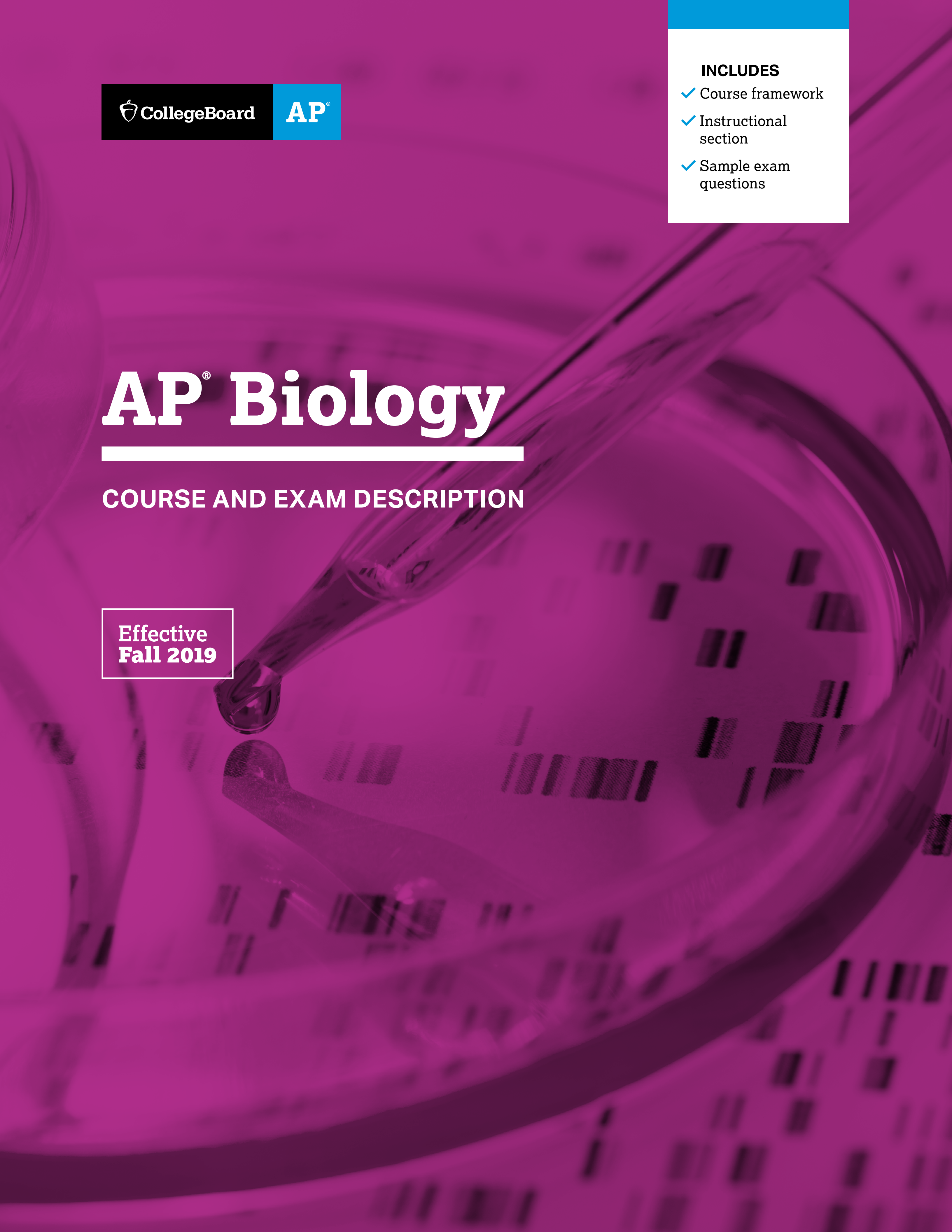

College Board AP

INCLUDES
- ✓ Course framework
- ✓ Instructional section
- ✓ Sample exam questions

AP® Biology

COURSE AND EXAM DESCRIPTION

Effective
Fall 2019

AP® CollegeBoard

AP® Biology

COURSE AND EXAM DESCRIPTION

Effective
Fall 2019

AP COURSE AND EXAM DESCRIPTIONS ARE UPDATED PERIODICALLY

Please visit AP Central (apcentral.collegeboard.org) to determine whether a more recent course and exam description is available.

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 (AP®). The organization also serves the education community through research and advocacy on behalf of students, educators, and schools.

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

AP Equity and Access Policy

College Board strongly encourages educators to make equitable access a guiding principle for their AP programs by giving all willing and academically prepared students the opportunity to participate in AP. We encourage the elimination of barriers that restrict access to AP for students from ethnic, racial, and socioeconomic groups that have been traditionally underrepresented. Schools should make every effort to ensure their AP classes reflect the diversity of their student population. College Board also believes that all students should have access to academically challenging course work before they enroll in AP classes, which can prepare them for AP success. It is only through a commitment to equitable preparation and access that true equity and excellence can be achieved.

Designers: Sonny Mui and Bill Tully

Visit College Board on the Web: **collegeboard.org**.

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About AP

College Board's Advanced Placement® Program (AP®) enables willing and academically prepared students to pursue college-level studies—with the opportunity to earn college credit, advanced placement, or both—while still in high school. Through AP courses in 38 subjects, each culminating in a challenging exam, students learn to think critically, construct solid arguments, and see many sides of an issue—skills that prepare them for college and beyond. Taking AP courses demonstrates to college admission officers that students have sought the most challenging curriculum available to them, and research indicates that students who score a 3 or higher on an AP Exam typically experience greater academic success in college and are more likely to earn a college degree than non-AP students. Each AP teacher's syllabus is evaluated and approved by faculty from some of the nation's leading colleges and universities, and AP Exams are developed and scored by college faculty and experienced AP teachers. Most four-year colleges and universities in the United States grant credit, advanced placement, or both on the basis of successful AP Exam scores—more than 3,300 institutions worldwide annually receive AP scores.

AP Course Development

In an ongoing effort to maintain alignment with best practices in college-level learning, AP courses and exams emphasize challenging, research-based curricula aligned with higher education expectations.

Individual teachers are responsible for designing their own curriculum for AP courses, selecting appropriate college-level readings, assignments, and resources. This course and exam description presents the content and skills that are the focus of the corresponding college course and that appear on the AP Exam. It also organizes the content and skills into a series of units that represent a sequence found in widely adopted college textbooks and that many AP teachers have told us they follow in order to focus their instruction. The intention of this publication is to respect teachers' time and expertise by providing a roadmap that they can modify and adapt to their local priorities and preferences. Moreover, by organizing the AP course content and skills into units, the AP Program is able to provide teachers and students with free formative assessments—Personal Progress Checks—that teachers can assign throughout the year to measure student progress as they acquire content knowledge and develop skills.

Enrolling Students: Equity and Access

College Board strongly encourages educators to make equitable access a guiding principle for their AP programs by giving all willing and academically prepared students the opportunity to participate in AP. We encourage the elimination of barriers that restrict access to AP for students from ethnic, racial, and socioeconomic groups that have been traditionally underserved. College Board also believes that all students should have access to academically challenging coursework before they enroll in AP classes, which can prepare them for AP success. It is only through a commitment to equitable preparation and access that true equity and excellence can be achieved.

Offering AP Courses: The AP Course Audit

The AP Program unequivocally supports the principle that each school implements its own curriculum that will enable students to develop the content understandings and skills described in the course framework.

While the unit sequence represented in this publication is optional, the AP Program does have a short list of curricular and resource requirements that must be fulfilled before a school can label a course "Advanced Placement" or "AP." Schools wishing to offer AP courses must participate in the AP Course Audit, a process through which AP teachers' course materials are reviewed by college faculty. The AP Course Audit was created to provide teachers and administrators with clear guidelines on curricular and resource requirements for AP courses and to help colleges and universities validate courses marked "AP" on students' transcripts. This process ensures that AP teachers' courses meet or exceed the curricular and resource expectations that college and secondary school faculty have established for college-level courses.

The AP Course Audit form is submitted by the AP teacher and the school principal (or designated administrator) to confirm awareness and understanding of the curricular and resource requirements. A syllabus or course outline, detailing how course requirements are met, is submitted by the AP teacher for review by college faculty.

Please visit **collegeboard.org/apcourseaudit** for more information to support the preparation and submission of materials for the AP Course Audit.

How the AP Program Is Developed

The scope of content for an AP course and exam is derived from an analysis of hundreds of syllabi and course offerings of colleges and universities. Using this research and data, a committee of college faculty and expert AP teachers work within the scope of the corresponding college course to articulate what students should know and be able to do upon the completion of the AP course. The resulting course framework is the heart of this course and exam description and serves as a blueprint of the content and skills that can appear on an AP Exam.

The AP Test Development Committees are responsible for developing each AP Exam, ensuring the exam questions are aligned to the course framework. The AP Exam development process is a multiyear endeavor; all AP Exams undergo extensive review, revision, piloting, and analysis to ensure that questions are accurate, fair, and valid, and that there is an appropriate spread of difficulty across the questions.

Committee members are selected to represent a variety of perspectives and institutions (public and private, small and large schools and colleges), and a range of gender, racial/ethnic, and regional groups. A list of each subject's current AP Test Development Committee members is available on **apcentral.collegeboard.org**.

Throughout AP course and exam development, College Board gathers feedback from various stakeholders in both secondary schools and higher education institutions. This feedback is carefully considered to ensure that AP courses and exams are able to provide students with a college-level learning experience and the opportunity to demonstrate their qualifications for advanced placement or college credit.

How AP Exams Are Scored

The exam scoring process, like the course and exam development process, relies on the expertise of both AP teachers and college faculty. While multiple-choice questions are scored by machine, the free-response questions and through-course performance assessments, as applicable, are scored by thousands of college faculty and expert AP teachers. Most are scored at the annual AP Reading, while a small portion is scored online. All AP Readers are thoroughly trained, and their work is monitored throughout the Reading for fairness and consistency. In each subject, a highly respected college faculty member serves as Chief Faculty Consultant and, with the help of AP Readers in leadership positions, maintains the accuracy of the scoring standards. Scores on the free-response questions and performance assessments are weighted and combined with the results of the computer-scored multiple-choice questions, and this raw score is converted into a composite AP score on a 1–5 scale.

AP Exams are not norm-referenced or graded on a curve. Instead, they are criterion-referenced, which means that every student who meets the criteria for an AP score of 2, 3, 4, or 5 will receive that score, no matter how many students that is. The criteria for the number of points students must earn on the AP Exam to receive scores of 3, 4, or 5—the scores that research consistently validates for credit and placement purposes—include:

- The number of points successful college students earn when their professors administer AP Exam questions to them.
- The number of points researchers have found to be predictive that an AP student will succeed when placed into a subsequent, higher-level college course.
- Achievement-level descriptions formulated by college faculty who review each AP Exam question.

Using and Interpreting AP Scores

The extensive work done by college faculty and AP teachers in the development of the course and exam and throughout the scoring process ensures that AP Exam scores accurately represent students' achievement in the equivalent college course. Frequent and regular research studies establish the validity of AP scores as follows:

AP Score	Credit Recommendation	College Grade Equivalent
5	Extremely well qualified	A
4	Well qualified	A–, B+, B
3	Qualified	B–, C+, C
2	Possibly qualified	n/a
1	No recommendation	n/a

While colleges and universities are responsible for setting their own credit and placement policies, most private colleges and universities award credit and/or advanced placement for AP scores of 3 or higher. Additionally, most states in the U.S. have adopted statewide credit policies that ensure college credit for scores of 3 or higher at public colleges and universities. To confirm a specific college's AP credit/placement policy, a search engine is available at **apstudent.org/creditpolicies**.

BECOMING AN AP READER

Each June, thousands of AP teachers and college faculty members from around the world gather for seven days in multiple locations to evaluate and score the free-response sections of the AP Exams. Ninety-eight percent of surveyed educators who took part in the AP Reading say it was a positive experience.

There are many reasons to consider becoming an AP Reader, including opportunities to:

- **Bring positive changes to the classroom:** Surveys show that the vast majority of returning AP Readers—both high school and college educators—make improvements to the way they teach or score because of their experience at the AP Reading.
- **Gain in-depth understanding of AP Exam and AP scoring standards:** AP Readers gain exposure to the quality and depth of the responses from the entire pool of AP Exam takers, and thus are better able to assess their students' work in the classroom.
- **Receive compensation:** AP Readers are compensated for their work during the Reading. Expenses, lodging, and meals are covered for Readers who travel.
- **Score from home:** AP Readers have online distributed scoring opportunities for certain subjects. Check **collegeboard.org/apreading** for details.
- **Earn Continuing Education Units (CEUs):** AP Readers earn professional development hours and CEUs that can be applied to PD requirements by states, districts, and schools.

How to Apply

Visit **collegeboard.org/apreading** for eligibility requirements and to start the application process.

AP Resources and Supports

By completing a simple activation process at the start of the school year, teachers and students receive access to a robust set of classroom resources.

AP Classroom

AP Classroom is a dedicated online platform designed to support teachers and students throughout their AP experience. The platform provides a variety of powerful resources and tools to provide yearlong support to teachers and enable students to receive meaningful feedback on their progress.

UNIT GUIDES

Appearing in this publication and on AP Classroom, these planning guides outline all required course content and skills, organized into commonly taught units. Each unit guide suggests a sequence and pacing of content, scaffolds skill instruction across units, organizes content into topics, and provides tips on taking the AP Exam.

PERSONAL PROGRESS CHECKS

Formative AP questions for every unit provide feedback to students on the areas where they need to focus. Available online, Personal Progress Checks measure knowledge and skills through multiple-choice questions with rationales to explain correct and incorrect answers, and free-response questions with scoring information. Because the Personal Progress Checks are formative, the results of these assessments cannot be used to evaluate teacher effectiveness or assign letter grades to students, and any such misuses are grounds for losing school authorization to offer AP courses.*

PROGRESS DASHBOARD

This dashboard allows teachers to review class and individual student progress throughout the year. Teachers can view class trends and see where students struggle with content and skills that will be assessed on the AP Exam. Students can view their own progress over time to improve their performance before the AP Exam.

AP QUESTION BANK

This online library of real AP Exam questions provides teachers with secure questions to use in their classrooms. Teachers can find questions indexed by course topics and skills, create customized tests, and assign them online or on paper. These tests enable students to practice and get feedback on each question.

*To report misuses, please call, 877-274-6474 (International: +1-212-632-1781).

Digital Activation

In order to teach an AP class and make sure students are registered to take the AP Exam, teachers must first complete the digital activation process. Digital activation gives students and teachers access to the resources and gathers students' exam registration information online, eliminating most of the answer sheet bubbling that has added to testing time and fatigue.

AP teachers and students begin by signing in to **My AP** and completing a simple activation process at the start of the school year, which provides access to all AP resources, including AP Classroom.

To complete digital activation:

- Teachers and students sign in to, or create, their College Board accounts.
- Teachers confirm that they have added the course they teach to their AP Course Audit account and have had it approved by their school's administrator.
- Teachers or AP Coordinators, depending on who the school has decided is responsible, set up class sections so students can access AP resources and have exams ordered on their behalf.
- Students join class sections with a join code provided by their teacher or AP coordinator.
- Students will be asked for additional registration information upon joining their first class section, which eliminates the need for extensive answer sheet bubbling on exam day.

While the digital activation process takes a short time for teachers, students, and AP coordinators to complete, overall it helps save time and provides the following additional benefits:

- **Access to AP resources and supports:** Teachers have access to resources specifically designed to support instruction and provide feedback to students throughout the school year as soon as activation is complete.
- **Streamlined exam ordering:** AP Coordinators can create exam orders from the same online class rosters that enable students to access resources. The coordinator reviews, updates, and submits this information as the school's exam order in the fall.
- **Student registration labels:** For each student included in an exam order, schools will receive a set of personalized AP ID registration labels, which replaces the AP student pack. The AP ID connects a student's exam materials with the registration information they provided during digital activation, eliminating the need for pre-administration sessions and reducing time spent bubbling on exam day.
- **Targeted Instructional Planning Reports:** AP teachers will get Instructional Planning Reports (IPRs) that include data on each of their class sections automatically rather than relying on special codes optionally bubbled in on exam day.

Instructional Model

Integrating AP resources throughout the course can help students develop skills and conceptual understandings. The instructional model outlined below shows possible ways to incorporate AP resources into the classroom.

Plan

Teachers may consider the following approaches as they plan their instruction before teaching each unit.

- Review the overview at the start of each **unit guide** to identify essential questions, conceptual understandings, and skills for each unit.
- Use the **Unit at a Glance** table to identify related topics that build toward a common understanding, and then plan appropriate pacing for students.
- Identify useful strategies in the **Instructional Approaches** section to help teach the concepts and skills.

Teach

When teaching, supporting resources could be used to build students' conceptual understanding and mastery of skills.

- Use the topic pages in the **unit guides** to identify the required content.
- Integrate the content with a skill, considering any appropriate scaffolding.
- Employ any of the instructional strategies previously identified.
- Use the available resources on the topic pages to bring a variety of assets into the classroom.

Assess

Teachers can measure student understanding of the content and skills covered in the unit and provide actionable feedback to students.

- At the end of each unit, use **AP Classroom** to assign students the online **Personal Progress Checks,** as homework or an in-class task.
- Provide question-level feedback to students through answer rationales; provide unit- and skill-level feedback using the progress dashboard.
- Create additional practice opportunities using the **AP Question Bank** and assign them through **AP Classroom**.

About the AP Biology Course

AP Biology is an introductory college-level biology course. Students cultivate their understanding of biology through inquiry-based investigations as they explore the following topics: evolution, cellular processes, energy and communication, genetics, information transfer, ecology, and interactions.

College Course Equivalent

The AP Biology course is equivalent to a two-semester college introductory biology course for biology majors.

Prerequisites

Students should have successfully completed high school courses in biology and chemistry.

Laboratory Requirement

This course requires that 25 percent of the instructional time will be spent in hands-on laboratory work, with an emphasis on inquiry-based investigations that provide students with opportunities to apply the science practices.

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AP BIOLOGY

Course Framework

Introduction

Given the speed with which scientific discoveries and research continuously expand scientific knowledge, many educators are faced with the challenge of balancing breadth of content coverage with depth of understanding. The AP Biology course outlined in this framework embraces this challenge by deemphasizing a traditional "content coverage" model of instruction in favor of one that focuses on enduring, conceptual understandings and the content that supports them. This approach enables students to spend less time on factual recall and more time on inquiry-based learning of essential concepts, helping them develop the reasoning skills necessary to engage in the science practices used throughout their study of AP Biology.

To foster this deeper level of learning, the breadth of content coverage in AP Biology is defined in a way that distinguishes content essential to support the enduring understandings from the many examples or applications that can overburden the course. Illustrative examples are provided that offer you a variety of optional instructional contexts to help your students achieve deeper understanding. Content that is outside the scope of the course and exam is also identified.

This framework encourages student development of inquiry and reasoning skills, such as designing a plan for collecting data, analyzing data, applying mathematical routines, and justifying arguments using evidence. The result will be readiness for the study of advanced topics in subsequent college courses—a goal of every AP course.

Course Framework Components

Overview

This course framework provides a clear and detailed description of the course requirements necessary for student success; it specifies what students must know, be able to do, and understand to qualify for college credit or placement.

The course framework includes two essential components:

1. **SCIENCE PRACTICES**
The science practices are central to the study and practice of biology. Students should develop and apply develop and apply the described practices on a regular basis over the span of the course.

2. **COURSE CONTENT**
The course content is organized into commonly taught units of study that provide a suggested sequence for the course. These units comprise the content and skills colleges and universities typically expect students to master to qualify for college credit and/or placement. This content is grounded in big ideas, which are crosscutting concepts that build conceptual understanding and spiral throughout the course.

1

AP BIOLOGY

Science Practices

The table that follows presents the science practices that students should develop during the AP Biology course. These practices form the basis of many tasks on the AP Biology Exam.

The unit guides that follow embed and spiral these practices throughout the course, providing teachers with one way to integrate the practices into the course content with sufficient repetition to prepare students to transfer those skills when taking the AP Biology Exam.

More detailed information about the teaching of the science practices can be found in the Instructional Approaches section of this publication.

AP BIOLOGY

Science Practices

Science Practice 1	Science Practice 2	Science Practice 3
Concept Explanation 1 Explain biological concepts, processes, and models presented in written format.	*Visual Representations* 2 Analyze visual representations of biological concepts and processes.	*Questions and Methods* 3 Determine scientific questions and methods.

SKILLS

Science Practice 1	Science Practice 2	Science Practice 3
1.A Describe biological concepts and/or processes. **1.B** Explain biological concepts and/or processes. **1.C** Explain biological concepts, processes, and/or models in applied contexts.	**2.A** Describe characteristics of a biological concept, process, or model represented visually. **2.B** Explain relationships between different characteristics of biological concepts, processes, or models represented visually a. In theoretical contexts. b. In applied contexts. **2.C** Explain how biological concepts or processes represented visually relate to larger biological principles, concepts, processes, or theories. **2.D** Represent relationships within biological models, including a. Mathematical models. b. Diagrams. c. Flow charts.	**3.A** Identify or pose a testable question based on an observation, data, or a model. **3.B** State the null or alternative hypotheses, or predict the results of an experiment. **3.C** Identify experimental procedures that are aligned to the question, including a. Identifying dependent and independent variables. b. Identifying appropriate controls. c. Justifying appropriate controls. **3.D** Make observations, or collect data from representations of laboratory setups or results. (Lab only; not assessed) **3.E** Propose a new/next investigation based on a. An evaluation of the evidence from an experiment. b. An evaluation of the design/methods.

AP BIOLOGY

Science Practices *(cont'd)*

Science Practice 4

Representing and Describing Data 4

Represent and describe data.

Science Practice 5

Statistical Tests and Data Analysis 5

Perform statistical tests and mathematical calculations to analyze and interpret data.

Science Practice 6

Argumentation 6

Develop and justify scientific arguments using evidence.

SKILLS

4.A Construct a graph, plot, or chart (*X,Y; Log Y; Bar; Histogram; Line, Dual Y; Box and Whisker; Pie*).

a. Orientation

b. Labeling

c. Units

d. Scaling

e. Plotting

f. Type

g. Trend line

4.B Describe data from a table or graph, including

a. Identifying specific data points.

b. Describing trends and/or patterns in the data.

c. Describing relationships between variables.

5.A Perform mathematical calculations, including

a. Mathematical equations in the curriculum.

b. Means.

c. Rates.

d. Ratios.

e. Percentages.

5.B Use confidence intervals and/or error bars (both determined using standard errors) to determine whether sample means are statistically different.

5.C Perform chi-square hypothesis testing.

5.D Use data to evaluate a hypothesis (or prediction), including

a. Rejecting or failing to reject the null hypothesis.

b. Supporting or refuting the alternative hypothesis.

6.A Make a scientific claim.

6.B Support a claim with evidence from biological principles, concepts, processes, and/or data.

6.C Provide reasoning to justify a claim by connecting evidence to biological theories.

6.D Explain the relationship between experimental results and larger biological concepts, processes, or theories.

