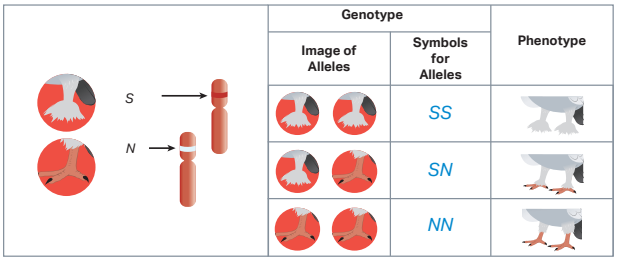
- Parts 1 and 2 of this task are designed to be conducted in pairs; you may want to assign student partners.
- For Part 2, you will assign each student one of the four pigeon genotypes listed. You can have approximately equal numbers of each genotype in the class. Also, as in previous pop-bead modeling activities, you will identify for students the bead colors they should use for modeling, based on the colors and quantities of pop beads that you have available.
- This performance assessment requires both collaborative and individual work from students. Students should be familiar with the development of chromosome models using pop beads from prior lessons. They will use pop beads again to examine the inheritance pattern of two pigeon traits—one showing Mendelian inheritance (crest trait) and one showing incomplete dominance (slipper trait). The first two parts of the performance assessment have students working collaboratively on these models, while the final part of the assessment should be completed individually.

UNIT 4

SCORING GUIDELINES

There are 23 possible points for this performance task.

Part 1
Question 1

Sample Solutions	Points Possible
 **Crest Inheritance Pattern:** Mendelian  **Slipper Inheritance Pattern:** Incomplete Dominance	**4 points maximum** 1 point for correctly identifying each gene's inheritance pattern 1 point for pairing all the images of alleles with the correct symbols for the alleles for each gene

Targeted Feedback for Student Responses

If students have difficulty correctly identifying the appropriate inheritance patterns, you can suggest they go back and annotate the introductory text to look for evidence that supports the inheritance types. You may also want to call their attention to the symbols used in the tables and have them think about why they may be different across the two traits.

TEACHER NOTES AND REFLECTIONS

Part 2, Making Models of Pigeon Chromosomes: Data Analysis

Question 1

Sample Solutions	Points Possible
Answers will vary.	**2 points maximum** 1 point for correctly identifying all possible genotypes 1 point for correctly calculating probabilities
Targeted Feedback for Student Responses	
Some students may need additional support in setting up and working through a monohybrid cross. You can have them think about what each pop-bead model represents first (homologous chromosomes with specific traits they are modeling) before populating the genotypes and calculating probabilities.	

TEACHER NOTES AND REFLECTIONS

UNIT 4

Part 2, Modeling Artificial Selection of Pigeon Traits: Data Analysis

Question 1

Sample Solutions	Points Possible
Answers will vary.	**4 points maximum** 1 point for selecting the F1 offspring that yields the highest probability of producing the *ccSS* genotype 1 point for selecting Pigeon D: *ccSS* 1 point for correctly identifying all possible genotypes 1 point for correctly calculating all probabilities
Targeted Feedback for Student Responses	
If students do not select the appropriate F1 offspring or Pigeon D, have them first analyze just one trait alone and predict which genotypes would yield the highest probabilities for the desired phenotypes.	

TEACHER NOTES AND REFLECTIONS

UNIT 4

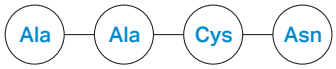
Part 3, Decoding the Crest Trait

Question 1

Sample Solutions

Phenotype	DNA and mRNA Sequences	
No Crest (wild type)	Template DNA Strand	CGACGGGCGTTG
	Complementary mRNA	GCUGCCCGCAAC
Crest	Template DNA Strand	CGACGGACGTTG
	Complementary mRNA	GCUGCCUGCAAC

No Crest Amino Acid Sequence



Crest Amino Acid Sequence

Points Possible

3 points maximum

1 point for correctly constructing mRNA strands for both phenotypes

1 point for correctly identifying nitrogenous base differences for both phenotypes

1 point for determining the correct amino acid sequences for both phenotypes

Targeted Feedback for Student Responses

If students' initial transcription is incorrect, it is often because they do not remember the structural differences between DNA and RNA. Challenge them to list at least three structural differences between these two nucleic acids.

TEACHER NOTES AND REFLECTIONS

UNIT 4

Part 3, Synthesis Questions

Question 1

Sample Solutions	Points Possible
In pigeons, one gene controls the presence or absence of a crest. This gene comes in two versions, or alleles: *crest* and *no crest* (*no crest* is also called *wild type*). There is only one nitrogenous base that is different between the two DNA sequences. The resulting codon codes for a different amino acid in the protein chain—arginine instead of cysteine. This difference determines whether the pigeon displays a crest or no crest phenotype.	**2 points maximum** 1 point for describing the nitrogenous base difference 1 point for connecting the nitrogenous base difference to protein synthesis and gene expression
Targeted Feedback for Student Responses	
Some students may struggle to provide appropriate connections between changes in nitrogen bases and the resulting phenotype. Have students review their work in Part 2 of Lesson 4.9: Albinism Investigation.	