6.E Predict the causes or effects of a change in, or disruption to, one or more components in a biological system based on

a. Biological concepts or processes.

b. A visual representation of a biological concept, process, or model.

c. Data.

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2

AP BIOLOGY

Course Content

Based on the Understanding by Design® (Wiggins and McTighe) model, this course framework provides a clear and detailed description of the course requirements necessary for student success. The framework specifies what students must know, be able to do, and understand, with a focus on the big ideas that encompass core principles, theories, and processes of the discipline. The framework also encourages instruction that prepares students for advanced work in STEM and life science–related majors.

Big Ideas

The big ideas serve as the foundation of the course and allow students to create meaningful connections among course concepts. Often, they are abstract concepts or themes that become threads that run throughout the course. Revisiting the big ideas and applying them in a variety of contexts allow students to develop deeper conceptual understandings. Following are the big ideas of the course and a brief description of each:

BIG IDEA 1: EVOLUTION (EVO)

The process of evolution drives the diversity and unity of life. Evolution is a change in the genetic makeup of a population over time, with natural selection as its major driving mechanism. Darwin's theory, which is supported by evidence from many scientific disciplines, states that inheritable variations occur in individuals in a population. Due to competition for limited resources, individuals with more favorable genetic variations are more likely to survive and produce more offspring, thus passing traits to future generations. A diverse gene pool is vital for the survival of species because environmental conditions change. The process of evolution explains the diversity and unity of life, but an explanation about the *origin* of life is less clear.

In addition to the process of natural selection, naturally occurring catastrophic and human-induced events as well as random environmental changes can result in alteration in the gene pools of populations. Scientific evidence supports that speciation and extinction have occurred throughout Earth's history and that life continues to evolve within a changing environment, thus explaining the diversity of life.

continued on next page

BIG IDEA 2: ENERGETICS (ENE)

Biological systems use energy and molecular building blocks to grow, reproduce, and maintain dynamic homeostasis. Cells and organisms must exchange matter with the environment. Organisms respond to changes in their environment at the molecular, cellular, physiological, and behavioral levels. Living systems require energy and matter to maintain order, grow, and reproduce. Organisms employ various strategies to capture, use, and store energy and other vital resources. Energy deficiencies are not only detrimental to individual organisms but they can cause disruptions at the population and ecosystem levels. Homeostatic mechanisms that are conserved or divergent across related organisms reflect either continuity due to common ancestry or evolutionary change in response to distinct selective pressures.

BIG IDEA 3: INFORMATION STORAGE AND TRANSMISSION (IST)

Living systems store, retrieve, transmit, and respond to information essential to life processes. Genetic information provides for continuity of life, and, in most cases, this information is passed from parent to offspring via DNA. Nonheritable information transmission influences behavior within and between cells, organisms, and populations. These behaviors are directed by underlying genetic information, and responses to information are vital to natural selection and evolution. Genetic information is a repository of instructions necessary for the survival, growth, and reproduction of the organism. Genetic variation can be advantageous for the long-term survival and evolution of a species.

BIG IDEA 4: SYSTEMS INTERACTIONS (SYI)

Biological systems interact, and these systems and their interactions exhibit complex properties. All biological systems comprise parts that interact with one another. These interactions result in characteristics and emergent properties not found in the individual parts alone. All biological systems from the molecular level to the ecosystem level exhibit properties of biocomplexity and diversity. These two properties provide robustness to biological systems, enabling greater resiliency and flexibility to tolerate and respond to changes in the environment.

UNITS

The course content is organized into commonly taught units. The units have been arranged in a common sequence frequently found in many college courses and textbooks.

The eight units in AP Biology, and their weightings on the multiple-choice section of the AP Exam, are listed below.

Pacing recommendations at the unit level and on the Course at Glance provide suggestions for how you can teach the required course content and administer the Personal Progress Checks. The suggested class periods are based on a schedule in which the class meets five days a week for 45 minutes each day. While these recommendations have been made to aid in planning, teachers should of course adjust the pacing based on the needs of their students, alternate schedules (e.g., block scheduling), or their school's academic calendar.

TOPICS

Each unit is broken down into teachable segments called topics. The topic pages (starting on p. 34) contain all required content for each topic. Although most topics can be taught in one or two class periods, teachers should pace the course to suit the needs of their students and school.

Units	Exam Weighting
Unit 1: Chemistry of Life	**8–11%**
Unit 2: Cell Structure and Function	**10–13%**
Unit 3: Cellular Energetics	**12–16%**
Unit 4: Cell Communication and Cell Cycle	**10–15%**
Unit 5: Heredity	**8–11%**
Unit 6: Gene Expression and Regulation	**12–16%**
Unit 7: Natural Selection	**13–20%**
Unit 8: Ecology	**10–15%**

Spiraling the Big Ideas

The following table shows how the big ideas spiral across units by showing the units in which each big idea appears.

Big Ideas	Unit 1 *Chemistry of Life*	Unit 2 *Cell Structure and Function*	Unit 3 *Cellular Energetics*	Unit 4 *Cell Communication and Cell Cycle*	Unit 5 *Heredity*	Unit 6 *Gene Expression and Regulation*	Unit 7 *Natural Selection*	Unit 8 *Ecology*
Evolution EVO		✓			✓		✓	✓
Energetics ENE	✓	✓	✓	✓				✓
Information Storage and Transmission IST	✓			✓	✓	✓		✓
Systems Interactions SYI	✓	✓	✓		✓		✓	✓

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Course at a Glance

Plan

The course at a glance provides a useful visual organization of the AP Biology curricular components, including:

- Sequence of units, along with approximate weighting and suggested pacing. Please note, pacing is based on 45-minute class periods, meeting five days each week for a full academic year
- Progression of topics within each unit
- Spiraling of the big ideas and science practices across units

Teach

SCIENCE PRACTICES

Science practices are spiralled throughout the course:

- 1 Concept Explanation
- 2 Visual Representations
- 3 Questions and Methods
- 4 Representing and Describing Data
- 5 Statistical Tests and Data Analysis
- 6 Argumentation

BIG IDEAS

The big ideas spiral across topics and units:

- EVO Evolution
- IST Information Storage and Transfer
- ENE Energetics
- SYI Systems Interactions

Assess

Assign the Personal Progress Checks—either as homework or in class—for each unit. Each Personal Progress Check contains formative multiple-choice and free-response questions. The feedback from the Personal Progress Checks shows students the areas where they need to focus.

UNIT 1 Chemistry of Life

~5-7 Class Periods | 8-11% AP Exam Weighting

Big Idea	Science Practice	Topic
SYI	2	1.1 Structure of Water and Hydrogen Bonding
ENE	2	1.2 Elements of Life
SYI	2	1.3 Introduction to Biological Macromolecules
SYI	1	1.4 Properties of Biological Macromolecules
SYI	6	1.5 Structure and Function of Biological Macromolecules
IST	2	1.6 Nucleic Acids

Personal Progress Check 1

Multiple-Choice: ~20 questions
Free-Response: 2 questions

- Conceptual Analysis (partial)
- Analyze Model or Visual Representation (partial)

UNIT 2 Cell Structure and Function

~11-13 Class Periods | 10-13% AP Exam Weighting

Big Idea	Science Practice	Topic
SYI	1	2.1 Cell Structure: Subcellular Components
SYI	6	2.2 Cell Structure and Function
ENE	5, 2	2.3 Cell Size
ENE	2	2.4 Plasma Membranes
ENE	3	2.5 Membrane Permeability
ENE	3	2.6 Membrane Transport
ENE	6	2.7 Facilitated Diffusion
ENE	4	2.8 Tonicity and Osmoregulation
ENE	1	2.9 Mechanisms of Transport
ENE	6	2.10 Cell Compartmentalization
EVO	6	2.11 Origins of Cell Compartmentalization

Personal Progress Check 2

Multiple-Choice: ~30 questions
Free-Response: 2 questions

- Interpreting and Evaluating Experimental Results (partial)
- Analyze Model or Visual Representation (partial)

NOTE: Partial versions of the free-response questions are provided to prepare students for more complex, full questions that they will encounter on the AP Exam.

UNIT 3 Cellular Energetics

~14-17 Class Periods | 12-16% AP Exam Weighting

- ENE 1 — 3.1 Enzyme Structure
- ENE 3 — 3.2 Enzyme Catalysis
- ENE 6 — 3.3 Environmental Impacts on Enzyme Function
- ENE 6 — 3.4 Cellular Energy
- ENE 6 — 3.5 Photosynthesis
- ENE 4 — 3.6 Cellular Respiration
- SYI 6 — 3.7 Fitness

Personal Progress Check 3

Multiple-Choice: ~20 questions
Free-Response: 2 questions

- Interpreting and Evaluating Experimental Results with Graphing (partial)
- Scientific Investigation (partial)

UNIT 4 Cell Communication and Cell Cycle

~9-11 Class Periods | 10-15% AP Exam Weighting

- IST 1 — 4.1 Cell Communication
- IST 1 — 4.2 Introduction to Signal Transduction
- IST 6 — 4.3 Signal Transduction
- IST 6 — 4.4 Changes in Signal Transduction Pathways
- ENE 6 — 4.5 Feedback
- IST 4, 5 — 4.6 Cell Cycle
- IST 6 — 4.7 Regulation of Cell Cycle

Personal Progress Check 4

Multiple-Choice: ~25 questions
Free-Response: 2 questions

- Interpreting and Evaluating Experimental Results (partial)
- Analyze Data

UNIT 5 Heredity

~9-11 Class Periods | 8-11% AP Exam Weighting

- IST 1 — 5.1 Meiosis
- IST 3 — 5.2 Meiosis and Genetic Diversity
- EVO, IST 6, 5 — 5.3 Mendelian Genetics
- IST 5 — 5.4 Non-Mendelian Genetics
- SYI 1 — 5.5 Environmental Effects on Phenotype
- SYI 6 — 5.6 Chromosomal Inheritance

Personal Progress Check 5

Multiple-Choice: ~25 questions
Free-Response: 2 questions

- Interpreting and Evaluating Experimental Results with Graphing
- Conceptual Analysis

NOTE: Partial versions of the free-response questions are provided to prepare students for more complex, full questions that they will encounter on the AP Exam.

UNIT 6 Gene Expression and Regulation

~18–21 Class Periods | 12–16% AP Exam Weighting

Big Idea	Skill	Topic
IST	1	6.1 DNA and RNA Structure
IST	2	6.2 Replication
IST	2	6.3 Transcription and RNA Processing
IST	6, 2	6.4 Translation
IST	6	6.5 Regulation of Gene Expression
IST	6	6.6 Gene Expression and Cell Specialization
IST	2, 3	6.7 Mutations
IST	6	6.8 Biotechnology

Personal Progress Check 6

Multiple-Choice: ~25 questions
Free-Response: 2 questions
- Interpreting and Evaluating Experimental Results
- Analyze Model or Visual Representation

UNIT 7 Natural Selection

~20–23 Class Periods | 13–20% AP Exam Weighting

Big Idea	Skill	Topic
EVO	2	7.1 Introduction to Natural Selection
EVO	1	7.2 Natural Selection
EVO	4	7.3 Artificial Selection
EVO	3	7.4 Population Genetics
EVO	5, 1	7.5 Hardy-Weinberg Equilibrium
EVO	4	7.6 Evidence of Evolution
EVO	6	7.7 Common Ancestry
EVO	3	7.8 Continuing Evolution
EVO	2	7.9 Phylogeny
EVO	6, 2	7.10 Speciation
EVO	3	7.11 Extinction
SYI	6	7.12 Variations in Populations
SYI	3	7.13 Origin of Life on Earth

Personal Progress Check 7

Multiple-Choice: ~40 questions
Free-Response: 2 questions
- Interpreting and Evaluating Experimental Results with Graphing
- Analyze Data

UNIT 8 Ecology

~18–21 Class Periods | 10–15% AP Exam Weighting

Big Idea	Skill	Topic
ENE, IST	3	8.1 Responses to the Environment
ENE	6	8.2 Energy Flow Through Ecosystems
SYI	4	8.3 Population Ecology
SYI	5	8.4 Effect of Density of Populations
ENE	5	8.5 Community Ecology
SYI	6	8.6 Biodiversity
EVO, SYI	5	8.7 Disruptions to Ecosystems

Personal Progress Check 8

Multiple-Choice: ~20 questions
Free-Response: 2 questions
- Interpreting and Evaluating Experimental Results with Graphing
- Scientific Investigation

AP BIOLOGY

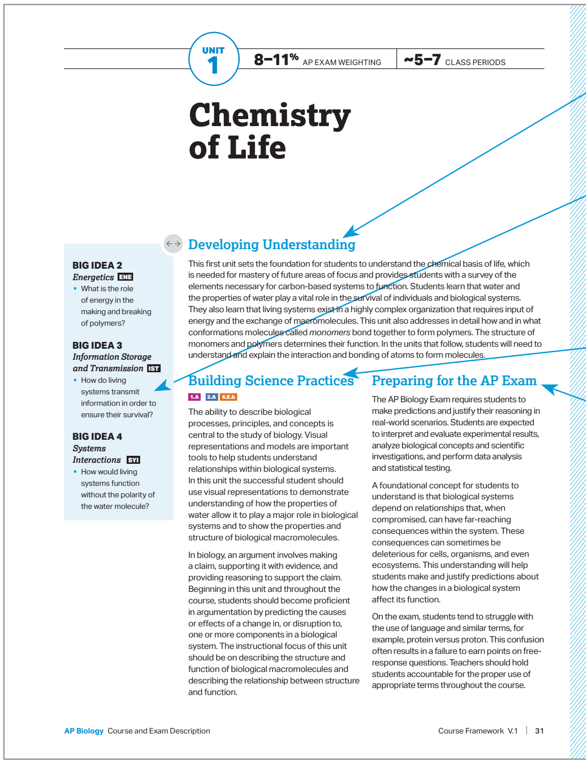
Unit Guides

Introduction

Developed with extensive input from the community of AP Biology educators, these unit guides offer all teachers helpful guidance in building students' skills and knowledge. The suggested sequence presented in the unit guides was identified through a thorough analysis of the syllabi of highly effective AP teachers and the organization of typical college textbooks.

This unit structure respects new AP teachers' time by providing one possible sequence they can adopt or modify, rather than having to build from scratch. An additional benefit is that these units enable the AP Program to provide interested teachers with formative assessments – the Personal Progress Checks – that they can assign their students at the end of each unit to gauge progress toward success on the AP exam. However, experienced AP teachers who are satisfied with their current course organization and exam results should feel no pressure to adopt these units, which comprise an optional sequence for this course.

Using the Unit Guides



UNIT 1 | 8–11% AP EXAM WEIGHTING | ~5–7 CLASS PERIODS

Chemistry of Life

BIG IDEA 2
Energetics ENE
- What is the role of energy in the making and breaking of polymers?

BIG IDEA 3
Information Storage and Transmission IST
- How do living systems transmit information in order to ensure their survival?

BIG IDEA 4
Systems Interactions SYI
- How would living systems function without the polarity of the water molecule?

Developing Understanding

This first unit sets the foundation for students to understand the chemical basis of life, which is needed for mastery of future areas of focus and provides students with a survey of the elements necessary for carbon-based systems to function. Students learn that water and the properties of water play a vital role in the survival of individuals and biological systems. They also learn that living systems exist in a highly complex organization that requires input of energy and the exchange of macromolecules. This unit also addresses in detail how and in what conformations molecules called *monomers* bond together to form polymers. The structure of monomers and polymers determines their function. In the units that follow, students will need to understand and explain the interaction and bonding of atoms to form molecules.

Building Science Practices

1.A 2.A 6.E.b

The ability to describe biological processes, principles, and concepts is central to the study of biology. Visual representations and models are important tools to help students understand relationships within biological systems. In this unit the successful student should use visual representations to demonstrate understanding of how the properties of water allow it to play a major role in biological systems and to show the properties and structure of biological macromolecules.

In biology, an argument involves making a claim, supporting it with evidence, and providing reasoning to support the claim. Beginning in this unit and throughout the course, students should become proficient in argumentation by predicting the causes or effects of a change in, or disruption to, one or more components in a biological system. The instructional focus of this unit should be on describing the structure and function of biological macromolecules and describing the relationship between structure and function.

Preparing for the AP Exam

The AP Biology Exam requires students to make predictions and justify their reasoning in real-world scenarios. Students are expected to interpret and evaluate experimental results, analyze biological concepts and scientific investigations, and perform data analysis and statistical testing.

A foundational concept for students to understand is that biological systems depend on relationships that, when compromised, can have far-reaching consequences within the system. These consequences can sometimes be deleterious for cells, organisms, and even ecosystems. This understanding will help students make and justify predictions about how the changes in a biological system affect its function.

On the exam, students tend to struggle with the use of language and similar terms, for example, protein versus proton. This confusion often results in a failure to earn points on free-response questions. Teachers should hold students accountable for the proper use of appropriate terms throughout the course.

AP Biology Course and Exam Description | Course Framework V.1 | 31

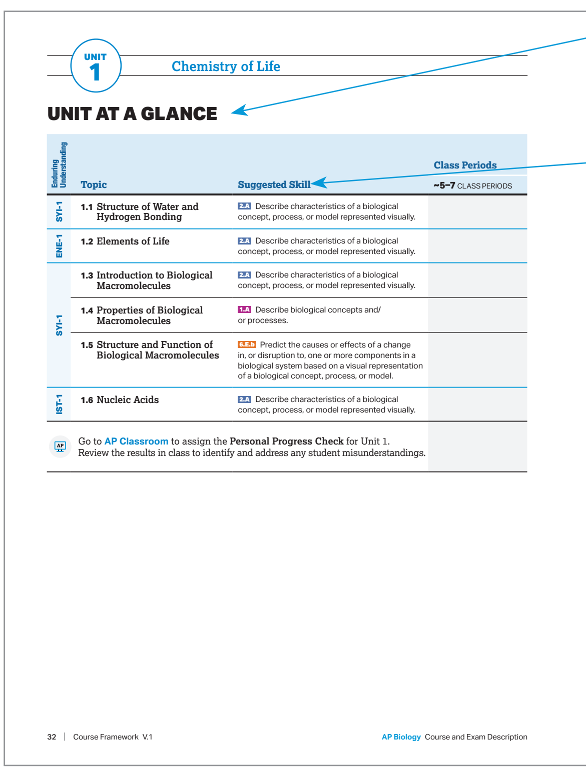
UNIT OPENERS

Developing Understanding provides an overview that contextualizes and situates the key content of the unit within the scope of the course.

The **big ideas** serve as the foundation of the course and help students to create meaningful connections among concepts. They are often overarching concepts or themes that spiral throughout the course. The **essential questions** are thought-provoking questions that motivate students and inspire inquiry.

Building Science Practices describes specific aspects of the practices that are appropriate to focus on in that unit.

Preparing for the AP Exam provides helpful tips and common student misunderstandings identified from prior exam data.



UNIT 1 | Chemistry of Life

UNIT AT A GLANCE

Enduring Understanding	Topic	Suggested Skill	Class Periods ~5–7 CLASS PERIODS
SYI-1	**1.1** Structure of Water and Hydrogen Bonding	2.A Describe characteristics of a biological concept, process, or model represented visually.	
ENE-1	**1.2** Elements of Life	2.A Describe characteristics of a biological concept, process, or model represented visually.	
SYI-1	**1.3** Introduction to Biological Macromolecules	2.A Describe characteristics of a biological concept, process, or model represented visually.	
	1.4 Properties of Biological Macromolecules	1.A Describe biological concepts and/or processes.	
	1.5 Structure and Function of Biological Macromolecules	6.E.b Predict the causes or effects of a change in, or disruption to, one or more components in a biological system based on a visual representation of a biological concept, process, or model.	
IST-1	**1.6** Nucleic Acids	2.A Describe characteristics of a biological concept, process, or model represented visually.	

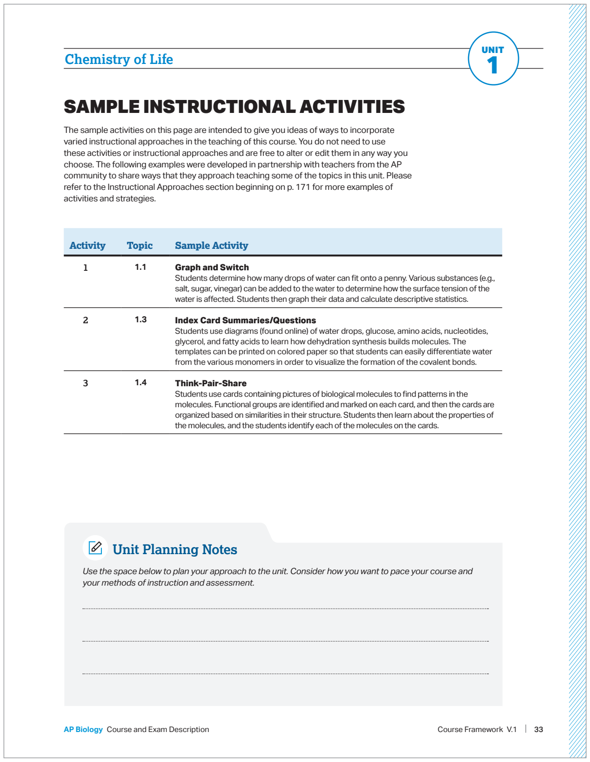
Go to **AP Classroom** to assign the **Personal Progress Check** for Unit 1. Review the results in class to identify and address any student misunderstandings.

32 | Course Framework V.1 | AP Biology Course and Exam Description

The **Unit at a Glance** table shows the topics, related enduring understandings, and suggested skills. The "class periods" column has been left blank so you can customize the time you spend on each topic.

The table includes **suggested skills** for each topic to show possible ways to link the content in that topic to specific AP Biology skills. The individual skills have been thoughtfully chosen in a way that allows you to scaffold the skills throughout the course. The questions on the Personal Progress Checks are based on this pairing. However, AP Exam questions can pair the content with any of the skills.

Using the Unit Guides



Chemistry of Life

UNIT 1

SAMPLE INSTRUCTIONAL ACTIVITIES

The sample activities on this page are intended to give you ideas of ways to incorporate varied instructional approaches in the teaching of this course. You do not need to use these activities or instructional approaches and are free to alter or edit them in any way you choose. The following examples were developed in partnership with teachers from the AP community to share ways that they approach teaching some of the topics in this unit. Please refer to the Instructional Approaches section beginning on p. 171 for more examples of activities and strategies.

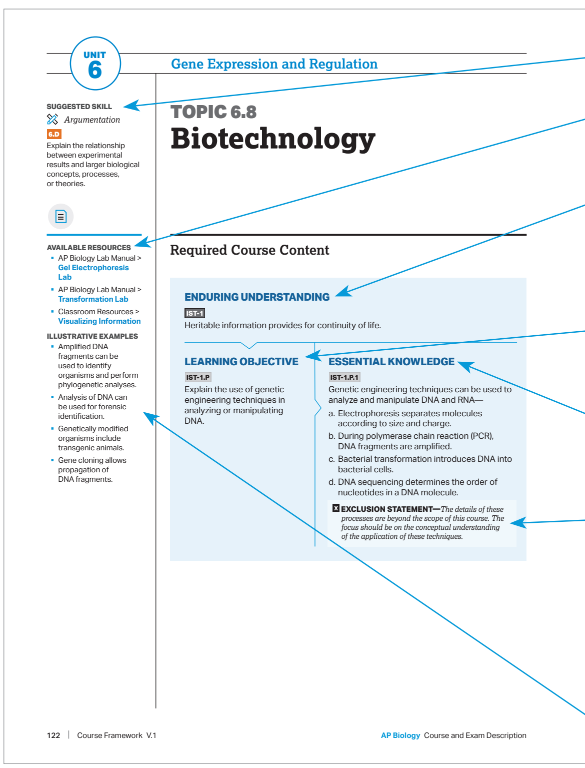
Activity	Topic	Sample Activity
1	1.1	**Graph and Switch** Students determine how many drops of water can fit onto a penny. Various substances (e.g., salt, sugar, vinegar) can be added to the water to determine how the surface tension of the water is affected. Students then graph their data and calculate descriptive statistics.
2	1.3	**Index Card Summaries/Questions** Students use diagrams (found online) of water drops, glucose, amino acids, nucleotides, glycerol, and fatty acids to learn how dehydration synthesis builds molecules. The templates can be printed on colored paper so that students can easily differentiate water from the various monomers in order to visualize the formation of the covalent bonds.
3	1.4	**Think-Pair-Share** Students use cards containing pictures of biological molecules to find patterns in the molecules. Functional groups are identified and marked on each card, and then the cards are organized based on similarities in their structure. Students then learn about the properties of the molecules, and the students identify each of the molecules on the cards.

Unit Planning Notes

Use the space below to plan your approach to the unit. Consider how you want to pace your course and your methods of instruction and assessment.

AP Biology Course and Exam Description Course Framework V.1 | 33

The **Sample Instructional Activities** page includes optional activities that can help tie together the content and skill of a particular topic. Additionally, this page offers space to make notes on your approach to the individual topics and the unit as a whole.



UNIT 6

Gene Expression and Regulation

SUGGESTED SKILL

Argumentation

6.D

Explain the relationship between experimental results and larger biological concepts, processes, or theories.

AVAILABLE RESOURCES

- AP Biology Lab Manual > Gel Electrophoresis Lab
- AP Biology Lab Manual > Transformation Lab
- Classroom Resources > Visualizing Information

ILLUSTRATIVE EXAMPLES

- Amplified DNA fragments can be used to identify organisms and perform phylogenetic analyses.
- Analysis of DNA can be used for forensic identification.
- Genetically modified organisms include transgenic animals.
- Gene cloning allows propagation of DNA fragments.

TOPIC 6.8

Biotechnology

Required Course Content

ENDURING UNDERSTANDING

IST-1

Heritable information provides for continuity of life.

LEARNING OBJECTIVE

IST-1.P

Explain the use of genetic engineering techniques in analyzing or manipulating DNA.

ESSENTIAL KNOWLEDGE

IST-1.P.1

Genetic engineering techniques can be used to analyze and manipulate DNA and RNA—

a. Electrophoresis separates molecules according to size and charge.

b. During polymerase chain reaction (PCR), DNA fragments are amplified.

c. Bacterial transformation introduces DNA into bacterial cells.

d. DNA sequencing determines the order of nucleotides in a DNA molecule.

EXCLUSION STATEMENT—*The details of these processes are beyond the scope of this course. The focus should be on the conceptual understanding of the application of these techniques.*

122 | Course Framework V.1 AP Biology Course and Exam Description

TOPIC PAGES

The **suggested skill** offers a possible skill to pair with the topic.

Available resources are included where possible to help address a particular topic in your classroom.

Enduring understandings 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.

Learning objectives define what a student needs to be able to do with content knowledge in order to progress toward the enduring understandings.

Essential knowledge statements describe the knowledge required to perform the learning objective.

Exclusion statements define content or specific details about the content that do not need to be included in the course because teaching this level of detail does not further the conceptual understanding students will need to be successful in this course. Although excluded content will not be assessed on the AP Biology Exam, such content may be provided as background or additional information for the concept and science practice(s) being assessed.

Illustrative examples are suggested, not required, contexts for instruction that can help students understand a required concept. They can be chosen according to the availability of data, regional relevance, interests of the students, and expertise of the instructor. Exposure to a variety of illustrative examples will allow students to focus their learning to apply a conceptual understanding across multiple biological systems and/or scales.

REQUIRED COURSE CONTENT LABELING SYSTEM

BIG IDEA	ENDURING UNDERSTANDING	LEARNING OBJECTIVE	ESSENTIAL KNOWLEDGE
EVO →	**EVO-1** →	**EVO-1.A** →	**EVO-1.A.3**
Evolution	Evolution is characterized by a change in the genetic makeup of a population over time and is supported by multiple lines of evidence.	Describe similarities and/or differences in compartmentalization between prokaryotic and eukaryotic cells.	Eukaryotic cells maintain internal membranes that partition the cell into specialized regions.

NOTE: Labels are used to distinguish each unique element of the required course content and are used throughout this course and exam description. Additionally, they are used in the AP Question Bank and other resources found in AP Classroom. Enduring understandings are labeled sequentially according to the big idea that they are related to. Learning objectives are labeled to correspond with the enduring understanding they relate to. Finally, essential knowledge statements are labeled to correspond with the learning objective they relate to.

AP BIOLOGY

UNIT 1

Chemistry of Life

8–11%
AP EXAM WEIGHTING

~5–7
CLASS PERIODS

Remember to go to **AP Classroom** to assign students the online **Personal Progress Check** for this unit.

Whether assigned as homework or completed in class, the **Personal Progress Check** provides each student with immediate feedback related to this unit's topic and skills.

Personal Progress Check 1

Multiple-choice: ~20 questions
Free-response: 2 questions

- Conceptual Analysis (partial)
- Analyze Model or Visual Representation (partial)

UNIT 1

8–11% AP EXAM WEIGHTING | **~5–7** CLASS PERIODS

Chemistry of Life

Developing Understanding

This first unit sets the foundation for students to understand the chemical basis of life, which is needed for mastery of future areas of focus and provides students with a survey of the elements necessary for carbon-based systems to function. Students learn that water and the properties of water play a vital role in the survival of individuals and biological systems. They also learn that living systems exist in a highly complex organization that requires input of energy and the exchange of macromolecules. This unit also addresses in detail how and in what conformations molecules called *monomers* bond together to form polymers. The structure of monomers and polymers determines their function. In the units that follow, students will need to understand and explain the interaction and bonding of atoms to form molecules.

BIG IDEA 2
***Energetics* ENE**
- What is the role of energy in the making and breaking of polymers?

BIG IDEA 3
***Information Storage and Transmission* IST**
- How do living systems transmit information in order to ensure their survival?

BIG IDEA 4
***Systems Interactions* SYI**
- How would living systems function without the polarity of the water molecule?

Building Science Practices

1.A 2.A 6.E.b

The ability to describe biological processes, principles, and concepts is central to the study of biology. Visual representations and models are important tools to help students understand relationships within biological systems. In this unit the successful student should use visual representations to demonstrate understanding of how the properties of water allow it to play a major role in biological systems and to show the properties and structure of biological macromolecules.

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On the exam, students tend to struggle with the use of language and similar terms, for example, protein versus proton. This confusion often results in a failure to earn points on free-response questions. Teachers should hold students accountable for the proper use of appropriate terms throughout the course.

UNIT AT A GLANCE

Enduring Understanding	Topic	Suggested Skill	Class Periods ~5–7 CLASS PERIODS
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SYI-1	1.3 Introduction to Biological Macromolecules	2.A Describe characteristics of a biological concept, process, or model represented visually.	
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IST-1	1.6 Nucleic Acids	2.A Describe characteristics of a biological concept, process, or model represented visually.	

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Review the results in class to identify and address any student misunderstandings.

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2	1.3	**Index Card Summaries/Questions** Students use diagrams (found online) of water drops, glucose, amino acids, nucleotides, glycerol, and fatty acids to learn how dehydration synthesis builds molecules. The templates can be printed on colored paper so that students can easily differentiate water from the various monomers in order to visualize the formation of the covalent bonds.
3	1.4	**Think-Pair-Share** Students use cards containing pictures of biological molecules to find patterns in the molecules. Functional groups are identified and marked on each card, and then the cards are organized based on similarities in their structure. Students then learn about the properties of the molecules, and the students identify each of the molecules on the cards.

Unit Planning Notes

Use the space below to plan your approach to the unit. Consider how you want to pace your course and your methods of instruction and assessment.

SUGGESTED SKILL

Visual Representations

2.A

Describe characteristics of a biological concept, process, or model represented visually.

TOPIC 1.1

Structure of Water and Hydrogen Bonding

Required Course Content

ENDURING UNDERSTANDING

SYI-1

Living systems are organized in a hierarchy of structural levels that interact.

LEARNING OBJECTIVE

SYI-1.A

Explain how the properties of water that result from its polarity and hydrogen bonding affect its biological function.

ESSENTIAL KNOWLEDGE

SYI-1.A.1

The subcomponents of biological molecules and their sequence determine the properties of that molecule.

SYI-1.A.2

Living systems depend on properties of water that result from its polarity and hydrogen bonding.

SYI-1.A.3

The hydrogen bonds between water molecules result in cohesion, adhesion, and surface tension.

TOPIC 1.2

Elements of Life

SUGGESTED SKILL

Visual Representations

2.A

Describe characteristics of a biological concept, process, or model represented visually.

Required Course Content

ENDURING UNDERSTANDING

ENE-1

The highly complex organization of living systems requires constant input of energy and the exchange of macromolecules.

LEARNING OBJECTIVE

ENE-1.A

Describe the composition of macromolecules required by living organisms.

ESSENTIAL KNOWLEDGE

ENE-1.A.1

Organisms must exchange matter with the environment to grow, reproduce, and maintain organization.

ENE-1.A.2

Atoms and molecules from the environment are necessary to build new molecules—

a. Carbon is used to build biological molecules such as carbohydrates, proteins, lipids, and nucleic acids. Carbon is used in storage compounds and cell formation in all organisms.

b. Nitrogen is used to build proteins and nucleic acids. Phosphorus is used to build nucleic acids and certain lipids.

SUGGESTED SKILL

Visual Representations

2.A
Describe characteristics of a biological concept, process, or model represented visually.

AVAILABLE RESOURCES
- Classroom Resources > **Visualizing Information**

TOPIC 1.3
Introduction to Biological Macromolecules

Required Course Content

ENDURING UNDERSTANDING

SYI-1
Living systems are organized in a hierarchy of structural levels that interact.

LEARNING OBJECTIVE

SYI-1.B
Describe the properties of the monomers and the type of bonds that connect the monomers in biological macromolecules.

ESSENTIAL KNOWLEDGE

SYI-1.B.1
Hydrolysis and dehydration synthesis are used to cleave and form covalent bonds between monomers.

X **EXCLUSION STATEMENT—***The molecular structure of specific nucleotides and amino acids is beyond the scope of the AP Exam.*

X **EXCLUSION STATEMENT—***The molecular structure of specific carbohydrate polymers is beyond the scope of the AP Exam.*

TOPIC 1.4

Properties of Biological Macromolecules

SUGGESTED SKILL

Concept Explanation

1.A

Describe biological concepts and/or processes.

AVAILABLE RESOURCES

- Classroom Resources > **Visualizing Information**

Required Course Content

ENDURING UNDERSTANDING

SYI-1

Living systems are organized in a hierarchy of structural levels that interact.

LEARNING OBJECTIVE

SYI-1.B

Describe the properties of the monomers and the type of bonds that connect the monomers in biological macromolecules.

ESSENTIAL KNOWLEDGE

SYI-1.B.2

Structure and function of polymers are derived from the way their monomers are assembled—

a. In nucleic acids, biological information is encoded in sequences of nucleotide monomers. Each nucleotide has structural components: a five-carbon sugar (deoxyribose or ribose), a phosphate, and a nitrogen base (adenine, thymine, guanine, cytosine, or uracil). DNA and RNA differ in structure and function.

b. In proteins, the specific order of amino acids in a polypeptide (primary structure) determines the overall shape of the protein. Amino acids have directionality, with an amino (NH_2) terminus and a carboxyl (COOH) terminus. The R group of an amino acid can be categorized by chemical properties (hydrophobic, hydrophilic, or ionic), and the interactions of these R groups determine structure and function of that region of the protein.

c. Complex carbohydrates comprise sugar monomers whose structures determine the properties and functions of the molecules.

continued on next page

LEARNING OBJECTIVE

SYI-1.B

Describe the properties of the monomers and the type of bonds that connect the monomers in biological macromolecules.

ESSENTIAL KNOWLEDGE

d. Lipids are nonpolar macromolecules—
   i. Differences in saturation determine the structure and function of lipids.
   ii. Phospholipids contain polar regions that interact with other polar molecules, such as water, and with nonpolar regions that are often hydrophobic.

X EXCLUSION STATEMENT—*The molecular structure of specific lipids is beyond the scope of the AP Exam.*

TOPIC 1.5
Structure and Function of Biological Macromolecules

Required Course Content

ENDURING UNDERSTANDING

SYI-1
Living systems are organized in a hierarchy of structural levels that interact.

LEARNING OBJECTIVE

SYI-1.C
Explain how a change in the subunits of a polymer may lead to changes in structure or function of the macromolecule.

ESSENTIAL KNOWLEDGE

SYI-1.C.1
Directionality of the subcomponents influences structure and function of the polymer—

a. Nucleic acids have a linear sequence of nucleotides that have ends, defined by the 3′ hydroxyl and 5′ phosphates of the sugar in the nucleotide. During DNA and RNA synthesis, nucleotides are added to the 3′ end of the growing strand, resulting in the formation of a covalent bond between nucleotides.

b. DNA is structured as an antiparallel double helix, with each strand running in opposite 5′ to 3′ orientation. Adenine nucleotides pair with thymine nucleotides via two hydrogen bonds. Cytosine nucleotides pair with guanine nucleotides by three hydrogen bonds.

c. Proteins comprise linear chains of amino acids, connected by the formation of covalent bonds at the carboxyl terminus of the growing peptide chain.

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SUGGESTED SKILL

Argumentation

6.E.b
Predict the causes or effects of a change in, or disruption to, one or more components in a biological system based on a visual representation of a biological concept, process, or model.

ILLUSTRATIVE EXAMPLE
- Cellulose versus starch versus glycogen

LEARNING OBJECTIVE

SYI-1.C

Explain how a change in the subunits of a polymer may lead to changes in structure or function of the macromolecule.

ESSENTIAL KNOWLEDGE

d. Proteins have primary structure determined by the sequence order of their constituent amino acids, secondary structure that arises through local folding of the amino acid chain into elements such as alpha-helices and beta-sheets, tertiary structure that is the overall three-dimensional shape of the protein and often minimizes free energy, and quaternary structure that arises from interactions between multiple polypeptide units. The four elements of protein structure determine the function of a protein.

e. Carbohydrates comprise linear chains of sugar monomers connected by covalent bonds. Carbohydrate polymers may be linear or branched.

TOPIC 1.6

Nucleic Acids

SUGGESTED SKILL

Visual Representations

2.A

Describe characteristics of a biological concept, process, or model represented visually.

Required Course Content

ENDURING UNDERSTANDING

IST-1

Heritable information provides for continuity of life.

LEARNING OBJECTIVE

IST-1.A

Describe the structural similarities and differences between DNA and RNA.

ESSENTIAL KNOWLEDGE

IST-1.A.1

DNA and RNA molecules have structural similarities and differences related to their function—

a. Both DNA and RNA have three components—sugar, a phosphate group, and a nitrogenous base—that form nucleotide units that are connected by covalent bonds to form a linear molecule with 5′ and 3′ ends, with the nitrogenous bases perpendicular to the sugar-phosphate backbone.

b. The basic structural differences between DNA and RNA include the following:

   i. DNA contains deoxyribose and RNA contains ribose.

   ii. RNA contains uracil and DNA contains thymine.

   iii. DNA is usually double stranded; RNA is usually single stranded.

   iv. The two DNA strands in double-stranded DNA are antiparallel in directionality.

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AP BIOLOGY

UNIT 2

Cell Structure and Function

10–13%
AP EXAM WEIGHTING

~11–13
CLASS PERIODS

Remember to go to **AP Classroom** to assign students the online **Personal Progress Check** for this unit.

Whether assigned as homework or completed in class, the **Personal Progress Check** provides each student with immediate feedback related to this unit's topic and skills.

Personal Progress Check 2

Multiple-choice: ~30 questions
Free-response: 2 questions

- Interpreting and Evaluating Experimental Results (partial)
- Analyze Model or Visual Representation (partial)

UNIT 2

10–13% AP EXAM WEIGHTING | **~11–13** CLASS PERIODS

Cell Structure and Function

BIG IDEA 1
Evolution **EVO**

- Defend the origin of eukaryotic cells.

BIG IDEA 2
Energetics **ENE**

- How do the mechanisms for transport across membranes support energy conservation?
- What are the advantages and disadvantages of cellular compartmentalization?

BIG IDEA 4
Systems Interactions **SYI**

- How are living systems affected by the presence or absence of subcellular components?

Developing Understanding

The cell is the basic unit of life. Cells contribute to the organization of life and provide the environment in which organelles function. Organelles in turn provide compartmentalization and organize cellular products for dispersal and waste for disposal. Cells have membranes that allow them to establish and maintain an internal environment. These membranes also control the exchange of material with the cell's external environment—an important, foundational concept. The maintenance of the internal and external conditions of a cell is called homeostasis. Student understanding of these concepts will be necessary in later units when the focus of instruction shifts to cellular products and by-products and when students learn why cellular exchange of energy and materials matters.

Building Science Practices

1.A 1.B 6.B 4.A 6.E.b 6.E.a 5.A.d

A solid understanding of the origin and function of organelles is the foundation for understanding cell biology. Students should explain the relationships between structure and function of organelles and cellular components on the subcellular and cellular levels.

Understanding biological systems frequently requires students to select the data necessary to solve a problem and use them to perform the appropriate calculations with correct units while showing their work and linking the results to a biological process. Students should gain proficiency in describing the characteristics of data given in a diagram, graph, or data table and identify patterns or trends in the data.

Selecting and creating the appropriate type of graph for a set of data are critical skills for communicating data that students should begin to master in this unit. Students should routinely practice analyzing different types of data, both hypothetical and those they collect, to identify patterns, connect variables, and perform statistical analysis.

Preparing for the AP Exam

On the exam, students frequently can correctly identify an organelle but fail to accurately describe its function. Students should be able to explain the relationships between structure and function on both the subcellular and cellular level. Avoid using catchy analogies (e.g., cell city) and food-based models because on the exam students tend to write about the analogy without demonstrating an understanding of its underlying concept using appropriate terminology.

The graphing skills learned in this unit are important. Students should be able to label the independent and dependent variables *with units*, correctly plot data points with appropriate scaling, and correctly represent the data in question. For instance, a line graph should be used for continuous data and a bar graph for categorical data. Students often fail to earn points because they draw error bars incorrectly and fail to use them to draw conclusions about the significance of the data.

UNIT AT A GLANCE

Enduring Understanding	Topic	Suggested Skill	Class Periods ~11–13 CLASS PERIODS
SYI-1	**2.1 Cell Structure: Subcellular Components**	1.A Describe biological concepts and/or processes.	
SYI-1	**2.2 Cell Structure and Function**	6.A Make a scientific claim.	
ENE-1	**2.3 Cell Size**	2.D.a Represent relationships within biological models, including mathematical models. 5.A.d Perform mathematical calculations, including ratios.	
ENE-2	**2.4 Plasma Membranes**	2.A Describe characteristics of a biological concept, process, or model represented visually.	
ENE-2	**2.5 Membrane Permeability**	3.D Make observations or collect data from representations of laboratory setups or results. 5.D.b Use data to evaluate a hypothesis (or prediction), including supporting or refuting the alternative hypothesis.	
ENE-2	**2.6 Membrane Transport**	3.E.b Propose a new/next investigation based on an evaluation of the design/methods.	
ENE-2	**2.7 Facilitated Diffusion**	6.E.b Predict the causes or effects of a change in, or disruption to, one or more components in a biological system based on a visual representation of a biological concept, process, or model.	
ENE-2	**2.8 Tonicity and Osmoregulation**	4.A Construct a graph, plot, or chart.	
ENE-2	**2.9 Mechanisms of Transport**	1.B Explain biological concepts and/or processes.	
ENE-2	**2.10 Cell Compartmentalization**	6.E.a Predict the causes or effects of a change in, or disruption to, one or more components in a biological system based on a biological concepts or processes.	
EVO-1	**2.11 Origins of Cell Compartmentalization**	6.B Support a claim with evidence from biological principles, concepts, processes, and/or data.	

Go to **AP Classroom** to assign the **Personal Progress Check** for Unit 2.
Review the results in class to identify and address any student misunderstandings.

SAMPLE INSTRUCTIONAL ACTIVITIES

The sample activities on this page are intended to give you ideas of ways to incorporate varied instructional approaches in the teaching of this course. You do not need to use these activities or approaches and are free to alter or edit them in any way you choose. The following examples were developed in partnership with teachers from the AP community to share ways that they approach teaching some of the topics in this unit. Please refer to the Instructional Approaches section beginning on p. 171 for more examples of activities and strategies.

Activity	Topic	Sample Activity
1	2.1	**Ask the Expert** Students can be divided into groups and each group assigned a subcellular component to study. Students then rotate through the expert stations to learn about the subcellular components required for this topic.
2	2.3	**Misconception Check** Students can take agar cubes of different sizes that are soaked in phenolphthalein and soak them in vinegar. The students can measure how long it takes for the cubes to become clear as the vinegar diffuses into the cubes. Students will find that the smaller cubes become clear before the larger cubes and can use their observations to determine how cell size affects cell function.
3	2.4	**One-Minute Essay** Before teaching the topic, have students read a case study about osmosis and answer questions (either those given with the case study or those you create) about the scenario. Ask students to draw what they they think is occurring on the cellular level. Then, teach the topic in the way that best fits your classroom. Once students have demonstrated an understanding of the topic, have them revisit their answers to the questions in the case study as well as their drawings.

Unit Planning Notes

Use the following space to plan your approach to the unit. Consider how you want to pace your course and your methods of instruction and assessment.

SUGGESTED SKILL

Concept Explanation

1.A

Describe biological concepts and/or processes.

ILLUSTRATIVE EXAMPLE

- Glycosylation and other chemical modifications of proteins that take place within the Golgi and determine protein function or targeting

TOPIC 2.1

Cell Structure: Subcellular Components

Required Course Content

ENDURING UNDERSTANDING

SYI-1

Living systems are organized in a hierarchy of structural levels that interact.

LEARNING OBJECTIVE

SYI-1.D

Describe the structure and/or function of subcellular components and organelles.

ESSENTIAL KNOWLEDGE

SYI-1.D.1

Ribosomes comprise ribosomal RNA (rRNA) and protein. Ribosomes synthesize protein according to mRNA sequence.