TEACHER NOTES AND REFLECTIONS

Question 2

Sample Solutions	Points Possible
Each pigeon receives a pair of homologous chromosomes for each trait. Offspring inherit one homologous chromosome from each parent: one from the female and one from the male.	**1 point maximum** 1 point for describing homologous chromosomes from the parents
Targeted Feedback for Student Responses	
If students don't appropriately recall concepts about homologous chromosomes, ask them to again examine their pop-bead model and explain why an individual pigeon would have two alleles for every single trait, as seen in the data table provided.	

TEACHER NOTES AND REFLECTIONS

UNIT 4

Question 3

Sample Solutions	Points Possible
The crest trait is an example of Mendelian inheritance, where traits are either present or absent based on the combination of dominant and recessive alleles received from the parents. To display the crest trait, for example, a pigeon must receive a recessive allele from both parents, resulting in a homozygous recessive genotype. The slipper trait is an example of incomplete dominance. Therefore, there are three distinct phenotypes—complete slipper (extreme foot feathering), no slipper, and intermediate slipper (moderate foot feathering). For example, a pigeon must receive two slipper alleles to show the most extreme form of foot feathering (*SS*).	**4 points maximum** 1 point for describing Mendelian inheritance for the crest trait 1 point for including an appropriate example of Mendelian inheritance from their task 1 point for describing incomplete dominance for the slipper trait 1 point for including an appropriate example of incomplete dominance from their task
Targeted Feedback for Student Responses	
If students don't see that the slipper trait is a non-Mendelian example of incomplete dominance, you can have them go back to the text and information provided about the pigeon traits and highlight evidence of how these traits differ.	

TEACHER NOTES AND REFLECTIONS

Question 4

Sample Solutions	Points Possible
This answer will vary. Students should provide the following to earn full points: ▪ Students should explain that they selected Pigeon D since the homozygous recessive crest genotype coupled with the homozygous slipper trait gives the highest chance of producing offspring with the same genotype. ▪ Students should explain why the genotype they selected from their F1 cross provides the highest chance for yielding the *ccSS* genotype. ▪ Students should use the probabilities of producing *ccSS* offspring, from data analysis question 1 on page 120, to explain their choices.	**3 points maximum** 1 point for providing accurate reasoning for selecting Pigeon D 1 point for providing reasoning for how they selected the F1 genotype that would give the highest probability of producing the desired phenotype 1 point for appropriate selection of data to justify their choices
Targeted Feedback for Student Responses	
Students may not provide specific evidence for their selections. If this occurs, encourage students to return to their predicted probabilities to support and justify their answers.	

TEACHER NOTES AND REFLECTIONS

PERFORMANCE TASK

Modeling Pigeon Trait Inheritance

One of the animals Darwin studied in depth was the domestic rock pigeon (*Columba livia*). Pigeon breeding was an ancient pastime even in the 1850s. Darwin decided to keep and breed pigeons himself. He joined two London pigeon clubs and attended pigeon competitions where he connected with breeders from around the world.

Model organisms like pigeons, which are easy to breed and study in the lab, help us understand not only simple characteristics but also complex ones. When scientists work out the molecular mechanism of feather pigmentation in pigeons, for example, they gain insight into how genes work together to produce complex and varied phenotypes. They can then apply this understanding to other complex characteristics, including human diseases.

During this performance task, you will investigate the genotype and phenotype of two rock pigeon traits. You will demonstrate your understanding of patterns of inheritance and the role of DNA and protein synthesis in expressing traits.

PART 1: EXPLORING PIGEON GENES

INVESTIGATING THE GENETICS OF TWO PIGEON TRAITS

The *Crest* Gene

Some pigeons have smooth heads like their wild ancestors. But on some domestic pigeons, the feathers on the back of the head and neck stand up to form a crest. In pigeons, only one gene controls the presence or absence of a crest. This gene has two different alleles: *crest* (*c*) and *no crest* (*C*). *No crest* is considered the wild type since it is the same as the pigeon's wild ancestor.