SYI-1.D.2

Ribosomes are found in all forms of life, reflecting the common ancestry of all known life.

SYI-1.D.3

Endoplasmic reticulum (ER) occurs in two forms—smooth and rough. Rough ER is associated with membrane-bound ribosomes—

a. Rough ER compartmentalizes the cell.

b. Smooth ER functions include detoxification and lipid synthesis.

X EXCLUSION STATEMENT—*Specific functions of smooth ER in specialized cells are beyond the scope of the course and the AP Exam.*

SYI-1.D.4

The Golgi complex is a membrane-bound structure that consists of a series of flattened membrane sacs—

a. Functions of the Golgi include the correct folding and chemical modification of newly synthesized proteins and packaging for protein trafficking.

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LEARNING OBJECTIVE

SYI-1.D

Describe the structure and/or function of subcellular components and organelles.

ESSENTIAL KNOWLEDGE

EXCLUSION STATEMENT—*The role of the Golgi in the synthesis of specific phospholipids and the packaging of specific enzymes for lysosomes, peroxisomes, and secretory vesicles are beyond the scope of the course and the AP Exam.*

SYI-1.D.5

Mitochondria have a double membrane. The outer membrane is smooth, but the inner membrane is highly convoluted, forming folds.

SYI-1.D.6

Lysosomes are membrane-enclosed sacs that contain hydrolytic enzymes.

SYI-1.D.7

A vacuole is a membrane-bound sac that plays many and differing roles. In plants, a specialized large vacuole serves multiple functions.

SYI-1.D.8

Chloroplasts are specialized organelles that are found in photosynthetic algae and plants. Chloroplasts have a double outer membrane.

SUGGESTED SKILL

Argumentation

6.A

Make a scientific claim.

TOPIC 2.2
Cell Structure and Function

Required Course Content

ENDURING UNDERSTANDING

SYI-1

Living systems are organized in a hierarchy of structural levels that interact.

LEARNING OBJECTIVE	ESSENTIAL KNOWLEDGE
SYI-1.E Explain how subcellular components and organelles contribute to the function of the cell.	**SYI-1.E.1** Organelles and subcellular structures, and the interactions among them, support cellular function— a. Endoplasmic reticulum provides mechanical support, carries out protein synthesis on membrane-bound ribosomes, and plays a role in intracellular transport. b. Mitochondrial double membrane provides compartments for different metabolic reactions. c. Lysosomes contain hydrolytic enzymes, which are important in intracellular digestion, the recycling of a cell's organic materials, and programmed cell death (apoptosis). d. Vacuoles have many roles, including storage and release of macromolecules and cellular waste products. In plants, it aids in retention of water for turgor pressure.
SYI-1.F Describe the structural features of a cell that allow organisms to capture, store, and use energy.	**SYI-1.F.1** The folding of the inner membrane increases the surface area, which allows for more ATP to be synthesized. **SYI-1.F.2** Within the chloroplast are thylakoids and the stroma.

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LEARNING OBJECTIVE	ESSENTIAL KNOWLEDGE
SYI-1.F Describe the structural features of a cell that allow organisms to capture, store, and use energy.	**SYI-1.F.3** The thylakoids are organized in stacks, called grana. **SYI-1.F.4** Membranes contain chlorophyll pigments and electron transport proteins that comprise the photosystems. **SYI-1.F.5** The light-dependent reactions of photosynthesis occur in the grana. **SYI-1.F.6** The stroma is the fluid within the inner chloroplast membrane and outside of the thylakoid. **SYI-1.F.7** The carbon fixation (Calvin-Benson cycle) reactions of photosynthesis occur in the stroma. **SYI-1.F.8** The Krebs cycle (citric acid cycle) reactions occur in the matrix of the mitochondria. **SYI-1.F.9** Electron transport and ATP synthesis occur on the inner mitochondrial membrane.

SUGGESTED SKILLS

Statistical Tests and Data Analysis

5.A.d

Perform mathematical calculations, including ratios.

Visual Representations

2.D.a

Represent relationships within biological models, including mathematical models.

ILLUSTRATIVE EXAMPLES
SA/V Ratios and Exchange

- Root hair cells
- Guard cells
- Gut epithelial cells

ILLUSTRATIVE EXAMPLES

- Vacuoles
- Cilia
- Stomata

TOPIC 2.3
Cell Size

Required Course Content

ENDURING UNDERSTANDING

ENE-1

The highly complex organization of living systems requires constant input of energy and the exchange of macromolecules.

LEARNING OBJECTIVE

ENE-1.B

Explain the effect of surface area-to-volume ratios on the exchange of materials between cells or organisms and the environment.

ESSENTIAL KNOWLEDGE

ENE-1.B.1

Surface area-to-volume ratios affect the ability of a biological system to obtain necessary resources, eliminate waste products, acquire or dissipate thermal energy, and otherwise exchange chemicals and energy with the environment.

RELEVANT EQUATIONS

Volume of a Sphere: $V = \frac{4}{3}\pi r^3$

Volume of a Cube: $V = s^2$

Volume of a Rectangular Solid: $V = lwh$

Volume of a Cylinder: $V = \pi r^2 h$

Surface Area of a Sphere: $SA = 4\pi r^2$

Surface Area of a Cube: $SA = 6s^2$

Surface Area of a Rectangular Solid: $SA = 2lh + 2lw + 2wh$

Surface Area of a Cylinder: $SA = 2\pi rh + 2\pi r^2$

r = radius

l = length

h = height

w = width

s = length of one side of a cube

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LEARNING OBJECTIVE	ESSENTIAL KNOWLEDGE
ENE-1.B Explain the effect of surface area-to-volume ratios on the exchange of materials between cells or organisms and the environment.	**ENE-1.B.2** The surface area of the plasma membrane must be large enough to adequately exchange materials— a. These limitations can restrict cell size and shape. Smaller cells typically have a higher surface area-to-volume ratio and more efficient exchange of materials with the environment. b. As cells increase in volume, the relative surface area decreases and the demand for internal resources increases. c. More complex cellular structures (e.g., membrane folds) are necessary to adequately exchange materials with the environment. d. As organisms increase in size, their surface area-to-volume ratio decreases, affecting properties like rate of heat exchange with the environment.
ENE-1.C Explain how specialized structures and strategies are used for the efficient exchange of molecules to the environment.	**ENE-1.C.1** Organisms have evolved highly efficient strategies to obtain nutrients and eliminate wastes. Cells and organisms use specialized exchange surfaces to obtain and release molecules from or into the surrounding environment.

SUGGESTED SKILL

Visual Representations

2.A
Describe characteristics of a biological concept, process, or model represented visually.

TOPIC 2.4
Plasma Membranes

Required Course Content

ENDURING UNDERSTANDING

ENE-2
Cells have membranes that allow them to establish and maintain internal environments that are different from their external environments.

LEARNING OBJECTIVE	ESSENTIAL KNOWLEDGE
ENE-2.A Describe the roles of each of the components of the cell membrane in maintaining the internal environment of the cell.	**ENE-2.A.1** Phospholipids have both hydrophilic and hydrophobic regions. The hydrophilic phosphate regions of the phospholipids are oriented toward the aqueous external or internal environments, while the hydrophobic fatty acid regions face each other within the interior of the membrane. **ENE-2.A.2** Embedded proteins can be hydrophilic, with charged and polar side groups, or hydrophobic, with nonpolar side groups.
ENE-2.B Describe the Fluid Mosaic Model of cell membranes.	**ENE-2.B.1** Cell membranes consist of a structural framework of phospholipid molecules that is embedded with proteins, steroids (such as cholesterol in eukaryotes), glycoproteins, and glycolipids that can flow around the surface of the cell within the membrane.

TOPIC 2.5
Membrane Permeability

SUGGESTED SKILL

Questions and Methods

3.D
Make observations or collect data from representations of laboratory setups or results.

Statistical Tests and Data Analysis

5.D.b
Use data to evaluate a hypothesis (or prediction), including supporting or refuting the alternative hypothesis.

Required Course Content

ENDURING UNDERSTANDING

ENE-2
Cells have membranes that allow them to establish and maintain internal environments that are different from their external environments.

LEARNING OBJECTIVE

ENE-2.C
Explain how the structure of biological membranes influences selective permeability.

ESSENTIAL KNOWLEDGE

ENE-2.C.1
The structure of cell membranes results in selective permeability.

ENE-2.C.2
Cell membranes separate the internal environment of the cell from the external environment.

ENE-2.C.3
Selective permeability is a direct consequence of membrane structure, as described by the fluid mosaic model.

ENE-2.C.4
Small nonpolar molecules, including N_2, O_2, and CO_2, freely pass across the membrane. Hydrophilic substances, such as large polar molecules and ions, move across the membrane through embedded channel and transport proteins.

ENE-2.C.5
Polar uncharged molecules, including H_2O, pass through the membrane in small amounts.

LEARNING OBJECTIVE

ENE-2.D
Describe the role of the cell wall in maintaining cell structure and function.

ESSENTIAL KNOWLEDGE

ENE-2.D.1
Cell walls provide a structural boundary, as well as a permeability barrier for some substances to the internal environments.

ENE-2.D.2
Cell walls of plants, prokaryotes, and fungi are composed of complex carbohydrates.

SUGGESTED SKILL

Questions and Methods

3.E.b

Propose a new/next investigation based on an evaluation of the design/methods.

TOPIC 2.6
Membrane Transport

Required Course Content

ENDURING UNDERSTANDING

ENE-2

Cells have membranes that allow them to establish and maintain internal environments that are different from their external environments.

LEARNING OBJECTIVE	ESSENTIAL KNOWLEDGE
ENE-2.E Describe the mechanisms that organisms use to maintain solute and water balance.	ENE-2.E.1 Passive transport is the net movement of molecules from high concentration to low concentration without the direct input of metabolic energy. ENE-2.E.2 Passive transport plays a primary role in the import of materials and the export of wastes. ENE-2.E.3 Active transport requires the direct input of energy to move molecules from regions of low concentration to regions of high concentration.
ENE-2.F Describe the mechanisms that organisms use to transport large molecules across the plasma membrane.	ENE-2.F.1 The selective permeability of membranes allows for the formation of concentration gradients of solutes across the membrane. ENE-2.F.2 The processes of endocytosis and exocytosis require energy to move large molecules into and out of cells— a. In exocytosis, internal vesicles fuse with the plasma membrane and secrete large macromolecules out of the cell. b. In endocytosis, the cell takes in macromolecules and particulate matter by forming new vesicles derived from the plasma membrane.

TOPIC 2.7

Facilitated Diffusion

SUGGESTED SKILL

Argumentation

6.E.b

Predict the causes or effects of a change in, or disruption to, one or more components in a biological system based on a visual representation of a biological concept, process, or model.

Required Course Content

ENDURING UNDERSTANDING

ENE-2

Cells have membranes that allow them to establish and maintain internal environments that are different from their external environments.

LEARNING OBJECTIVE

ENE-2.G

Explain how the structure of a molecule affects its ability to pass through the plasma membrane.

ESSENTIAL KNOWLEDGE

ENE-2.G.1

Membrane proteins are required for facilitated diffusion of charged and large polar molecules through a membrane—

a. Large quantities of water pass through aquaporins.

b. Charged ions, including Na^+ and K^+, require channel proteins to move through the membrane.

c. Membranes may become polarized by movement of ions across the membrane.

ENE-2.G.2

Membrane proteins are necessary for active transport.

ENE-2.G.3

Metabolic energy (such as from ATP) is required for active transport of molecules and/or ions across the membrane and to establish and maintain concentration gradients.

ENE-2.G.4

The Na^+/K^+ ATPase contributes to the maintenance of the membrane potential.

SUGGESTED SKILL

Representing and Describing Data

4.A
Construct a graph, plot, or chart.

AVAILABLE RESOURCES
- Classroom Resources > **Investigation 4: Diffusion and Osmosis**
- Classroom Resources > **Visualizing Information**

ILLUSTRATIVE EXAMPLES
- Contractile vacuole in protists
- Central vacuoles in plant cells

TOPIC 2.8
Tonicity and Osmoregulation

Required Course Content

ENDURING UNDERSTANDING

ENE-2
Cells have membranes that allow them to establish and maintain internal environments that are different from their external environments.

LEARNING OBJECTIVE

ENE-2.H
Explain how concentration gradients affect the movement of molecules across membranes.

ESSENTIAL KNOWLEDGE

ENE-2.H.1
External environments can be hypotonic, hypertonic or isotonic to internal environments of cells—

a. Water moves by osmosis from areas of high water potential/low osmolarity/low solute concentration to areas of low water potential/high osmolarity/high solute concentration.

RELEVANT EQUATION

Water Potential:

$$\Psi = \Psi_p + \Psi_s$$

Ψ_p = pressure potential

Ψ_s = solute potential

LEARNING OBJECTIVE

ENE-2.I
Explain how osmoregulatory mechanisms contribute to the health and survival of organisms.

ESSENTIAL KNOWLEDGE

ENE-2.I.1
Growth and homeostasis are maintained by the constant movement of molecules across membranes.

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LEARNING OBJECTIVE

ENE-2.I

Explain how osmoregulatory mechanisms contribute to the health and survival of organisms.

ESSENTIAL KNOWLEDGE

ENE-2.I.2

Osmoregulation maintains water balance and allows organisms to control their internal solute composition/water potential.

SOLUTE POTENTIAL OF A SOLUTION

$$\Psi_s = -iCRT$$

where:

i = ionization constant

C = molar concentration

R = pressure constant

$$\left(R = 0.0831 \frac{L \cdot bars}{mol \cdot K} \right)$$

T = temperature in Kelvin (°C + 273)

SUGGESTED SKILL

Concept Explanation

1.B

Explain biological concepts and/or processes.

TOPIC 2.9
Mechanisms of Transport

Required Course Content

ENDURING UNDERSTANDING

ENE-2

Cells have membranes that allow them to establish and maintain internal environments that are different from their external environments.

LEARNING OBJECTIVE

ENE-2.J

Describe the processes that allow ions and other molecules to move across membranes.

ESSENTIAL KNOWLEDGE

ENE-2.J.1

A variety of processes allow for the movement of ions and other molecules across membranes, including passive and active transport, endocytosis and exocytosis.

TOPIC 2.10
Compartmentalization

SUGGESTED SKILL

Argumentation

6.E.a

Predict the causes or effects of a change in, or disruption to, one or more components in a biological system based on biological concepts or processes.

Required Course Content

ENDURING UNDERSTANDING

ENE-2

Cells have membranes that allow them to establish and maintain internal environments that are different from their external environments.

LEARNING OBJECTIVE	ESSENTIAL KNOWLEDGE
ENE-2.K Describe the membrane-bound structures of the eukaryotic cell.	**ENE-2.K.1** Membranes and membrane-bound organelles in eukaryotic cells compartmentalize intracellular metabolic processes and specific enzymatic reactions.
ENE-2.L Explain how internal membranes and membrane-bound organelles contribute to compartmentalization of eukaryotic cell functions.	**ENE-2.L.1** Internal membranes facilitate cellular processes by minimizing competing interactions and by increasing surface areas where reactions can occur.

SUGGESTED SKILL

Argumentation

6.B

Support a claim with evidence from biological principles, concepts, processes, and/or data.

TOPIC 2.11

Origins of Cell Compartmentalization

Required Course Content

ENDURING UNDERSTANDING

EVO-1

Evolution is characterized by a change in the genetic makeup of a population over time and is supported by multiple lines of evidence.

LEARNING OBJECTIVE	ESSENTIAL KNOWLEDGE
EVO-1.A Describe similarities and/or differences in compartmentalization between prokaryotic and eukaryotic cells.	**EVO-1.A.1** Membrane-bound organelles evolved from once free-living prokaryotic cells via endosymbiosis. **EVO-1.A.2** Prokaryotes generally lack internal membrane-bound organelles but have internal regions with specialized structures and functions. **EVO-1.A.3** Eukaryotic cells maintain internal membranes that partition the cell into specialized regions.
EVO-1.B Describe the relationship between the functions of endosymbiotic organelles and their free-living ancestral counterparts.	**EVO-1.B.1** Membrane-bound organelles evolved from previously free-living prokaryotic cells via endosymbiosis.

AP BIOLOGY

UNIT 3

Cellular Energetics

12–16%
AP EXAM WEIGHTING

~14–17
CLASS PERIODS

Remember to go to **AP Classroom** to assign students the online **Personal Progress Check** for this unit.

Whether assigned as homework or completed in class, the **Personal Progress Check** provides each student with immediate feedback related to this unit's topic and skills.

Personal Progress Check 3

Multiple-choice: ~20 questions
Free-response: 2 questions

- Interpreting and Evaluating Experimental Results with Graphing (partial)
- Scientific Investigation (partial)

UNIT 3

12–16% AP EXAM WEIGHTING | ~14–17 CLASS PERIODS

Cellular Energetics

BIG IDEA 2
Energetics **ENE**
- How is energy captured and then used by a living system?

BIG IDEA 4
Systems Interactions **SYI**
- How do organisms use energy or conserve energy to respond to environmental stimuli?

Developing Understanding

In Unit 3, students build on knowledge gained in Unit 2 about the structure and function of cells, focusing on cellular energetics. Living systems are complex in their organization and require constant energy input. This unit will provide students with the knowledge necessary to master the concepts of energy capture and use. Students work through enzyme structure and function, learning the ways in which the environment plays a role in how enzymes perform their function(s). Students gain a deeper understanding of the processes of photosynthesis and cellular respiration, knowledge they will use in Unit 6 while studying how cells use energy to fuel life processes.

Building Science Practices

1.B 3.C.b 3.C.c 4.A 6.B 6.C 6.E.c

Since students learned how to make scientific claims in the previous unit, the instructional focus of this unit should be on gaining proficiency in argumentation through supporting claims with evidence. The evidence can be from biological principles, concepts, processes, and/or data. Students should provide reasoning to justify a claim by connecting evidence to biological theories.

A key concept in this unit is structure-function relationships. This should be reinforced in context as students proceed through the course. It is important that students understand rates of enzyme reactions and how they are affected by environmental factors, such as enzyme or substrate concentration, pH, temperature, and the presence of inhibitors.

As students learn about cellular respiration and photosynthesis, be sure to emphasize the differences between the two processes, how they function together within an ecosystem, and the consequences of a disruption in either process on a cellular, organismal, and ecosystem level.

Preparing for the AP Exam

Students often lack an understanding of metabolic pathways, confusing them with other processes. Students should know inputs and outputs of metabolic pathways, predict how changes in reactants affect them, and explain how organisms and ecosystems are affected by changes.

Common misconceptions include: only animals conduct cellular respiration, oxygen is created during photosynthesis, and only plants conduct photosynthesis. Be sure to make clear the distinction between memorizing molecules and demonstrating an understanding of how molecular events connect to overall function of organisms and to carbon transfer within ecosystems. Students should have an understanding of cellular respiration and photosynthesis to predict and justify the effect of environmental changes on those processes.

Students may be required to graph data from an experiment—using the skills learned in Unit 2—and calculate reaction rates. Students are advised to show their calculations, ensuring that units are included in their final answer.

UNIT AT A GLANCE

Enduring Understanding	Topic	Suggested Skill	Class Periods ~14–17 CLASS PERIODS
ENE-1	**3.1 Enzyme Structure**	1.B Explain biological concepts and/or processes.	
	3.2 Enzyme Catalysis	3.C.b Identify experimental procedures that are aligned to the question, including identifying appropriate controls. 3.C.c Identify experimental procedures that are aligned to the question, including justifying appropriate controls.	
	3.3 Environmental Impacts on Enzyme Function	6.E.c Predict the causes or effects of a change in, or disruption to, one or more components in a biological system based on data.	
	3.4 Cellular Energy	6.C Provide reasoning to justify a claim by connecting evidence to biological theories.	
	3.5 Photosynthesis	6.B Support a claim with evidence from biological principles, concepts, processes, and/or data.	
	3.6 Cellular Respiration	4.A Construct a graph, plot, or chart.	
SYI-3	**3.7 Fitness**	6.C Provide reasoning to justify a claim by connecting evidence to biological theories.	

Go to **AP Classroom** to assign the **Personal Progress Check** for Unit 3. Review the results in class to identify and address any student misunderstandings.

SAMPLE INSTRUCTIONAL ACTIVITIES

The sample activities on this page are intended to give you ideas of ways to incorporate varied instructional approaches in the teaching of this course. You do not need to use these activities or approaches and are free to alter or edit them in any way you choose. The following examples were developed in partnership with teachers from the AP community to share ways that they approach teaching some of the topics in this unit. Please refer to the Instructional Approaches section beginning on p. 171 for more examples of activities and strategies.

Activity	Topic	Sample Activity
1	3.2	**QuickWrite** Perform the "toothpickase" activity, in which students use their fingers to break as many as 100 toothpicks in 10-second intervals (without looking) onto a paper towel. All broken toothpicks must remain mixed with the unbroken. Broken toothpicks should not be removed from the pile, and each toothpick can only be broken once. Continue breaking toothpicks for these total time intervals (60, 120, and 180 seconds). Students then graph the number of toothpicks broken versus time (10, 20, 30, 60, 120, and 180 seconds).
2	3.6	**Graph and Switch** Have students perform a yeast fermentation lab using the sucrose solutions from the Diffusion and Osmosis Lab your students may have performed in Unit 2. Students can measure the amount of carbon dioxide produced as the dependent variable. At the conclusion of the lab, collect class data. Have students graph the class data, including error bars on their graphs. To enhance this activity, have students test different kinds of fresh and processed fruit juices and then compare the rates of fermentation among the different solutions.
3	3.7	**Misconception Check** Using one of many available online resources, have students learn about the work of Peter and Rosemary Grant. Using data from their work, help students to build their graphing and statistical analysis skills. Additionally, this is a good opportunity to allow students to practice explaining trends in data and supporting their claims with evidence.

Unit Planning Notes

Use the space below to plan your approach to the unit. Consider how you want to pace your course and your methods of instruction and assessment.

SUGGESTED SKILL

Concept Explanation

1.B

Explain biological concepts and/or processes.

TOPIC 3.1
Enzyme Structure

Required Course Content

ENDURING UNDERSTANDING

ENE-1

The highly complex organization of living systems requires constant input of energy and the exchange of macromolecules.

LEARNING OBJECTIVE

ENE-1.D

Describe the properties of enzymes.

ESSENTIAL KNOWLEDGE

ENE-1.D.1

The structure of enzymes includes the active site that specifically interacts with substrate molecules.

ENE-1.D.2

For an enzyme-mediated chemical reaction to occur, the shape and charge of the substrate must be compatible with the active site of the enzyme.

TOPIC 3.2
Enzyme Catalysis

SUGGESTED SKILLS

Questions and Methods

3.C.b
Identify experimental procedures that are aligned to the question, including identifying appropriate controls.

3.C.c
Identify experimental procedures that are aligned to the question, including justifying appropriate controls.

Required Course Content

ENDURING UNDERSTANDING

ENE-1
The highly complex organization of living systems requires constant input of energy and the exchange of macromolecules.

LEARNING OBJECTIVE

ENE-1.E
Explain how enzymes affect the rate of biological reactions.

ESSENTIAL KNOWLEDGE

ENE-1.E.1
The structure and function of enzymes contribute to the regulation of biological processes—

a. Enzymes are biological catalysts that facilitate chemical reactions in cells by lowering the activation energy.

SUGGESTED SKILL

Argumentation

6.E.c

Predict the causes or effects of a change in, or disruption to, one or more components in a biological system based on data.

AVAILABLE RESOURCES

- AP Biology Lab Manual > **Enzyme Lab**
- Classroom Resources > **Visualizing Information**

TOPIC 3.3

Environmental Impacts on Enzyme Function

Required Course Content

ENDURING UNDERSTANDING

ENE-1

The highly complex organization of living systems requires constant input of energy and the exchange of macromolecules.

LEARNING OBJECTIVE	ESSENTIAL KNOWLEDGE
ENE-1.F Explain how changes to the structure of an enzyme may affect its function.	**ENE-1.F.1** Change to the molecular structure of a component in an enzymatic system may result in a change of the function or efficiency of the system— a. Denaturation of an enzyme occurs when the protein structure is disrupted, eliminating the ability to catalyze reactions. b. Environmental temperatures and pH outside the optimal range for a given enzyme will cause changes to its structure, altering the efficiency with which it catalyzes reactions. **ENE-1.F.2** In some cases, enzyme denaturation is reversible, allowing the enzyme to regain activity.
ENE-1.G Explain how the cellular environment affects enzyme activity.	**ENE-1.G.1** Environmental pH can alter the efficiency of enzyme activity, including through disruption of hydrogen bonds that provide enzyme structure.

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LEARNING OBJECTIVE

ENE-1.G

Explain how the cellular environment affects enzyme activity.

ESSENTIAL KNOWLEDGE

RELEVANT EQUATION

$$pH = -\log[H^+]$$

EXCLUSION STATEMENT—*Students must understand the underlying concepts and applications of this equation, but performing calculations using this equation are beyond the scope of the course and the AP Exam.*

ENE-1.G.2

The relative concentrations of substrates and products determine how efficiently an enzymatic reaction proceeds.

ENE-1.G.3

Higher environmental temperatures increase the speed of movement of molecules in a solution, increasing the frequency of collisions between enzymes and substrates and therefore increasing the rate of reaction.

ENE-1G.4

Competitive inhibitor molecules can bind reversibly or irreversibly to the active site of the enzyme. Noncompetitive inhibitors can bind allosteric sites, changing the activity of the enzyme.

SUGGESTED SKILL

Argumentation

6.C

Provide reasoning to justify a claim by connecting evidence to biological theories.

TOPIC 3.4
Cellular Energy

Required Course Content

ENDURING UNDERSTANDING

ENE-1

The highly complex organization of living systems requires constant input of energy and the exchange of macromolecules.

LEARNING OBJECTIVE

ENE-1.H

Describe the role of energy in living organisms.

ESSENTIAL KNOWLEDGE

ENE-1.H.1

All living systems require constant input of energy.

ENE-1.H.2

Life requires a highly ordered system and does not violate the second law of thermodynamics—

a. Energy input must exceed energy loss to maintain order and to power cellular processes.

b. Cellular processes that release energy may be coupled with cellular processes that require energy.

c. Loss of order or energy flow results in death.

X EXCLUSION STATEMENT—*Students will need to understand the concept of energy, but the equation for Gibbs free energy is beyond the scope of the course and the AP Exam.*

ENE-1.H.3

Energy-related pathways in biological systems are sequential to allow for a more controlled and efficient transfer of energy. A product of a reaction in a metabolic pathway is generally the reactant for the subsequent step in the pathway.

TOPIC 3.5

Photosynthesis

SUGGESTED SKILL

Argumentation

6.B

Support a claim with evidence from biological principles, concepts, processes, and/or data.

AVAILABLE RESOURCES

- AP Biology Lab Manual > **Photosynthesis Lab**
- Classroom Resources > **Visualizing Information**

Required Course Content

ENDURING UNDERSTANDING

ENE-1

The highly complex organization of living systems requires constant input of energy and the exchange of macromolecules.

LEARNING OBJECTIVE	ESSENTIAL KNOWLEDGE
ENE-1.I Describe the photosynthetic processes that allow organisms to capture and store energy.	**ENE-1.I.1** Organisms capture and store energy for use in biological processes— a. Photosynthesis captures energy from the sun and produces sugars. i. Photosynthesis first evolved in prokaryotic organisms. ii. Scientific evidence supports the claim that prokaryotic (cyanobacterial) photosynthesis was responsible for the production of an oxygenated atmosphere. iii. Prokaryotic photosynthetic pathways were the foundation of eukaryotic photosynthesis. **ENE-1.I.2** The light-dependent reactions of photosynthesis in eukaryotes involve a series of coordinated reaction pathways that capture energy present in light to yield ATP and NADPH, which power the production of organic molecules.
ENE-1.J Explain how cells capture energy from light and transfer it to biological molecules for storage and use.	**ENE-1.J.1** During photosynthesis, chlorophylls absorb energy from light, boosting electrons to a higher energy level in photosystems I and II.

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LEARNING OBJECTIVE	ESSENTIAL KNOWLEDGE
ENE-1.J Explain how cells capture energy from light and transfer it to biological molecules for storage and use.	**ENE-1.J.2** Photosystems I and II are embedded in the internal membranes of chloroplasts and are connected by the transfer of higher energy electrons through an electron transport chain (ETC).
	ENE-1.J.3 When electrons are transferred between molecules in a sequence of reactions as they pass through the ETC, an electrochemical gradient of protons (hydrogen ions) is established across the internal membrane.
	ENE-1.J.4 The formation of the proton gradient is linked to the synthesis of ATP from ADP and inorganic phosphate via ATP synthase.
	ENE-1.J.5 The energy captured in the light reactions and transferred to ATP and NADPH powers the production of carbohydrates from carbon dioxide in the Calvin cycle, which occurs in the stroma of the chloroplast.
	EXCLUSION STATEMENT—*Memorization of the steps in the Calvin cycle, the structure of the molecules, and the names of enzymes (with the exception of ATP synthase) are beyond the scope of the course and the AP Exam.*

TOPIC 3.6
Cellular Respiration

SUGGESTED SKILL

Representing and Describing Data

4.A
Construct a graph, plot, or chart.

AVAILABLE RESOURCES
- AP Biology Lab Manual > **Cellular Respiration Lab**
- Classroom Resources > **Visualizing Information**

Required Course Content

ENDURING UNDERSTANDING

ENE-1
The highly complex organization of living systems requires constant input of energy and the exchange of macromolecules.

LEARNING OBJECTIVE

ENE-1.K
Describe the processes that allow organisms to use energy stored in biological macromolecules.

ESSENTIAL KNOWLEDGE

ENE-1.K.1
Fermentation and cellular respiration use energy from biological macromolecules to produce ATP. Respiration and fermentation are characteristic of all forms of life.

ENE-1.K.2
Cellular respiration in eukaryotes involves a series of coordinated enzyme-catalyzed reactions that capture energy from biological macromolecules.

ENE-1.K.3
The electron transport chain transfers energy from electrons in a series of coupled reactions that establish an electrochemical gradient across membranes—

a. Electron transport chain reactions occur in chloroplasts, mitochondria, and prokaryotic plasma membranes.

b. In cellular respiration, electrons delivered by NADH and $FADH_2$ are passed to a series of electron acceptors as they move toward the terminal electron acceptor, oxygen. In photosynthesis, the terminal electron acceptor is $NADP^+$. Aerobic prokaryotes use oxygen as a terminal electron acceptor, while anaerobic prokaryotes use other molecules.

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LEARNING OBJECTIVE

ENE-1.K

Describe the processes that allow organisms to use energy stored in biological macromolecules.

ESSENTIAL KNOWLEDGE

c. The transfer of electrons is accompanied by the formation of a proton gradient across the inner mitochondrial membrane or the internal membrane of chloroplasts, with the membrane(s) separating a region of high proton concentration from a region of low proton concentration. In prokaryotes, the passage of electrons is accompanied by the movement of protons across the plasma membrane.

d. The flow of protons back through membrane-bound ATP synthase by chemiosmosis drives the formation of ATP from ADP and inorganic phosphate. This is known as oxidative phosphorylation in cellular respiration, and photophosphorylation in photosynthesis.

e. In cellular respiration, decoupling oxidative phosphorylation from electron transport generates heat. This heat can be used by endothermic organisms to regulate body temperature.

X EXCLUSION STATEMENT—*The names of the specific electron carriers in the electron transport chain are beyond the scope of the course and the AP Exam.*

ENE-1.L

Explain how cells obtain energy from biological macromolecules in order to power cellular functions.

ENE-1.L.1

Glycolysis is a biochemical pathway that releases energy in glucose to form ATP from ADP and inorganic phosphate, NADH from NAD+, and pyruvate.

ENE-1.L.2

Pyruvate is transported from the cytosol to the mitochondrion, where further oxidation occurs.

ENE-1.L.3

In the Krebs cycle, carbon dioxide is released from organic intermediates, ATP is synthesized from ADP and inorganic phosphate, and electrons are transferred to the coenzymes NADH and $FADH_2$.

ENE-1.L.4

Electrons extracted in glycolysis and Krebs cycle reactions are transferred by NADH and $FADH_2$ to the electron transport chain in the inner mitochondrial membrane.

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LEARNING OBJECTIVE	ESSENTIAL KNOWLEDGE
ENE-1.L Explain how cells obtain energy from biological macromolecules in order to power cellular functions.	**ENE-1.L.5** When electrons are transferred between molecules in a sequence of reactions as they pass through the ETC, an electrochemical gradient of protons (hydrogen ions) across the inner mitochondrial membrane is established.
	ENE-1.L.6 Fermentation allows glycolysis to proceed in the absence of oxygen and produces organic molecules, including alcohol and lactic acid, as waste products.
	ENE-1.L.7 The conversion of ATP to ADP releases energy, which is used to power many metabolic processes.
	X **EXCLUSION STATEMENT—***Specific steps, names of enzymes, and intermediates of the pathways for these processes are beyond the scope of the course and the AP Exam.*
	X **EXCLUSION STATEMENT—***Memorization of the steps in glycolysis and the Krebs cycle, and of the structures of the molecules and the names of the enzymes involved, are beyond the scope of the course and the AP Exam.*

SUGGESTED SKILL

Argumentation

6.C

Provide reasoning to justify a claim by connecting evidence to biological theories.

AVAILABLE RESOURCES

- Classroom Resource > **Evolution and Change**
- AP Biology Lab Manual > **BLAST Lab**

ILLUSTRATIVE EXAMPLES

- Different types of phospholipids in cell membranes allow the organism flexibility to adapt to different environmental temperatures.
- Different types of hemoglobin maximize oxygen absorption in organisms at different developmental stages.
- Different chlorophylls give the plant greater flexibility to exploit/absorb incoming wavelengths of light for photosynthesis.

TOPIC 3.7
Fitness

Required Course Content

ENDURING UNDERSTANDING

SYI-3

Naturally occurring diversity among and between components within biological systems affects interactions with the environment.

LEARNING OBJECTIVE

SYI-3.A

Explain the connection between variation in the number and types of molecules within cells to the ability of the organism to survive and/or reproduce in different environments.

ESSENTIAL KNOWLEDGE

SYI-3.A.1

Variation at the molecular level provides organisms with the ability to respond to a variety of environmental stimuli.

SYI-3.A.2

Variation in the number and types of molecules within cells provides organisms a greater ability to survive and/or reproduce in different environments.

AP BIOLOGY

UNIT 4

Cell Communication and Cell Cycle

10–15%
AP EXAM WEIGHTING

~9–11
CLASS PERIODS

Remember to go to **AP Classroom** to assign students the online **Personal Progress Check** for this unit.

Whether assigned as homework or completed in class, the **Personal Progress Check** provides each student with immediate feedback related to this unit's topic and skills.

Personal Progress Check 4

Multiple-choice: ~25 questions
Free-response: 2 questions

- Interpreting and Evaluating Experimental Results (partial)
- Analyze Data

UNIT 4

10–15% AP EXAM WEIGHTING | **~9–11** CLASS PERIODS

Cell Communication and Cell Cycle

BIG IDEA 2
Energetics **ENE**
- In what ways do cells use energy to communicate with one another?

BIG IDEA 3
Information Storage and Transmission **IST**
- How does the cell cycle aid in the conservation of genetic information?
- Why and in what ways do cells communicate with one another?

Developing Understanding

In Unit 4, students continue to learn about the role of cells, focusing on how cells use energy and information transmission to communicate and replicate. Through systems of complex transduction pathways, cells can communicate with one another. Cells can also generate and receive signals, coordinate mechanisms for growth, and respond to environmental cues. To maintain homeostasis, cells respond to their environment. They can also replicate and regulate replication as part of the cell cycle that provides for the continuity of life. In Unit 5, students will move on to learn about heredity.

Building Science Practices

1.A 1.B 3.D 4.A 6.A 6.B 6.E.b

Students build on their abilities to describe and explain biological concepts and processes by describing the cell cycle regulation. Students should now be able to explain the relationships between structure and function for all organelles and cellular components on both the subcellular and the cellular level.

By performing laboratory investigations focused on the concepts of cell cycle, students should develop an understanding of how to formulate and devise a plan to investigate the answer to a scientific question—critical skills for scientific inquiry. Students continue to build skills in communicating the results of scientific inquiry. This is a unit where students can be given opportunities to practice their graphing skills.

Preparing for the AP Exam

For the AP Exam, students must have a deep understanding of the significance of the steps in cell signaling, the amplification of the signal, the recycling of relay molecules between activated and inactivated forms to regulate the cellular response, and the multiple roles of the same molecules in providing specificity. Using the principles of cell signaling, students should be able to explain—using claim, evidence, and reasoning—how a drug works or how the symptoms of a chronic disease arise. Students should understand that signal molecules bind to receptors and that gene expression can be stimulated by signal transduction.

Students may be expected to predict the effect on a cell if there is a disruption in the cell cycle. A common error on the exam is failure to explain the purpose and timing of the cell cycle checkpoints. Students should also be prepared to answer a comparative question about mitosis and meiosis.

UNIT AT A GLANCE

Enduring Understanding	Topic	Suggested Skill	Class Periods ~9–11 CLASS PERIODS
IST-3	**4.1 Cell Communication**	1.B Explain biological concepts and/or processes.	
IST-3	**4.2 Introduction to Signal Transduction**	1.A Describe biological concepts and/or processes.	
IST-3	**4.3 Signal Transduction**	6.C Provide reasoning to justify a claim by connecting evidence to biological theories.	
IST-3	**4.4 Changes in Signal Transduction Pathways**	6.E.b Predict the causes or effects of a change in, or disruption to, one or more components in a biological system based on a visual representation of a biological concept, process, or model.	
ENE-3	**4.5 Feedback**	6.E.b Predict the causes or effects of a change in, or disruption to, one or more components in a biological system based on a visual representation of a biological concept, process, or model.	
IST-1	**4.6 Cell Cycle**	4.B.b Describe data from a table or graph, including describing trends and/or patterns in the data. 5.A.e Perform mathematical calculations, including percentages.	
IST-1	**4.7 Regulation of Cell Cycle**	6.E.a Predict the causes or effects of a change in, or disruption to, one or more components in a biological system based on biological concepts or processes.	

Go to **AP Classroom** to assign the **Personal Progress Check** for Unit 4.
Review the results in class to identify and address any student misunderstandings.

SAMPLE INSTRUCTIONAL ACTIVITIES

The sample activities on this page are intended to give you ideas of ways to incorporate varied instructional approaches in the teaching of this course. You do not need to use these activities or approaches and are free to alter or edit them in any way you choose. The following examples were developed in partnership with teachers from the AP community to share ways that they approach teaching some of the topics in this unit. Please refer to the Instructional Approaches section beginning on p. 171 for more examples of activities and strategies.

Activity	Topic	Sample Activity
1	4.1	**One-Minute Essay** Have students do research online (provide reputable websites for them to use) to learn about diseases that result from a breakdown in cell communication. Assign students a one-minute essay with a prompt that allows the formative assessment of their understanding, such as, "Describe an example of communication between two cells."
2	4.2	**Ask the Expert** Students can be divided into three groups. Each group will complete one of the three sections of the Signal Transduction POGIL. The teacher can debrief with each group to clarify misconceptions. Students will then rotate between groups so that they share their understandings of the model they studied and learn from one another. The teacher can follow up with a debrief to clarify any outstanding misconceptions.
3	4.4	**Fishbowl** Students can read a case study about cell signaling and then answer any questions that may accompany the case study. Alternately, teachers can provide appropriate questions and/or assignments to ensure that students understand the concepts addressed in the case study. Students can then do a fishbowl to discuss their learnings from the case study and applications to real life.

Unit Planning Notes

Use the space below to plan your approach to the unit. Consider how you want to pace your course and your methods of instruction and assessment.

SUGGESTED SKILL

Concept Explanation

1.B

Explain biological concepts and/or processes.

AVAILABLE RESOURCES

- Classroom Resource > **Cell-to-Cell Communication—Cell Signaling**

ILLUSTRATIVE EXAMPLES

Cell-to-Cell Contact IST.3.A.1

- Immune cells interact by cell-to-cell contact, antigen-presenting cells (APCs), helper T-cells, and killer T-cells.
- Plasmodesmata between plant cells allow material to be transported from cell to cell.

Cell Communication Using Local Regulators IST-3.B.1

- Neurotransmitters
- Plant immune response
- Quorum sensing in bacteria
- Morphogens in embryonic development

IST-3.B.1.a

- Insulin
- Human growth hormone
- Thyroid hormones
- Testosterone
- Estrogen

TOPIC 4.1
Cell Communication

Required Course Content

ENDURING UNDERSTANDING

IST-3

Cells communicate by generating, transmitting, receiving, and responding to chemical signals.

LEARNING OBJECTIVE	ESSENTIAL KNOWLEDGE
IST-3.A Describe the ways that cells can communicate with one another.	IST-3.A.1 Cells communicate with one another through direct contact with other cells or from a distance via chemical signaling— a. Cells communicate by cell-to-cell contact.
IST-3.B Explain how cells communicate with one another over short and long distances.	IST-3.B.1 Cells communicate over short distances by using local regulators that target cells in the vicinity of the signal-emitting cell— a. Signals released by one cell type can travel long distances to target cells of another cell type.

TOPIC 4.2

Introduction to Signal Transduction

Required Course Content

ENDURING UNDERSTANDING

IST-3

Cells communicate by generating, transmitting, receiving, and responding to chemical signals.

LEARNING OBJECTIVE

IST-3.C

Describe the components of a signal transduction pathway.

ESSENTIAL KNOWLEDGE

IST-3.C.1

Signal transduction pathways link signal reception with cellular responses.

IST-3.C.2

Many signal transduction pathways include protein modification and phosphorylation cascades.

LEARNING OBJECTIVE

IST-3.D

Describe the role of components of a signal transduction pathway in producing a cellular response.

ESSENTIAL KNOWLEDGE

IST-3.D.1

Signaling begins with the recognition of a chemical messenger—a ligand—by a receptor protein in a target cell—

a. The ligand-binding domain of a receptor recognizes a specific chemical messenger, which can be a peptide, a small chemical, or protein, in a specific one-to-one relationship.

b. G protein-coupled receptors are an example of a receptor protein in eukaryotes.

IST-3.D.2

Signaling cascades relay signals from receptors to cell targets, often amplifying the incoming signals, resulting in the appropriate responses by the cell, which could include cell growth, secretion of molecules, or gene expression—

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SUGGESTED SKILL

Concept Application

1.A

Describe biological concepts and/or processes.

AVAILABLE RESOURCES

- Classroom Resource > **Cell-to-Cell Communication—Cell Signaling**

LEARNING OBJECTIVE

IST-3.D

Describe the role of components of a signal transduction pathway in producing a cellular response.

ESSENTIAL KNOWLEDGE

a. After the ligand binds, the intracellular domain of a receptor protein changes shape, initiating transduction of the signal.

b. Second messengers (such as cyclic AMP) are molecules that relay and amplify the intracellular signal.

c. Binding of ligand-to-ligand-gated channels can cause the channel to open or close.

TOPIC 4.3
Signal Transduction

Required Course Content

ENDURING UNDERSTANDING

IST-3

Cells communicate by generating, transmitting, receiving, and responding to chemical signals.

LEARNING OBJECTIVE

IST-3.E

Describe the role of the environment in eliciting a cellular response.

ESSENTIAL KNOWLEDGE

IST-3.E.1

Signal transduction pathways influence how the cell responds to its environment.

LEARNING OBJECTIVE

IST-3.F

Describe the different types of cellular responses elicited by a signal transduction pathway.

ESSENTIAL KNOWLEDGE

IST-3.F.1

Signal transduction may result in changes in gene expression and cell function, which may alter phenotype or result in programmed cell death (apoptosis).

SUGGESTED SKILL

Argumentation

6.C

Provide reasoning to justify a claim by connecting evidence to biological theories.

AVAILABLE RESOURCES

- Classroom Resource > **Cell-to-Cell Communication—Cell Signaling**

ILLUSTRATIVE EXAMPLES

Using Signal Transduction to Respond to the Environment

- Use of chemical messengers by microbes to communicate with other nearby cells and to regulate specific pathways in response to population density (quorum sensing)
- Epinephrine stimulation of glycogen breakdown in mammals

IST-3.F.1

- Cytokines regulate gene expression to allow for cell replication and division.
- Mating pheromones in yeast trigger mating gene expression.
- Expression of the *SRY* gene triggers the male sexual development pathway in animals.
- Ethylene levels cause changes in the production, of different enzymes allowing fruits to ripen.
- HOX genes and their role in development.

SUGGESTED SKILL

Argumentation

6.E.b

Predict the causes or effects of a change in, or disruption to, one or more components in a biological system based on a visual representation of a biological concept, process, or model.

AVAILABLE RESOURCES

- Classroom Resource > **Cell-to-Cell Communication—Cell Signaling**

TOPIC 4.4

Changes in Signal Transduction Pathways

Required Course Content

ENDURING UNDERSTANDING

IST-3

Cells communicate by generating, transmitting, receiving, and responding to chemical signals.

LEARNING OBJECTIVE

IST-3.G

Explain how a change in the structure of any signaling molecule affects the activity of the signaling pathway.

ESSENTIAL KNOWLEDGE

IST-3.G.1

Changes in signal transduction pathways can alter cellular response—

a. Mutations in any domain of the receptor protein or in any component of the signaling pathway may affect the downstream components by altering the subsequent transduction of the signal.

IST-3.G.2

Chemicals that interfere with any component of the signaling pathway may activate or inhibit the pathway.

TOPIC 4.5
Feedback

Required Course Content

ENDURING UNDERSTANDING

ENE-3

Timing and coordination of biological mechanisms involved in growth, reproduction, and homeostasis depend on organisms responding to environmental cues.