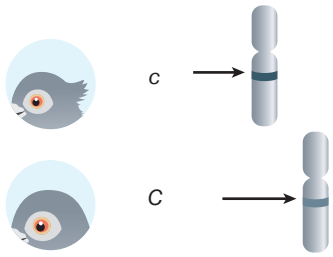
The *Slipper* Gene

Most pigeons have scales on their feet, the same as their wild ancestor; this is the wild type. But some carry a genetic variation (or two) that gives them feathers on their feet. Feathering can be subtle, with just a hint of fuzz on the feet, or it can be so extreme that the feet look almost like an extra set of wings. It can also be almost anywhere in between. You will investigate one of the genes that control foot feathers—the *slipper* gene. The *slipper* gene has two different alleles: *slipper* (*S*) and *no slipper* (*N*).

PERFORMANCE TASK

1. Before you begin modeling inheritance patterns, fill in the missing information about the *crest* gene and the *slipper* gene in the two tables shown below by completing the following tasks:
   - Analyze the information about the *crest* gene and *slipper* gene provided in the tables below, and fill in the appropriate symbols for each genotype.
   - Use the background information provided above and information from the tables to identify the type of inheritance pattern displayed by each gene.

The *Crest* Gene

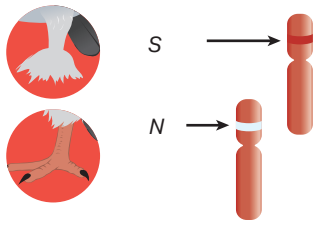


Genotype		Phenotype
Image of Alleles	Symbols for Alleles	

Crest Inheritance Pattern: _____

(e.g., Mendelian, Codominance, Incomplete Dominance)

The *Slipper* Gene



Genotype		Phenotype
Image of Alleles	Symbols for Alleles	

Slipper Inheritance Pattern: _____

(e.g., Mendelian, Codominance, Incomplete Dominance)

PERFORMANCE TASK

PART 2: MODELING THE PASSING OF PIGEON TRAITS

In this part of the task you will use pop beads to model how crest and slipper traits are passed from one generation to the next. There are four pigeons in our breeding pool that will be used in our first parental cross (F1). First, you will create the chromosome of a pigeon. Then, your teacher will pair you with another student and you will conduct a cross between your pigeons. Your teacher will assign you one of the following pigeons:

Pigeon A: *CcSS*

Pigeon B: *CcSN*

Pigeon C: *CCSN*

Pigeon D: *ccSS*

MAKING MODELS OF PIGEON CHROMOSOMES

The *crest* gene is found on a shorter chromosome in pigeons. Here, the shorter chromosome is represented by seven beads (including the centromere). The *slipper* gene is found on a longer chromosome. The long chromosome is represented by nine beads (including the centromere). Your teacher will indicate what color beads you should use; record this information in the table below.

Key for Pigeon Chromosome Models

Structure	Bead Color	Modeling Description
Shorter Chromosome (carries the *crest* gene)	_____ beads	Represents DNA on shorter chromosome
	_____ bead	Represents *crest* allele (*c*) on shorter chromosome
Longer Chromosome (carries the *slipper* gene)	_____ beads	Represents DNA on longer chromosome
	_____ bead	Represents *slipper* allele (*S*) on longer chromosome
Centromere Region	Yellow bead	Centromere

Example models of the two chromosomes

PERFORMANCE TASK

Procedure

1. Record your pigeon's genotype in the Data Analysis section below. Next, using your pop beads and the color key above, create two sets of homologous chromosomes in order to model the genotype you have been assigned.
2. Now that you have constructed your homologous chromosomes, partner with another student to perform a cross. (You do not need to have the same genotype as your partner.) Fill in your partner's genotype below in the Data Analysis section. (Your genotype should already be filled in.)
3. Align both sets of model chromosomes appropriately along the two Punnett square tables provided on the first page of the **Pigeon Trait Inheritance: Two-Factor Cross Worksheet**.
4. Pull the model chromosomes into each square to visually examine the genotype resulting from your cross. Then, replace the chromosomes using the symbols for the genotypes you developed in Part 1. Now, in each square, write in the phenotype that corresponds to the genotype in that square.
5. Develop a list of all the possible genotypes that are in your F1 generation using a two-factor cross. Use this list to create a table that shows the F1 frequency of each possible genotype that could result from your cross. (See question 1 in the Data Analysis section, below.)

Data Analysis

1. Develop a data table titled "F1 Genotypes" that represents the percentages of the different genotypes that are possible from your cross. (Use the tables on the worksheet to perform the cross.)

   Parental Cross Genotypes: _____ × _____

   (Your genotype) (Partner's genotype)

PERFORMANCE TASK

MODELING ARTIFICIAL SELECTION OF PIGEON TRAITS

In this part of the task, you will design a cross between two pigeons that yields the highest chance of producing a pigeon with a crest and extreme foot feathering.