LEARNING OBJECTIVE	ESSENTIAL KNOWLEDGE
ENE-3.A Describe positive and/or negative feedback mechanisms.	**ENE-3.A.1** Organisms use feedback mechanisms to maintain their internal environments and respond to internal and external environmental changes.
ENE-3.B Explain how negative feedback helps to maintain homeostasis.	**ENE-3.B.1** Negative feedback mechanisms maintain homeostasis for a particular condition by regulating physiological processes. If a system is perturbed, negative feedback mechanisms return the system back to its target set point. These processes operate at the molecular and cellular levels.
ENE-3.C Explain how positive feedback affects homeostasis.	**ENE-3.C.1** Positive feedback mechanisms amplify responses and processes in biological organisms. The variable initiating the response is moved farther away from the initial set point. Amplification occurs when the stimulus is further activated, which, in turn, initiates an additional response that produces system change.

SUGGESTED SKILL

Argumentation

6.E.b

Predict the causes or effects of a change in, or disruption to, one or more components in a biological system based on a visual representation of a biological concept, process, or model.

AVAILABLE RESOURCES

- Classroom Resource > **Cell-to-Cell Communication—Cell Signaling**

ILLUSTRATIVE EXAMPLE

ENE-3.B.1

- Blood sugar regulation by insulin/glucagon

ENE-3.C.1

- Lactation in mammals
- Onset of labor in childbirth
- Ripening of fruit

SUGGESTED SKILLS

Representing and Describing Data

4.B.b

Describe data from a table or graph, including describing trends and/or patterns in the data.

Statistical Tests and Data Analysis

5.A.e

Perform mathematical calculations, including percentages.

AVAILABLE RESOURCES

- AP Biology Lab Manual > **Mitosis Lab**

TOPIC 4.6
Cell Cycle

Required Course Content

ENDURING UNDERSTANDING

IST-1

Heritable information provides for continuity of life.

LEARNING OBJECTIVE	ESSENTIAL KNOWLEDGE
IST-1.B Describe the events that occur in the cell cycle.	**IST-1.B.1** In eukaryotes, cells divide and transmit genetic information via two highly regulated processes. **IST-1.B.2** The cell cycle is a highly regulated series of events for the growth and reproduction of cells— a. The cell cycle consists of sequential stages of interphase (G1, S, G2), mitosis, and cytokinesis. b. A cell can enter a stage (G0) where it no longer divides, but it can reenter the cell cycle in response to appropriate cues. Nondividing cells may exit the cell cycle or be held at a particular stage in the cell cycle.
IST-1.C Explain how mitosis results in the transmission of chromosomes from one generation to the next.	**IST-1.C.1** Mitosis is a process that ensures the transfer of a complete genome from a parent cell to two genetically identical daughter cells— a. Mitosis plays a role in growth, tissue repair, and asexual reproduction. b. Mitosis alternates with interphase in the cell cycle. c. Mitosis occurs in a sequential series of steps (prophase, metaphase, anaphase, telophase).

TOPIC 4.7

Regulation of Cell Cycle

SUGGESTED SKILL

Argumentation

6.E.a

Predict the causes or effects of a change in, or disruption to, one or more components in a biological system based on biological concepts or processes.

Required Course Content

ENDURING UNDERSTANDING

IST-1

Heritable information provides for continuity of life.

LEARNING OBJECTIVE	ESSENTIAL KNOWLEDGE
IST-1.D Describe the role of checkpoints in regulating the cell cycle.	IST-1.D.1 A number of internal controls or checkpoints regulate progression through the cycle. IST-1.D.2 Interactions between cyclins and cyclin-dependent kinases control the cell cycle. **EXCLUSION STATEMENT—***Knowledge of specific cyclin-CdK pairs or growth factors is beyond the scope of the course and the AP Exam.*
IST-1.E Describe the effects of disruptions to the cell cycle on the cell or organism.	IST-1.E.1 Disruptions to the cell cycle may result in cancer and/or programmed cell death (apoptosis).

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AP BIOLOGY

UNIT 5

Heredity

8–11%
AP EXAM WEIGHTING

~9–11
CLASS PERIODS

Remember to go to **AP Classroom** to assign students the online **Personal Progress Check** for this unit.

Whether assigned as homework or completed in class, the **Personal Progress Check** provides each student with immediate feedback related to this unit's topic and skills.

Personal Progress Check 5

Multiple-choice: ~25 questions
Free-response: 2 questions

- Interpreting and Evaluating Experimental Results with Graphing
- Conceptual Analysis

UNIT 5

8–11% AP EXAM WEIGHTING | ~9–11 CLASS PERIODS

Heredity

BIG IDEA 1
***Evolution* EVO**

- How is our understanding of evolution influenced by our knowledge of genetics?

BIG IDEA 3
***Information Storage and Transmission* IST**

- Why is it important that not all inherited characteristics get expressed in the next generation?
- How would Mendel's laws have been affected if he had studied a different type of plant?

BIG IDEA 4
***Systems Interactions* SYI**

- How does the diversity of a species affect inheritance?

Developing Understanding

Unit 5 focuses on heredity and the biological concepts and processes involved in ensuring the continuity of life. Students learn that the storage and transmission of genetic information via chromosomes from one generation to the next occur through meiosis. Meiotic division ensures genetic diversity, which is crucial to the survival of a species. In this unit, students gain a deeper understanding of Mendelian genetics and learning how non-Mendelian genetics describes those patterns of inheritance that seem to violate Mendel's laws. This unit also teaches the role played by chromosomal inheritance, environmental factors, and nondisjunction on an individual's phenotype. In Unit 6, students move on to learn about gene expression and regulation.

Building Science Practices

1.B 1.C 3.A 5.C 6.E.b 6.E.c

Data can convey important information about biological systems. In order to understand that information, students need to practice describing data and then identifying and describing the patterns and trends that might make the data meaningful for the researcher and possibly lead to the discovery of new information or the development of new concepts. Comparing patterns and trends in data helps students describe biological changes that occur over time, predict short-term and long-term changes, and draw conclusions about the causes and/or solutions to problems in biological systems.

Students should understand the value and application of the chi-square test in additional contexts beyond genetics. Students should learn the difference between null and alternate hypotheses while understanding that the chi-square is not always the most appropriate statistical test to analyze the results of an experiment.

Preparing for the AP Exam

In this unit students need to analyze and construct models of chromosomal exchange, using them to predict the results of a given scenario, such as a mistake in crossing over or the haploid results of meiosis.

Students also need to calculate genotypic and/or phenotypic ratios. Be sure students understand the difference in these two types of ratios, as confusion between them is a common student error on the exam.

Additionally, students should expect to calculate a chi-square value and explain the meaning in context of a given scenario. On the exam, students commonly fail to identify the null hypothesis rather than an alternate hypothesis; thus, they will need multiple and varied opportunities to practice this skill. Building their skills in experimental design throughout the course will help address this misconception. Emphasis should be on helping students understand when to reject or fail to reject the null hypothesis.

UNIT AT A GLANCE

Enduring Understanding	Topic	Suggested Skill	Class Periods ~9–11 CLASS PERIODS
IST-1	**5.1 Meiosis**	1.B Explain biological concepts and/or processes.	
IST-1	**5.2 Meiosis and Genetic Diversity**	3.A Identify or pose a testable question based on an observation, data, or a model.	
EVO-2, IST-1	**5.3 Mendelian Genetics**	5.C Perform chi-square hypothesis testing. 6.E.c Predict the causes or effects of a change in, or disruption to, one or more components in a biological system based on data.	
IST-1	**5.4 Non-Mendelian Genetics**	5.A.b Perform mathematical calculations, including means. 5.C Perform chi-square hypothesis testing.	
SYI-3	**5.5 Environmental Effects on Phenotype**	1.C Explain biological concepts, processes, and/or models in applied contexts.	
SYI-3	**5.6 Chromosomal Inheritance**	6.E.b Predict the causes or effects of a change in, or disruption to, one or more components in a biological system based on a visual representation of a biological concept, process, or model.	

Go to **AP Classroom** to assign the **Personal Progress Check** for Unit 5.
Review the results in class to identify and address any student misunderstandings.

SAMPLE INSTRUCTIONAL ACTIVITIES

The sample activities on this page are intended to give you ideas of ways to incorporate varied instructional approaches in the teaching of this course. You do not need to use these activities or approaches and are free to alter or edit them in any way you choose. The following examples were developed in partnership with teachers from the AP community to share ways that they approach teaching some of the topics in this unit. Please refer to the Instructional Approaches section beginning on p. 171 for more examples of activities and strategies.

Activity	Topic	Sample Activity
1	5.1	**Think-Pair-Share** Students can construct simulated chromosomes with pop beads or pipe cleaners and manipulate them through the stages of meiosis. As students are modeling the process, they can make a sketch or take a photograph of each stage. They should begin with either a $2n=4$ or a $2n=6$ "cell" so that they can build their understanding using a simpler system before applying what they have learned to meiosis in humans. This can be introduced or de-briefed using a Think-Pair-Share approach.
2	5.3	**Construct an Argument** Students can use genetic corn to apply the chi-square test to a dihybrid cross. First, students calculate the expected genotypic and phenotypic ratios using a Punnett square. They then formulate null hypotheses for the cross and perform a chi-square test. They conclude by stating whether they should reject or fail to reject the null hypothesis and justify their reasoning.
3	5.5	**Debate** Students can read a case study about the genetics and evolution of skin color, then answer any questions that may accompany the case study. Alternately, teachers can provide appropriate questions and/or assignments to ensure that students understand the concepts addressed in the case study. Instead of answering the questions on paper, students can be divided into groups to debate possible answers to some or all of the questions. This activity can be augmented by having students read an article about the biology of skin color.

Unit Planning Notes

Use the space below to plan your approach to the unit. Consider how you want to pace your course and your methods of instruction and assessment.

SUGGESTED SKILL

Concept Explanation

1.B

Explain biological concepts and/or processes.

AVAILABLE RESOURCES

- AP Biology Lab Manual > **Meiosis Lab**

TOPIC 5.1
Meiosis

Required Course Content

ENDURING UNDERSTANDING

IST-1

Heritable information provides for continuity of life.

LEARNING OBJECTIVE	ESSENTIAL KNOWLEDGE
IST-1.F Explain how meiosis results in the transmission of chromosomes from one generation to the next.	**IST-1.F.1** Meiosis is a process that ensures the formation of haploid gamete cells in sexually reproducing diploid organisms— a. Meiosis results in daughter cells with half the number of chromosomes of the parent cell. b. Meiosis involves two rounds of a sequential series of steps (meiosis I and meiosis II).
IST-1.G Describe similarities and/or differences between the phases and outcomes of mitosis and meiosis.	**IST-1.G.1** Mitosis and meiosis are similar in the way chromosomes segregate but differ in the number of cells produced and the genetic content of the daughter cells.

TOPIC 5.2

Meiosis and Genetic Diversity

SUGGESTED SKILL

Questions and Methods

3.A

Identify or pose a testable question based on an observation, data, or a model.

AVAILABLE RESOURCES

- AP Biology Lab Manual> **Meiosis Lab**

Required Course Content

ENDURING UNDERSTANDING

IST-1

Heritable information provides for continuity of life.

LEARNING OBJECTIVE

IST-1.H

Explain how the process of meiosis generates genetic diversity.

ESSENTIAL KNOWLEDGE

IST-1.H.1

Separation of the homologous chromosomes in meiosis I ensures that each gamete receives a haploid (1*n*) set of chromosomes that comprises both maternal and paternal chromosomes.

IST-1.H.2

During meiosis I, homologous chromatids exchange genetic material via a process called "crossing over" (recombination), which increases genetic diversity among the resultant gametes.

IST-1.H.3

Sexual reproduction in eukaryotes involving gamete formation—including crossing over, the random assortment of chromosomes during meiosis, and subsequent fertilization of gametes—serves to increase variation.

EXCLUSION STATEMENT—*The details of sexual reproduction cycles in various plants and animals are beyond the scope of the course and the AP Exam.*

SUGGESTED SKILLS

Argumentation

6.E.c

Predict the causes or effects of a change in, or disruption to, one or more components in a biological system based on data.

Statistical Tests and Data Analysis

5.C

Perform chi-square hypothesis testing.

TOPIC 5.3

Mendelian Genetics

Required Course Content

ENDURING UNDERSTANDING

EVO-2

Organisms are linked by lines of descent from common ancestry.

IST-1

Heritable information provides for continuity of life.

LEARNING OBJECTIVE	ESSENTIAL KNOWLEDGE
EVO-2.A Explain how shared, conserved, fundamental processes and features support the concept of common ancestry for all organisms.	**EVO-2.A.1** DNA and RNA are carriers of genetic information. **EVO-2.A.2** Ribosomes are found in all forms of life. **EVO-2.A.3** Major features of the genetic code are shared by all modern living systems. **EVO-2.A.4** Core metabolic pathways are conserved across all currently recognized domains.
IST-1.I Explain the inheritance of genes and traits as described by Mendel's laws.	**IST-1.I.1** Mendel's laws of segregation and independent assortment can be applied to genes that are on different chromosomes.

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LEARNING OBJECTIVE

IST-1.I

Explain the inheritance of genes and traits as described by Mendel's laws.

ESSENTIAL KNOWLEDGE

IST-1.I.2

Fertilization involves the fusion of two haploid gametes, restoring the diploid number of chromosomes and increasing genetic variation in populations by creating new combinations of alleles in the zygote—

a. Rules of probability can be applied to analyze passage of single-gene traits from parent to offspring.

b. The pattern of inheritance (monohybrid, dihybrid, sex-linked, and genetically linked genes) can often be predicted from data, including pedigree, that give the parent genotype/phenotype and the offspring genotypes/phenotypes.

RELEVANT EQUATION

Laws of Probability—

If A and B are mutually exclusive, then:

$P(A \text{ or } B) = P(A) + P(B)$

If A and B are independent, then:

$P(A \text{ and } B) = P(A) \times P(B)$

SUGGESTED SKILLS

Statistical Tests and Data Analysis

5.A.b
Perform mathematical calculations, including means.

5.C
Perform chi-square hypothesis testing.

ILLUSTRATIVE EXAMPLES

- Sex-linked genes reside on sex chromosomes.
- In mammals and flies, females are XX and males are XY; as such, X-linked recessive traits are always expressed in males.
- In certain species, the chromosomal basis of sex determination is not based on X and Y chromosomes (such as ZW in birds, haplodiploidy in bees).

TOPIC 5.4

Non-Mendelian Genetics

Required Course Content

ENDURING UNDERSTANDING

IST-1
Heritable information provides for continuity of life.

LEARNING OBJECTIVE

IST-1.J
Explain deviations from Mendel's model of the inheritance of traits.

ESSENTIAL KNOWLEDGE

IST-1.J.1
Patterns of inheritance of many traits do not follow ratios predicted by Mendel's laws and can be identified by quantitative analysis, where observed phenotypic ratios statistically differ from the predicted ratios—

a. Genes that are adjacent and close to one another on the same chromosome may appear to be genetically linked; the probability that genetically linked genes will segregate as a unit can be used to calculate the map distance between them.

IST-1.J.2
Some traits are determined by genes on sex chromosomes and are known as sex-linked traits. The pattern of inheritance of sex-linked traits can often be predicted from data, including pedigree, indicating the parent genotype/phenotype and the offspring genotypes/phenotypes.

IST-1.J.3
Many traits are the product of multiple genes and/or physiological processes acting in combination; these traits therefore do not segregate in Mendelian patterns.

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LEARNING OBJECTIVE

IST-1.J

Explain deviations from Mendel's model of the inheritance of traits.

ESSENTIAL KNOWLEDGE

IST-1.J.4

Some traits result from non-nuclear inheritance—

a. Chloroplasts and mitochondria are randomly assorted to gametes and daughter cells; thus, traits determined by chloroplast and mitochondrial DNA do not follow simple Mendelian rules.

b. In animals, mitochondria are transmitted by the egg and not by sperm; as such, traits determined by the mitochondrial DNA are maternally inherited.

c. In plants, mitochondria and chloroplasts are transmitted in the ovule and not in the pollen; as such, mitochondria-determined and chloroplast-determined traits are maternally inherited.

SUGGESTED SKILL

Concept Explanation

1.C

Explain biological concepts, processes, and/or models in applied contexts.

ILLUSTRATIVE EXAMPLES

- Height and weight in humans
- Flower color based on soil pH
- Seasonal fur color in arctic animals
- Sex determination in reptiles
- Effect of increased UV on melanin production in animals
- Presence of the opposite mating type on pheromone production in yeast and other fungi

TOPIC 5.5

Environmental Effects on Phenotype

Required Course Content

ENDURING UNDERSTANDING

SYI-3

Naturally occurring diversity among and between components within biological systems affects interactions with the environment.

LEARNING OBJECTIVE

SYI-3.B

Explain how the same genotype can result in multiple phenotypes under different environmental conditions.

ESSENTIAL KNOWLEDGE

SYI-3.B.1

Environmental factors influence gene expression and can lead to phenotypic plasticity. Phenotypic plasticity occurs when individuals with the same genotype exhibit different phenotypes in different environments.

TOPIC 5.6
Chromosomal Inheritance

Required Course Content

ENDURING UNDERSTANDING

SYI-3

Naturally occurring diversity among and between components within biological systems affects interactions with the environment.

LEARNING OBJECTIVE

SYI-3.C

Explain how chromosomal inheritance generates genetic variation in sexual reproduction.

ESSENTIAL KNOWLEDGE

SYI-3.C.1

Segregation, independent assortment of chromosomes, and fertilization result in genetic variation in populations.

SYI-3.C.2

The chromosomal basis of inheritance provides an understanding of the pattern of transmission of genes from parent to offspring.

SYI-3.C.3

Certain human genetic disorders can be attributed to the inheritance of a single affected or mutated allele or specific chromosomal changes, such as nondisjunction.

SUGGESTED SKILL

Argumentation

6.E.b

Predict the causes or effects of a change in, or disruption to, one or more components in a biological system based on a visual representation of a biological concept, process, or model.

ILLUSTRATIVE EXAMPLES

SYI-3.C.3

- Sickle cell anemia
- Tay-Sachs disease
- Huntington's disease
- X-linked color blindness
- Trisomy 21/Down syndrome

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AP BIOLOGY

UNIT 6

Gene Expression and Regulation

12–16%
AP EXAM WEIGHTING

~18–21
CLASS PERIODS

Remember to go to **AP Classroom** to assign students the online **Personal Progress Check** for this unit.

Whether assigned as homework or completed in class, the **Personal Progress Check** provides each student with immediate feedback related to this unit's topic and skills.

Personal Progress Check 6

Multiple-choice: ~25 questions
Free-response: 2 questions

- Interpreting and Evaluating Experimental Results
- Analyze Model or Visual Representation

UNIT 6

12–16% AP EXAM WEIGHTING | **~18–21** CLASS PERIODS

Gene Expression and Regulation

BIG IDEA 3
Information Storage and Transmission **IST**

- How does gene regulation relate to the continuity of life?
- How is a species' genetic information diversified from generation to generation?

Developing Understanding

Progressing from the continuity of life to gene expression, in Unit 6 students gain in-depth knowledge about nucleic acids and their role in gene expression. Students receive a finer focus on the comparison between the structures of DNA and RNA. This unit highlights how an individual's genotype is physically expressed through that individual's phenotype. Understanding protein synthesis (transcription and translation) is vital to answering essential questions about gene expression. Regulation of gene expression and cell specialization are instrumental in ensuring survival within an individual and across populations. Unit 7 moves on to cover natural selection.

Building Science Practices

1.C 2.B.b 2.C 6.A 6.B 6.D 6.E.a

The ability to describe, analyze, and create models and representations to explain and/or illustrate biological processes and make predictions about them is an important skill for students to master. The primary learning goal in this unit is to create or use a representation/model to communicate biological phenomena, use the model to solve a problem, and refine the model or representation to analyze situations or solve problems.

Throughout the course, students should have had multiple opportunities that involve making a claim, supporting it with evidence, and providing reasoning to support the claim. In this unit and throughout the course, students should become proficient in argumentation by predicting the causes or effects of a change in, or disruption to, one or more components in a biological system.

Preparing for the AP Exam

Students often do not understand the difference between a gene and an allele. Gene expression occurs at many levels, all of which are crucial in producing an organism's phenotype. Students can use the *lac* operon in *E. coli* to help them understand the significance of positive gene regulation.

Often on the exam, students fail to provide reasoning connecting a change on the molecular level (e.g., a mutation) to a change in phenotype (e.g., an increase or decrease in protein levels). Students should understand that the location of a mutation in the codon can affect the structure and function of a protein. Common errors include stating that mutations result in the denaturation of a protein or that point mutations cause frameshift mutations. Students also tend to describe all mutations as having negative effects; exposure to examples of mutations that have no impact on phenotype can help prevent this misunderstanding.

UNIT AT A GLANCE

Enduring Understanding	Topic	Suggested Skill	Class Periods ~18–21 CLASS PERIODS
IST-1	6.1 DNA and RNA Structure	1.C Explain biological concepts, processes, and/or models in applied contexts.	
	6.2 Replication	2.B.b Explain relationships between different characteristics of biological concepts, processes, or models represented visually in applied contexts.	
	6.3 Transcription and RNA Processing	2.B.b Explain relationships between different characteristics of biological concepts, processes, or models represented visually in applied contexts.	
	6.4 Translation	2.D.b Represent relationships within biological models, including diagrams. 6.E.a Predict the causes or effects of a change in, or disruption to, one or more components in a biological system based on biological concepts.	
IST-2	6.5 Regulation of Gene Expression	6.A Make a scientific claim.	
	6.6 Gene Expression and Cell Specialization	6.B Support a claim with evidence from biological principles, concepts, processes, and/or data.	
IST-2, IST-4	6.7 Mutations	2.C Explain how biological concepts or processes represented visually relate to larger biological principles, concepts, processes, or theories. 3.D Make observations or collect data from representations of laboratory setups or results.	
IST-1	6.8 Biotechnology	6.D Explain the relationship between experimental results and larger biological concepts, processes, or theories.	

Go to **AP Classroom** to assign the **Personal Progress Check** for Unit 6. Review the results in class to identify and address any student misunderstandings.

SAMPLE INSTRUCTIONAL ACTIVITIES

The sample activities on this page are intended to give you ideas of ways to incorporate varied instructional approaches in the teaching of this course. You do not need to use these activities or approaches and are free to alter or edit them in any way you choose. The following examples were developed in partnership with teachers from the AP community to share ways that they approach teaching some of the topics in this unit. Please refer to the Instructional Approaches section beginning on p. 171 for more examples of activities and strategies.

Activity	Topic	Sample Activity
1	6.2	**Misconception Check** Using diagrams of nucleotides that can be found on the internet and photocopied, students can model the process of replication, explaining what is happening as they go. You can easily assess their understanding by observing the results of replication that students produce.
2	6.3	**Think-Pair-Share** Students build a model of transcription using pool noodles that can be purchased at a dollar store. Using everyday materials, such as tape, colored paper, yarn (or string), and markers, they identify the promoter region, TATA box, transcription start site, and terminal sequence. They describe the process of transcription from the initial binding of the transcription factors to the production of the transcript. This can be introduced or de-briefed using a Think-Pair-Share approach.
3	6.4	**Construct an Argument** Students develop a skit to demonstrate the process of translation. Once they have an understanding of the process, challenge them to act out what might happen if there were a change in the DNA sequence or if one of the needed components was unavailable. Debrief by having students explain the rationale for the modifications they made in their skit.

Unit Planning Notes

Use the space below to plan your approach to the unit. Consider how you want to pace your course and your methods of instruction and assessment.

SUGGESTED SKILL

Concept Explanation

1.C

Explain biological concepts, processes, and/or models in applied contexts.

AVAILABLE RESOURCES

- Classroom Resources > **From Gene to Protein—A Historical Perspective**
- Classroom Resources > **Rosalind Franklin: She's Worth Another Look**

TOPIC 6.1

DNA and RNA Structure

Required Course Content

ENDURING UNDERSTANDING

IST-1

Heritable information provides for continuity of life.

LEARNING OBJECTIVE	ESSENTIAL KNOWLEDGE
IST-1.K Describe the structures involved in passing hereditary information from one generation to the next.	**IST-1.K.1** DNA, and in some cases RNA, is the primary source of heritable information. **IST-1.K.2** Genetic information is transmitted from one generation to the next through DNA or RNA— a. Genetic information is stored in and passed to subsequent generations through DNA molecules and, in some cases, RNA molecules. b. Prokaryotic organisms typically have circular chromosomes, while eukaryotic organisms typically have multiple linear chromosomes. **IST-1.K.3** Prokaryotes and eukaryotes can contain plasmids, which are small extra-chromosomal, double-stranded, circular DNA molecules.
IST-1.L Describe the characteristics of DNA that allow it to be used as the hereditary material.	**IST-1.L.1** DNA, and sometimes RNA, exhibits specific nucleotide base pairing that is conserved through evolution: adenine pairs with thymine or uracil (A-T or A-U) and cytosine pairs with guanine (C-G)— a. Purines (G and A) have a double ring structure. b. Pyrimidines (C, T, and U) have a single ring structure.

TOPIC 6.2
Replication

SUGGESTED SKILL

Visual Representations

2.B.b

Explain relationships between different characteristics of biological concepts, processes, or models represented visually in applied contexts.

AVAILABLE RESOURCES

- Classroom Resources > **From Gene to Protein—A Historical Perspective**

Required Course Content

ENDURING UNDERSTANDING

IST-1

Heritable information provides for continuity of life.

LEARNING OBJECTIVE

IST-1.M

Describe the mechanisms by which genetic information is copied for transmission between generations.

ESSENTIAL KNOWLEDGE

IST-1.M.1

DNA replication ensures continuity of hereditary information—

a. DNA is synthesized in the 5′ to 3′ direction.

b. Replication is a semiconservative process—that is, one strand of DNA serves as the template for a new strand of complementary DNA.

c. Helicase unwinds the DNA strands.

d. Topoisomerase relaxes supercoiling in front of the replication fork.

e. DNA polymerase requires RNA primers to initiate DNA synthesis.

f. DNA polymerase synthesizes new strands of DNA continuously on the leading strand and discontinuously on the lagging strand.

g. Ligase joins the fragments on the lagging strand.

EXCLUSION STATEMENT—*The names of the steps and particular enzymes involved—beyond DNA polymerase, ligase, RNA polymerase, helicase, and topoisomerase—are beyond the scope of the course and the AP Exam.*

SUGGESTED SKILL

Visual Representations

2.B.b

Explain relationships between different characteristics of biological concepts, processes, or models represented visually in applied contexts.

AVAILABLE RESOURCES

- Classroom Resources > **From Gene to Protein—A Historical Perspective**

TOPIC 6.3

Transcription and RNA Processing

Required Course Content

ENDURING UNDERSTANDING

IST-1

Heritable information provides for continuity of life.

LEARNING OBJECTIVE

IST-1.N

Describe the mechanisms by which genetic information flows from DNA to RNA to protein.

ESSENTIAL KNOWLEDGE

IST-1.N.1

The sequence of the RNA bases, together with the structure of the RNA molecule, determines RNA function—

a. mRNA molecules carry information from DNA to the ribosome.

b. Distinct tRNA molecules bind specific amino acids and have anti-codon sequences that base pair with the mRNA. tRNA is recruited to the ribosome during translation to generate the primary peptide sequence based on the mRNA sequence.

c. rRNA molecules are functional building blocks of ribosomes.

IST-1.N.2

Genetic information flows from a sequence of nucleotides in DNA to a sequence of bases in an mRNA molecule to a sequence of amino acids in a protein.

IST-1.N.3

RNA polymerases use a single template strand of DNA to direct the inclusion of bases in the newly formed RNA molecule. This process is known as transcription.

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LEARNING OBJECTIVE

IST-1.N

Describe the mechanisms by which genetic information flows from DNA to RNA to protein.

ESSENTIAL KNOWLEDGE

IST-1.N.4

The DNA strand acting as the template strand is also referred to as the noncoding strand, minus strand, or antisense strand. Selection of which DNA strand serves as the template strand depends on the gene being transcribed.

IST-1.N.5

The enzyme RNA polymerase synthesizes mRNA molecules in the 5′ to 3′ direction by reading the template DNA strand in the 3′ to 5′ direction.

IST-1.N.6

In eukaryotic cells the mRNA transcript undergoes a series of enzyme-regulated modifications—

a. Addition of a poly-A tail.

b. Addition of a GTP cap.

c. Excision of introns and splicing and retention of exons.

d. Excision of introns and splicing and retention of exons can generate different versions of the resulting mRNA molecule; this is known as alternative splicing.

SUGGESTED SKILLS

Argumentation

6.E.a

Predict the causes or effects of a change in, or disruption to, one or more components in a biological system based on biological concepts.

Visual Representations

2.D.b

Represent relationships within biological models, including diagrams.

AVAILABLE RESOURCES

- Classroom Resources > **From Gene to Protein—A Historical Perspective**

TOPIC 6.4
Translation

Required Course Content

ENDURING UNDERSTANDING

IST-1

Heritable information provides for continuity of life.

LEARNING OBJECTIVE

IST-1.O

Explain how the phenotype of an organism is determined by its genotype.

ESSENTIAL KNOWLEDGE

IST-1.O.1

Translation of the mRNA to generate a polypeptide occurs on ribosomes that are present in the cytoplasm of both prokaryotic and eukaryotic cells and on the rough endoplasmic reticulum of eukaryotic cells.

IST-1.O.2

In prokaryotic organisms, translation of the mRNA molecule occurs while it is being transcribed.

IST-1.O.3

Translation involves energy and many sequential steps, including initiation, elongation, and termination.

EXCLUSION STATEMENT—*The details and names of the enzymes and factors involved in each of these steps are beyond the scope of the course and the AP Exam.*

IST-1.O.4

The salient features of translation include—

a. Translation is initiated when the rRNA in the ribosome interacts with the mRNA at the start codon.

b. The sequence of nucleotides on the mRNA is read in triplets called codons.

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LEARNING OBJECTIVE

IST-1.O

Explain how the phenotype of an organism is determined by its genotype.

ESSENTIAL KNOWLEDGE

c. Each codon encodes a specific amino acid, which can be deduced by using a genetic code chart. Many amino acids are encoded by more than one codon.
d. Nearly all living organisms use the same genetic code, which is evidence for the common ancestry of all living organisms.
e. tRNA brings the correct amino acid to the correct place specified by the codon on the mRNA.
f. The amino acid is transferred to the growing polypeptide chain.
g. The process continues along the mRNA until a stop codon is reached.
h. The process terminates by release of the newly synthesized polypeptide/protein.

X **EXCLUSION STATEMENT—***Memorization of the genetic code is beyond the scope of the course and the AP Exam.*

IST-1.O.5

Genetic information in retroviruses is a special case and has an alternate flow of information: from RNA to DNA, made possible by reverse transcriptase, an enzyme that copies the viral RNA genome into DNA. This DNA integrates into the host genome and becomes transcribed and translated for the assembly of new viral progeny.

X **EXCLUSION STATEMENT—***The names of the steps and particular enzymes involved—beyond DNA polymerase, ligase, RNA polymerase, helicase, and topoisomerase—are beyond the scope of the course and the AP Exam.*

SUGGESTED SKILL

Argumentation

6.A

Make a scientific claim.

AVAILABLE RESOURCES

- Classroom Resources > **From Gene to Protein—A Historical Perspective**

TOPIC 6.5

Regulation of Gene Expression

Required Course Content

ENDURING UNDERSTANDING

IST-2

Differences in the expression of genes account for some of the phenotypic differences between organisms.

LEARNING OBJECTIVE

IST-2.A

Describe the types of interactions that regulate gene expression.

ESSENTIAL KNOWLEDGE

IST-2.A.1

Regulatory sequences are stretches of DNA that interact with regulatory proteins to control transcription.

IST-2.A.2

Epigenetic changes can affect gene expression through reversible modifications of DNA or histones.

IST-2.A.3

The phenotype of a cell or organism is determined by the combination of genes that are expressed and the levels at which they are expressed—

a. Observable cell differentiation results from the expression of genes for tissue-specific proteins.

b. Induction of transcription factors during development results in sequential gene expression.

LEARNING OBJECTIVE

IST-2.B

Explain how the location of regulatory sequences relates to their function.

ESSENTIAL KNOWLEDGE

IST-2.B.1

Both prokaryotes and eukaryotes have groups of genes that are coordinately regulated—

a. In prokaryotes, groups of genes called operons are transcribed in a single mRNA molecule. The *lac* operon is an example of an inducible system.

b. In eukaryotes, groups of genes may be influenced by the same transcription factors to coordinately regulate expression.

TOPIC 6.6

Gene Expression and Cell Specialization

Required Course Content

ENDURING UNDERSTANDING

IST-2

Differences in the expression of genes account for some of the phenotypic differences between organisms.

LEARNING OBJECTIVE

IST-2.C

Explain how the binding of transcription factors to promoter regions affects gene expression and/or the phenotype of the organism.

ESSENTIAL KNOWLEDGE

IST-2.C.1

Promoters are DNA sequences upstream of the transcription start site where RNA polymerase and transcription factors bind to initiate transcription.

IST-2.C.2

Negative regulatory molecules inhibit gene expression by binding to DNA and blocking transcription.

LEARNING OBJECTIVE

IST-2.D

Explain the connection between the regulation of gene expression and phenotypic differences in cells and organisms.

ESSENTIAL KNOWLEDGE

IST-2.D.1

Gene regulation results in differential gene expression and influences cell products and function.

IST-2.D.2

Certain small RNA molecules have roles in regulating gene expression.

SUGGESTED SKILL

Argumentation

6.B

Support a claim with evidence from biological principles, concepts, processes, and/or data.

AVAILABLE RESOURCES

- Classroom Resources > **From Gene to Protein—A Historical Perspective**

TOPIC 6.7
Mutations

SUGGESTED SKILLS

Visual Representations

2.C
Explain how biological concepts or processes represented visually relate to larger biological principles, concepts, processes, or theories.

Questions and Methods

3.D
Make observations or collect data from representations of laboratory setups or results.

AVAILABLE RESOURCES

- Classroom Resources > **From Gene to Protein—A Historical Perspective**

ILLUSTRATIVE EXAMPLES

IST-2.E.1

- Mutations in the *CFTR* gene disrupt ion transport and result in cystic fibrosis.
- Mutations in the *MC1R* gene give adaptive melanism in pocket mice.

IST-4.B.1

- Antibiotic resistance mutations
- Pesticide resistance mutations
- Sickle cell disorder and heterozygote advantage

Required Course Content

ENDURING UNDERSTANDING

IST-2
Differences in the expression of genes account for some of the phenotypic differences between organisms.

LEARNING OBJECTIVE

IST-2.E
Describe the various types of mutation.

ESSENTIAL KNOWLEDGE

IST-2.E.1
Changes in genotype can result in changes in phenotype—

a. The function and amount of gene products determine the phenotype of organisms.
   i. The normal function of the genes and gene products collectively comprises the normal function of organisms.
   ii. Disruptions in genes and gene products cause new phenotypes.

IST-2.E.2
Alterations in a DNA sequence can lead to changes in the type or amount of the protein produced and the consequent phenotype. DNA mutations can be positive, negative, or neutral based on the effect or the lack of effect they have on the resulting nucleic acid or protein and the phenotypes that are conferred by the protein.

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ENDURING UNDERSTANDING

IST-4

The processing of genetic information is imperfect and is a source of genetic variation.

LEARNING OBJECTIVE	ESSENTIAL KNOWLEDGE
IST-4.A Explain how changes in genotype may result in changes in phenotype.	**IST-4.A.1** Errors in DNA replication or DNA repair mechanisms, and external factors, including radiation and reactive chemicals, can cause random mutations in the DNA— a. Whether a mutation is detrimental, beneficial, or neutral depends on the environmental context. b. Mutations are the primary source of genetic variation. **IST-4.A.2** Errors in mitosis or meiosis can result in changes in phenotype— a. Changes in chromosome number often result in new phenotypes, including sterility caused by triploidy, and increased vigor of other polyploids. b. Changes in chromosome number often result in human disorders with developmental limitations, including Down syndrome/Trisomy 21 and Turner syndrome.
IST-4.B Explain how alterations in DNA sequences contribute to variation that can be subject to natural selection.	**IST-4.B.1** Changes in genotype may affect phenotypes that are subject to natural selection. Genetic changes that enhance survival and reproduction can be selected for by environmental conditions— a. The horizontal acquisitions of genetic information primarily in prokaryotes via transformation (uptake of naked DNA), transduction (viral transmission of genetic information), conjugation (cell-to-cell transfer of DNA), and transposition (movement of DNA segments within and between DNA molecules) increase variation. b. Related viruses can combine/recombine genetic information if they infect the same host cell. c. Reproduction processes that increase genetic variation are evolutionarily conserved and are shared by various organisms.

SUGGESTED SKILL

Argumentation

6.D
Explain the relationship between experimental results and larger biological concepts, processes, or theories.

AVAILABLE RESOURCES
- AP Biology Lab Manual > **Gel Electrophoresis Lab**
- AP Biology Lab Manual > **Transformation Lab**
- Classroom Resources > **Visualizing Information**

ILLUSTRATIVE EXAMPLES
- Amplified DNA fragments can be used to identify organisms and perform phylogenetic analyses.
- Analysis of DNA can be used for forensic identification.
- Genetically modified organisms include transgenic animals.
- Gene cloning allows propagation of DNA fragments.

TOPIC 6.8
Biotechnology

Required Course Content

ENDURING UNDERSTANDING

IST-1
Heritable information provides for continuity of life.

LEARNING OBJECTIVE

IST-1.P
Explain the use of genetic engineering techniques in analyzing or manipulating DNA.

ESSENTIAL KNOWLEDGE

IST-1.P.1
Genetic engineering techniques can be used to analyze and manipulate DNA and RNA—

a. Electrophoresis separates molecules according to size and charge.
b. During polymerase chain reaction (PCR), DNA fragments are amplified.
c. Bacterial transformation introduces DNA into bacterial cells.
d. DNA sequencing determines the order of nucleotides in a DNA molecule.

EXCLUSION STATEMENT—*The details of these processes are beyond the scope of this course. The focus should be on the conceptual understanding of the application of these techniques.*

AP BIOLOGY

UNIT 7

Natural Selection

13–20%
AP EXAM WEIGHTING

~20–23
CLASS PERIODS

Remember to go to **AP Classroom** to assign students the online **Personal Progress Check** for this unit.

Whether assigned as homework or completed in class, the **Personal Progress Check** provides each student with immediate feedback related to this unit's topic and skills.

Personal Progress Check 7

Multiple-choice: ~40 questions
Free-response: 2 questions

- Interpreting and Evaluating Experimental Results with Graphing
- Analyze Data

UNIT 7

13–20% AP EXAM WEIGHTING | ~20–23 CLASS PERIODS

Natural Selection

BIG IDEA 1
Evolution **EVO**

- What conditions in a population make it more or less likely to evolve?
- Scientifically defend the theory of evolution.

BIG IDEA 4
Systems Interactions **SYI**

- How does species interaction encourage or slow changes in species?

Developing Understanding

The concepts in Unit 7 build on foundational content from previous units as students discover natural selection, a mechanism of evolution—the theory that populations that are better adapted to their environment will survive and reproduce. Thus, the evolution of a species involves a change in its genetic makeup over time. In this unit, students study the evidence for and mechanisms of evolutionary change. Students also learn what happens when a species does not adapt to a changing or volatile environment and about the Hardy-Weinberg equilibrium as a model for describing and predicting allele frequencies in nonevolving populations. Students will learn to calculate and draw conclusions about the evolution, or lack thereof, of a population from data related to allele frequencies. Biological principles studied here and in previous units will culminate in Unit 8, which covers ecology.

Building Science Practices

1.B 2.A 2.D.c 3.B 3.E.a 4.B.c 5.A.a 6.C 6.E.b

By now, students should be accustomed to using visual models and representations to explain or illustrate biological processes. This unit provides students the opportunity to gain proficiency in describing a given model or representation and communicating the biological meaning it represents. Mastery is demonstrated when students can create or use models such as cladograms and phylogenetic trees to communicate biological phenomena, analyze situations, or solve new problems.

Hardy-Weinberg equations are used with respect to a specific gene. Thus, when teaching students how to use the equations, be careful to distinguish between allele and genotype frequencies. The Hardy-Weinberg principle clarifies the factors that alter allele frequency, but it does not imply that allele frequencies are static. This is an important understanding that students need in order to make predictions about a change in a population and to justify the reasoning for their predictions.

Preparing for the AP Exam

The principle of natural selection and its components appears throughout the course. It is important that students are precise in the language they use when writing about evolution, being careful to avoid writing statements that are Lamarckian. A common student error is using buzzwords such as "fitness" without proper explanation of the underlying concept. Students should recall the sources of genetic variation learned in Unit 5 in order to demonstrate the understanding that genetic variation is necessary for natural selection and describe its role in reproductive success. In their writing, students should be clear that while natural selection acts on individuals, it is populations that evolve. Another common error on the exam is that students do not clearly differentiate the types of reproductive isolating mechanisms that lead to speciation.

UNIT AT A GLANCE

Enduring Understanding	Topic	Suggested Skill	Class Periods ~20–23 CLASS PERIODS
EVO-1	**7.1 Introduction to Natural Selection**	2.A Describe characteristics of a biological concept, process, or model represented visually.	
EVO-1	**7.2 Natural Selection**	1.B Explain biological concepts and/or processes.	
EVO-1	**7.3 Artificial Selection**	4.B.c Describe data from a table or graph, including describing relationships between variables.	
EVO-1	**7.4 Population Genetics**	3.B State the null or alternative hypotheses, or predict the results of an experiment.	
EVO-1	**7.5 Hardy-Weinberg Equilibrium**	5.A.a Perform mathematical calculations, including mathematical equations in the curriculum. 1.C Explain biological concepts, processes, and/or models in applied contexts.	
EVO-1, EVO-2	**7.6 Evidence of Evolution**	4.B.a Describe data from a table or graph, including identifying specific data points.	
EVO-2	**7.7 Common Ancestry**	6.E.b Predict the causes or effects of a change in, or disruption to, one or more components in a biological system based on a visual representation of a biological concept, process, or model.	

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UNIT AT A GLANCE *(cont'd)*

Enduring Understanding	Topic	Suggested Skill	Class Periods ~20–23 CLASS PERIODS
EVO-3	**7.8 Continuing Evolution**	3.E.a Propose a new/next investigation based on an evaluation of the evidence from an experiment.	
	7.9 Phylogeny	2.D.c Represent relationships within biological models, including flowcharts.	
	7.10 Speciation	6.E.a Predict the causes or effects of a change in, or disruption to, one or more components in a biological system based on biological concepts or processes. 2.B.a Explain relationships between different characteristics of biological concepts, processes, or models represented visually in theoretical contexts.	
	7.11 Extinction	3.B State the null or alternative hypotheses, or predict the results of an experiment.	
SYI-3	**7.12 Variations in Populations**	6.C Provide reasoning to justify a claim by connecting evidence to biological theories.	
	7.13 Origin of Life on Earth	3.B State the null or alternative hypotheses, or predict the results of an experiment.	

Go to **AP Classroom** to assign the **Personal Progress Check** for Unit 7.
Review the results in class to identify and address any student misunderstandings.

SAMPLE INSTRUCTIONAL ACTIVITIES

The sample activities on this page are intended to give you ideas of ways to incorporate varied instructional approaches in the teaching of this course. You do not need to use these activities or approaches and are free to alter or edit them in any way you choose. The following examples were developed in partnership with teachers from the AP community to share ways that they approach teaching some of the topics in this unit. Please refer to the Instructional Approaches section beginning on p. 171 for more examples of activities and strategies.

Activity	Topic	Suggested Activity
1	7.3	**Construct an Argument** Students can perform a brine shrimp lab, placing groups of brine shrimp eggs in petri dishes with various concentrations of salt in the water. They monitor the number of eggs and swimming shrimp in the petri dishes at regular time intervals over a period of two to three days. Students can calculate the hatching viability in each petri dish and then graph their data. Chi-square can be used to analyze the null hypothesis.
2	7.5	**Error Analysis** Have students use one of the Rock Pocket Mouse activities available online to learn the principles of the Hardy-Weinberg theorem and to calculate allele frequencies in a population.
3	7.10	**Ask the Expert** Show students a cartoon of an isolating mechanism that leads to speciation. Discuss with students what is happening in this cartoon and how it relates to speciation. Students should do research on other isolating mechanisms and draw their own cartoon to illustrate their learnings.

Unit Planning Notes

Use the space below to plan your approach to the unit. Consider how you want to pace your course and your methods of instruction and assessment.

TOPIC 7.1

Introduction to Natural Selection

SUGGESTED SKILL

Visual Representations

2.A

Describe characteristics of a biological concept, process, or model represented visually.

AVAILABLE RESOURCES

- Classroom Resources > **Visualizing Information**
- Classroom Resources > **Evolution and Change**

Required Course Content

ENDURING UNDERSTANDING

EVO-1

Evolution is characterized by a change in the genetic makeup of a population over time and is supported by multiple lines of evidence.

LEARNING OBJECTIVE	ESSENTIAL KNOWLEDGE
EVO-1.C Describe the causes of natural selection.	**EVO-1.C.1** Natural selection is a major mechanism of evolution. **EVO-1.C.2** According to Darwin's theory of natural selection, competition for limited resources results in differential survival. Individuals with more favorable phenotypes are more likely to survive and produce more offspring, thus passing traits to subsequent generations.
EVO-1.D Explain how natural selection affects populations.	**EVO-1.D.1** Evolutionary fitness is measured by reproductive success. **EVO-1.D.2** Biotic and abiotic environments can be more or less stable/fluctuating, and this affects the rate and direction of evolution; different genetic variations can be selected in each generation.

SUGGESTED SKILL

Concept Explanation

1.B

Explain biological concepts and/or processes.