Procedure

1. To begin, select one potential offspring from your first cross. In order to do this, reference your F1 genotype table to review all the potential genotypes you have to choose from. Then, select the genotype that has the greatest likelihood of producing the desired phenotype.
2. Next, select one of the pigeon genotypes from the original breeding list (Pigeons A–D) to cross with your F1 pigeon. Remember, you want to choose a pigeon to breed with your F1 offspring that gives the highest percent chance of getting the traits you desire.
3. Select the appropriate pop beads to model the cross between the F1 genotype and the original genotype you selected.
4. Align the chromosomes appropriately along the Punnett square table provided on the second page of the worksheet. Pull the model chromosomes into each square to visually examine the genotype resulting from your cross. Then, replace the chromosomes using the symbols for the genotypes you developed in Part 1. Now, write in the phenotype that corresponds to the genotype in each square.
5. Develop a list of all the possible genotypes that result from using a two-factor cross. Use this list to create a table that shows the frequency of each possible genotype that could result from your artificial selection cross. Record this in the Data Analysis section, below.

Data Analysis

1. Develop a data table titled "Genotypes and Phenotypes in Artificial Selection Cross" that represents the percentages of the different genotypes that are possible from your cross. (Use the tables on the worksheet to perform the cross.) Then, write in the appropriate phenotype for each genotype listed.

   Artificial Selection Cross Genotypes: _____ × _____

   (From F1 generation) (From original list)

PERFORMANCE TASK

PART 3: DRAWING CONCLUSIONS

Now that you have modeled the inheritance of two pigeon traits and analyzed genetic data, you will use your model to draw some conclusions about the genetic inheritance of pigeon traits.

DECODING THE CREST TRAIT

In this next part of the task, you will analyze differences between the DNA sequences that code for crest and no crest traits and identify the variation between amino acid sequences. You will need to reference the universal genetic code chart.

Universal Genetic Code Chart
Messenger RNA Codons and Amino Acids for Which They Code

First Base	Second Base: U	Second Base: C	Second Base: A	Second Base: G	Third Base
U	UUU, UUC: PHE UUA, UUG: LEU	UCU, UCC, UCA, UCG: SER	UAU, UAC: TYR UAA, UAG: STOP	UGU, UGC: CYS UGA: STOP UGG: TRP	U C A G
C	CUU, CUC, CUA, CUG: LEU	CCU, CCC, CCA, CCG: PRO	CAU, CAC: HIS CAA, CAG: GLN	CGU, CGC, CGA, CGG: ARG	U C A G
A	AUU, AUC, AUA: ILE AUG: MET or START	ACU, ACC, ACA, ACG: THR	AAU, AAC: ASN AAA, AAG: LYS	AGU, AGC: SER AGA, AGG: ARG	U C A G
G	GUU, GUC, GUA, GUG: VAL	GCU, GCC, GCA, GCG: ALA	GAU, GAC: ASP GAA, GAG: GLU	GGU, GGC, GGA, GGG: GLY	U C A G

1. Examine the template DNA strands, provided in the table below, for each phenotype, and then answer the questions that follow.

Phenotype	DNA and mRNA Sequences	
No Crest (wild type)	Template DNA Strand	CGACGGGCGTTG
	Complementary mRNA	
Crest	Template DNA Strand	CGACGGACGTTG
	Complementary mRNA	

PERFORMANCE TASK

(a) For each phenotype, write the complementary mRNA strand in the table on the previous page. Compare the mRNA strands for the different phenotypes and circle any differences you notice between the two mRNA strands.

(b) Now, use the mRNA strands identified for each phenotype and the Universal Genetic Code Chart to construct the protein strands below. In each space provided, fill in the three-letter amino acid abbreviation that corresponds to the correct codon in each sequence, and begin building the portion of protein that expresses each segment of the DNA sequence. The first amino acid on the no crest chain has been filled in for you, as an example. Fill in the other amino acids.

No Crest Amino Acid Sequence Crest Amino Acid Sequence

SYNTHESIS QUESTIONS

1. Explain why some pigeons display the crest trait and some do not. Use specific pieces of evidence from the task and the previous question.

2. Describe why you had to build two chromosomes for each of the pigeon's traits you were modeling.

3. Explain how the inheritance pattern for the crest trait is different from that for the slipper trait. Use specific examples of genotypes and phenotypes of these inheritance patterns to justify your answer.

4. Justify which genotypes you selected to cross in data analysis question 1 on page 120 to produce the highest percent chance of getting a pigeon with crest and extreme foot feathering. Use evidence from your data to justify your choice.

Pigeon Trait Inheritance: Two-Factor Cross Worksheet

PERFORMANCE TASK

***Crest* gene** from each parent (_____ × _____)

***Slipper* gene** from each parent (_____ × _____)

PERFORMANCE TASK

***Crest* gene** from each parent (_____ × _____)

***Slipper* gene** from each parent (_____ × _____)