AVAILABLE RESOURCES

- Classroom Resources > **Evolution and Change**

ILLUSTRATIVE EXAMPLES

EVO-1.E.2

- Flowering time in relation to global climate change
- Peppered moth

EVO-1.E.3 B

- Sickle cell anemia
- DDT resistance in insects

TOPIC 7.2

Natural Selection

Required Course Content

ENDURING UNDERSTANDING

EVO-1

Evolution is characterized by a change in the genetic makeup of a population over time and is supported by multiple lines of evidence.

LEARNING OBJECTIVE

EVO-1.E

Describe the importance of phenotypic variation in a population.

ESSENTIAL KNOWLEDGE

EVO-1.E.1

Natural selection acts on phenotypic variations in populations.

EVO-1.E.2

Environments change and apply selective pressures to populations.

EVO-1.E.3

Some phenotypic variations significantly increase or decrease fitness of the organism in particular environments.

TOPIC 7.3

Artificial Selection

Required Course Content

ENDURING UNDERSTANDING

EVO-1

Evolution is characterized by a change in the genetic makeup of a population over time and is supported by multiple lines of evidence.

LEARNING OBJECTIVE	ESSENTIAL KNOWLEDGE
EVO-1.F Explain how humans can affect diversity within a population.	**EVO-1.F.1** Through artificial selection, humans affect variation in other species.
EVO-1.G Explain the relationship between changes in the environment and evolutionary changes in the population.	**EVO-1.G.1** Convergent evolution occurs when similar selective pressures result in similar phenotypic adaptations in different populations or species.

SUGGESTED SKILL

Representing and Describing Data

4.B.c

Describe data from a table or graph, including describing relationships between variables.

AVAILABLE RESOURCES

- Classroom Resources > **Evolution and Change**
- AP Biology Lab Manual > **Artificial Selection Lab**

SUGGESTED SKILL

Questions and Methods

3.B

State the null or alternative hypotheses, or predict the results of an experiment.

AVAILABLE RESOURCES

- Classroom Resources > **Evolution and Change**

TOPIC 7.4

Population Genetics

Required Course Content

ENDURING UNDERSTANDING

EVO-1

Evolution is characterized by a change in the genetic makeup of a population over time and is supported by multiple lines of evidence.

LEARNING OBJECTIVE	ESSENTIAL KNOWLEDGE
EVO-1.H Explain how random occurrences affect the genetic makeup of a population.	**EVO-1.H.1** Evolution is also driven by random occurrences— a. Mutation is a random process that contributes to evolution. b. Genetic drift is a nonselective process occurring in small populations— i. Bottlenecks. ii. Founder effect. c. Migration/gene flow can drive evolution.
EVO-1.I Describe the role of random processes in the evolution of specific populations.	**EVO-1.I.1** Reduction of genetic variation within a given population can increase the differences between populations of the same species.
EVO-1.J Describe the change in the genetic makeup of a population over time.	**EVO-1.J.1** Mutation results in genetic variation, which provides phenotypes on which natural selection acts.

TOPIC 7.5

Hardy-Weinberg Equilibrium

Required Course Content

ENDURING UNDERSTANDING

EVO-1

Evolution is characterized by a change in the genetic makeup of a population over time and is supported by multiple lines of evidence.

LEARNING OBJECTIVE

EVO-1.K

Describe the conditions under which allele and genotype frequencies will change in populations.

ESSENTIAL KNOWLEDGE

EVO-1.K.1

Hardy-Weinberg is a model for describing and predicting allele frequencies in a nonevolving population. Conditions for a population or an allele to be in Hardy-Weinberg equilibrium are—(1) a large population size, (2) absence of migration, (3) no net mutations, (4) random mating, and (5) absence of selection. These conditions are seldom met, but they provide a valuable null hypothesis.

EVO-1.K.2

Allele frequencies in a population can be calculated from genotype frequencies.

RELEVANT EQUATION

Hardy-Weinberg Equation—

$$p^2 + 2pq + q^2 = 1$$

$$p + q = 1$$

where:

p = frequency of allele 1 in the population

q = frequency of allele 2 in the population

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SUGGESTED SKILLS

Statistical Tests

5.A.a

Perform mathematical calculations, including mathematical equations in the curriculum.

Data Analysis and Concept Explanation

1.C

Explain biological concepts, processes, and/or models in applied contexts.

AVAILABLE RESOURCES

- Classroom Resources > **Evolution and Change**
- AP Biology Lab Manual > **Mathematical Modeling**

ILLUSTRATIVE EXAMPLE

EVE-1.K.2

- Graphical analysis of allele frequencies in a population

LEARNING OBJECTIVE

EVO-1.L

Explain the impacts on the population if any of the conditions of Hardy-Weinberg are not met.

ESSENTIAL KNOWLEDGE

EVO-1.L.1

Changes in allele frequencies provide evidence for the occurrence of evolution in a population.

EVO-1.L.2

Small populations are more susceptible to random environmental impact than large populations.

TOPIC 7.6

Evidence of Evolution

SUGGESTED SKILL

Representing and Describing Data

4.B.a

Describe data from a table or graph, including identifying specific data points.

AVAILABLE RESOURCES

- Classroom Resources > **Evolution and Change**

Required Course Content

ENDURING UNDERSTANDING

EVO-1

Evolution is characterized by a change in the genetic makeup of a population over time and is supported by multiple lines of evidence.

LEARNING OBJECTIVE

EVO-1.M

Describe the types of data that provide evidence for evolution.

ESSENTIAL KNOWLEDGE

EVO-1.M.1

Evolution is supported by scientific evidence from many disciplines (geographical, geological, physical, biochemical, and mathematical data).

LEARNING OBJECTIVE

EVO-1.N

Explain how morphological, biochemical, and geological data provide evidence that organisms have changed over time.

ESSENTIAL KNOWLEDGE

EVO-1.N.1

Molecular, morphological, and genetic evidence from extant and extinct organisms adds to our understanding of evolution—

a. Fossils can be dated by a variety of methods. These include:
   i. The age of the rocks where a fossil is found
   ii. The rate of decay of isotopes including carbon-14
   iii. Geographical data
b. Morphological homologies, including vestigial structures, represent features shared by common ancestry.

EVO-1.N.2

A comparison of DNA nucleotide sequences and/or protein amino acid sequences provides evidence for evolution and common ancestry.

ENDURING UNDERSTANDING

EVO-2

Organisms are linked by lines of descent from common ancestry.

LEARNING OBJECTIVE

EVO-2.B

Describe the fundamental molecular and cellular features shared across all domains of life, which provide evidence of common ancestry.

ESSENTIAL KNOWLEDGE

EVO-2.B.1

Many fundamental molecular and cellular features and processes are conserved across organisms.

EVO-2.B.2

Structural and functional evidence supports the relatedness of organisms in all domains.

TOPIC 7.7
Common Ancestry

Required Course Content

ENDURING UNDERSTANDING

EVO-2

Organisms are linked by lines of descent from common ancestry.

LEARNING OBJECTIVE

EVO-2.C

Describe structural and functional evidence on cellular and molecular levels that provides evidence for the common ancestry of all eukaryotes.

ESSENTIAL KNOWLEDGE

EVO-2.C.1

Structural evidence indicates common ancestry of all eukaryotes—

a. Membrane-bound organelles
b. Linear chromosomes
c. Genes that contain introns

SUGGESTED SKILL

Argumentation

6.E.b

Predict the causes or effects of a change in, or disruption to, one or more components in a biological system based on a visual representation of a biological concept, process, or model.

AVAILABLE RESOURCES

- Classroom Resources > **Evolution and Change**

SUGGESTED SKILL

Questions and Methods

3.E.a
Propose a new/next investigation based on an evaluation of the evidence from an experiment.

AVAILABLE RESOURCES

- Classroom Resources > **Evolution and Change**

TOPIC 7.8
Continuing Evolution

Required Course Content

ENDURING UNDERSTANDING

EVO-3
Life continues to evolve within a changing environment.

LEARNING OBJECTIVE

EVO-3.A
Explain how evolution is an ongoing process in all living organisms.

ESSENTIAL KNOWLEDGE

EVO-3.A.1
Populations of organisms continue to evolve.

EVO-3.A.2
All species have evolved and continue to evolve—

a. Genomic changes over time.
b. Continuous change in the fossil record.
c. Evolution of resistance to antibiotics, pesticides, herbicides, or chemotherapy drugs.
d. Pathogens evolve and cause emergent diseases.

TOPIC 7.9
Phylogeny

SUGGESTED SKILL

Visual Representations

2.D.c

Represent relationships within biological models, including flowcharts.

AVAILABLE RESOURCES

- Classroom Resources > **Evolution and Change**

Required Course Content

ENDURING UNDERSTANDING

EVO-3

Life continues to evolve within a changing environment.

LEARNING OBJECTIVE

EVO-3.B

Describe the types of evidence that can be used to infer an evolutionary relationship.

ESSENTIAL KNOWLEDGE

EVO-3.B.1

Phylogenetic trees and cladograms show evolutionary relationships among lineages—

a. Phylogenetic trees and cladograms both show relationships between lineages, but phylogenetic trees show the amount of change over time calibrated by fossils or a molecular clock.

b. Traits that are either gained or lost during evolution can be used to construct phylogenetic trees and cladograms—

  i. Shared characters are present in more than one lineage.

  ii. Shared, derived characters indicate common ancestry and are informative for the construction of phylogenetic trees and cladograms.

  iii. The out-group represents the lineage that is least closely related to the remainder of the organisms in the phylogenetic tree or cladogram.

c. Molecular data typically provide more accurate and reliable evidence than morphological traits in the construction of phylogenetic trees or cladograms.

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LEARNING OBJECTIVE	ESSENTIAL KNOWLEDGE
EVO-3.C Explain how a phylogenetic tree and/or cladogram can be used to infer evolutionary relatedness.	**EVO-3.C.1** Phylogenetic trees and cladograms can be used to illustrate speciation that has occurred. The nodes on a tree represent the most recent common ancestor of any two groups or lineages.
	EVO-3.C.2 Phylogenetic trees and cladograms can be constructed from morphological similarities of living or fossil species and from DNA and protein sequence similarities.
	EVO-3.C.3 Phylogenetic trees and cladograms represent hypotheses and are constantly being revised, based on evidence.

TOPIC 7.10
Speciation

Required Course Content

ENDURING UNDERSTANDING

EVO-3
Life continues to evolve within a changing environment.

LEARNING OBJECTIVE	ESSENTIAL KNOWLEDGE
EVO-3.D Describe the conditions under which new species may arise.	**EVO-3.D.1** Speciation may occur when two populations become reproductively isolated from each other. **EVO-3.D.2** The biological species concept provides a commonly used definition of species for sexually reproducing organisms. It states that species can be defined as a group capable of interbreeding and exchanging genetic information to produce viable, fertile offspring.
EVO-3.E Describe the rate of evolution and speciation under different ecological conditions.	**EVO-3.E.1** Punctuated equilibrium is when evolution occurs rapidly after a long period of stasis. Gradualism is when evolution occurs slowly over hundreds of thousands or millions of years. **EVO-3.E.2** Divergent evolution occurs when adaptation to new habitats results in phenotypic diversification. Speciation rates can be especially rapid during times of adaptive radiation as new habitats become available.

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SUGGESTED SKILLS

Argumentation

6.E.a
Predict the causes or effects of a change in, or disruption to, one or more components in a biological system based on biological concepts or processes.

Visual Representations

2.B.a
Explain relationships between different characteristics of biological concepts, processes, or models represented visually in theoretical contexts.

AVAILABLE RESOURCES
- Classroom Resources > **Evolution and Change**

ILLUSTRATIVE EXAMPLES

EVO-3.F.1
- Hawaiian *Drosophila*
- Caribbean *Anolis*
- Apple maggot *Rhagoletis*

LEARNING OBJECTIVE	ESSENTIAL KNOWLEDGE
EVO-3.F Explain the processes and mechanisms that drive speciation.	**EVO-3.F.1** Speciation results in diversity of life forms. **EVO-3.F.2** Speciation may be sympatric or allopatric. **EVO-3.F.3** Various prezygotic and postzygotic mechanisms can maintain reproductive isolation and prevent gene flow between populations.

TOPIC 7.11
Extinction

SUGGESTED SKILL

Questions and Methods

3.B
State the null or alternative hypotheses, or predict the results of an experiment.

AVAILABLE RESOURCES
- Classroom Resources > **Evolution and Change**

Required Course Content

ENDURING UNDERSTANDING

EVO-3
Life continues to evolve within a changing environment.

LEARNING OBJECTIVE	ESSENTIAL KNOWLEDGE
EVO-3.G Describe factors that lead to the extinction of a population.	**EVO-3.G.1** Extinctions have occurred throughout Earth's history. **EVO-3.G.2** Extinction rates can be rapid during times of ecological stress.
EVO-3.H Explain how the risk of extinction is affected by changes in the environment.	**EVO-3.H.1** Human activity can drive changes in ecosystems that cause extinctions.
EVO-3.I Explain species diversity in an ecosystem as a function of speciation and extinction rates.	**EVO-3.I.1** The amount of diversity in an ecosystem can be determined by the rate of speciation and the rate of extinction.
EVO-3.J Explain how extinction can make new environments available for adaptive radiation.	**EVO-3.J.1** Extinction provides newly available niches that can then be exploited by different species.

SUGGESTED SKILL

Argumentation

6.C

Provide reasoning to justify a claim by connecting evidence to biological theories.

AVAILABLE RESOURCES

- Classroom Resources > **Evolution and Change**

ILLUSTRATIVE EXAMPLES

SYI-3.D.1.a

- California condors
- Black-footed ferrets
- Prairie chickens
- Potato blight
- Corn rust
- Genetic diversity and selective pressures
- Antibiotic resistance in bacteria. (Not all individuals in a diverse population are susceptible to a disease outbreak.)

TOPIC 7.12 Variations in Populations

Required Course Content

ENDURING UNDERSTANDING

SYI-3

Naturally occurring diversity among and between components within biological systems affects interactions with the environment.

LEARNING OBJECTIVE

SYI-3.D

Explain how the genetic diversity of a species or population affects its ability to withstand environmental pressures.

ESSENTIAL KNOWLEDGE

SYI-3.D.1

The level of variation in a population affects population dynamics—

a. Population ability to respond to changes in the environment is influenced by genetic diversity. Species and populations with little genetic diversity are at risk of decline or extinction.

b. Genetically diverse populations are more resilient to environmental perturbation because they are more likely to contain individuals who can withstand the environmental pressure.

c. Alleles that are adaptive in one environmental condition may be deleterious in another because of different selective pressures.

TOPIC 7.13
Origins of Life on Earth

SUGGESTED SKILL

Questions and Methods

3.B
State the null or alternative hypotheses, or predict the results of an experiment.

AVAILABLE RESOURCES
- Classroom Resources > **Evolution and Change**

Required Course Content

ENDURING UNDERSTANDING

SYI-3
Naturally occurring diversity among and between components within biological systems affects interactions with the environment.

LEARNING OBJECTIVE

SYI-3.E
Describe the scientific evidence that provides support for models of the origin of life on Earth.

ESSENTIAL KNOWLEDGE

SYI-3.E.1
Several hypotheses about the origin of life on Earth are supported with scientific evidence—

a. Geological evidence provides support for models of the origin of life on Earth.
   i. Earth formed approximately 4.6 billion years ago (bya). The environment was too hostile for life until 3.9 bya, and the earliest fossil evidence for life dates to 3.5 bya. Taken together, this evidence provides a plausible range of dates when the origin of life could have occurred.
b. There are several models about the origin of life on Earth—
   i. Primitive Earth provided inorganic precursors from which organic molecules could have been synthesized because of the presence of available free energy and the absence of a significant quantity of atmospheric oxygen (O_2).
   ii. Organic molecules could have been transported to Earth by a meteorite or other celestial event.

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LEARNING OBJECTIVE

SYI-3.E

Describe the scientific evidence that provides support for models of the origin of life on Earth.

ESSENTIAL KNOWLEDGE

c. Chemical experiments have shown that it is possible to form complex organic molecules from inorganic molecules in the absence of life—
   i. Organic molecules/monomers served as building blocks for the formation of more complex molecules, including amino acids and nucleotides.
   ii. The joining of these monomers produced polymers with the ability to replicate, store, and transfer information.

SYI-3.E.2

The RNA World Hypothesis proposes that RNA could have been the earliest genetic material.

AP BIOLOGY

UNIT 8

Ecology

10–15%
AP EXAM WEIGHTING

~18–21
CLASS PERIODS

Remember to go to **AP Classroom** to assign students the online **Personal Progress Check** for this unit.

Whether assigned as homework or completed in class, the **Personal Progress Check** provides each student with immediate feedback related to this unit's topic and skills.

Personal Progress Check 8

Multiple-choice: ~20 questions
Free-response: 2 questions

- Interpreting and Evaluating Experimental Results with Graphing
- Scientific Investigation

UNIT 8

10–15% AP EXAM WEIGHTING | **~18–21** CLASS PERIODS

Ecology

BIG IDEA 1
Evolution **EVO**
- How does diversity among and between species in a biological system affect the evolution of species within the system?

BIG IDEA 2
Energetics **ENE**
- How does the acquisition of energy relate to the health of a biological system?
- How do communities and ecosystems change, for better or worse, due to biological disruption?

BIG IDEA 3
Information Storage and Transmission **IST**
- How does a disruption of a biological system affect genetic information storage and transmission?

BIG IDEA 4
Systems Interactions **SYI**
- How do species interactions affect the survival of an ecosystem?

Developing Understanding

As a culmination of this course, Unit 8 brings together all other units to show how a system's interactions are directly related to the system's available energy and its ability to evolve and respond to changes in its environment. When highly complex living systems interact, communities and ecosystems will change based on those interactions. The more biodiversity present in a system, the more likely that system is to maintain its health and success in the face of disruption. Energy flows through systems; the rate of flow determines the success of the species within the systems. By this point in the curriculum, a student should be able to accurately determine what happens within biological systems when disruptions occur.

Building Science Practices

3.C.a 4.A 5.A.c 5.B 5.D.a 6.D 6.E.c

Designing research to test biological systems is at the heart of this course. Students should be able to understand and evaluate experimental plans designed and conducted by others. They should be able to identify the experimental methods, measurements, and data collection methods used and articulate the hypothesis. They should also be able to plan and implement data collection strategies that test biological systems, in order to understand and develop solutions to problems within biological systems. An understanding of how to design experiments that test biological systems is demonstrated by the ability to interpret the results of an experiment in relation to a hypothesis. Sometimes, experimental procedures will need to be modified in order to collect appropriate data; students should understand how to modify a procedure to collect data and test a hypothesis.

Preparing for the AP Exam

Students should demonstrate understanding of the relationship between organisms and their environment by constructing and analyzing food chains and food webs and analyzing trophic diagrams. On past exams, when students have been asked to construct a food web from a data table, they have struggled with inferring the correct relationships between the organisms and with translating how a relationship between two organisms resulted in their placement on the food web. Another common error is the incorrect placement of the arrows that indicate energy flow. Students should use their knowledge from Unit 3 to explain how energy and carbon are transferred through an ecosystem so that they can predict how changes in the environment can impact an ecosystem, both positively and negatively.

Throughout the course, students should practice providing support for their claims about biological systems. Connections to ecology throughout the course are fundamental and will help students to build this skill.

UNIT AT A GLANCE

Enduring Understanding	Topic	Suggested Skill	Class Periods ~18–21 CLASS PERIODS
ENE-3, IST-5	8.1 Responses to the Environment	3.C.a Identify experimental procedures that are aligned to the question, including identifying dependent and independent variables.	
ENE-1	8.2 Energy Flow Through Ecosystems	6.D Explain the relationship between experimental results and larger biological concepts, processes, or theories.	
SYI-1	8.3 Population Ecology	4.A Construct a graph, plot, or chart.	
SYI-1	8.4 Effect of Density of Populations	5.A.c Perform mathematical calculations, including rates.	
ENE-4	8.5 Community Ecology	5.B Use confidence intervals and/or error bars (both determined using standard errors) to determine whether sample means are statistically different.	
SYI-3	8.6 Biodiversity	6.E.c Predict the causes or effects of a change in, or disruption to, one or more components in a biological system based on data.	
EVO-1, SYI-2	8.7 Disruptions to Ecosystems	5.D.a Use data to evaluate a hypothesis (or prediction), including rejecting or failing to reject the null hypothesis. 5.D.b Use data to evaluate a hypothesis (or prediction), including supporting or refuting the alternative hypothesis.	

Go to **AP Classroom** to assign the **Personal Progress Check** for Unit 8. Review the results in class to identify and address any student misunderstandings.

SAMPLE INSTRUCTIONAL ACTIVITIES

The sample activities on this page are intended to give you ideas of ways to incorporate varied instructional approaches in the teaching of this course. You do not need to use these activities or approaches and are free to alter or edit them in any way you choose. The following examples were developed in partnership with teachers from the AP community to share ways that they approach teaching some of the topics in this unit. Please refer to the Instructional Approaches section beginning on p. 171 for more examples of activities and strategies.

Activity	Topic	Sample Activity
1	8.1	**Error Analysis** Students can perform an animal behavior lab using pill bugs. They can use choice chambers to study the responses of pill bugs to environmental stimuli. Create different environments on either side of the choice chamber. Place the same number of pill bugs on both sides of the choice chamber. Count the number of pill bugs on both sides of the choice chamber at regular intervals for a defined period of time. Chi-square can be used to analyze the null hypothesis.
2	8.5	**Graph and Switch** Students can read about the moose and wolves of Isle Royale to obtain background information on the two organisms. They can download a data spreadsheet and graph data about the two populations from the Internet. They can use their graph to make and justify predictions about how the two populations can change relative to each other.
3	8.6	**Index Card Summaries/Questions** Students can perform the “hula hoop diversity” activity. Divide students into groups, and give each group a hula hoop and a magnifying glass. Students should place their hula hoop in a grassy/woodsy area or garden and then make observations and collect a variety of data from their sampling area about the plants, animals, and abiotic factors inside the hula hoop. At the conclusion of the activity, have students predict what will happen to organisms in an ecosystem when its biodiversity changes, discuss the relationship between biodiversity and species endangerment, and predict what changes might occur in an ecosystem when a biotic or abiotic factor changes.

Unit Planning Notes

Use the space below to plan your approach to the unit. Consider how you want to pace your course and your methods of instruction and assessment.

SUGGESTED SKILL

Questions and Methods

3.C.a

Identify experimental procedures that are aligned to the question, including identifying dependent and independent variables.

AVAILABLE RESOURCES

- AP Biology Lab Manual > **Transpiration Lab**
- AP Biology Lab Manual > **Fruit Fly Behavior Lab**
- Classroom Resources > **Visualizing Information**
- Classroom Resources > **Quantitative Skills in the AP Sciences (2018)**

ILLUSTRATIVE EXAMPLES

ENE-3.D.1

- Photoperiodism and phototropism in plants
- Taxis and kinesis in animals
- Nocturnal and diurnal activity

ENE-3.D.2

- Fight-or-flight response
- Predator warnings
- Plant responses to herbivory

IST-5.A.2.a

- Territorial marking in mammals
- Coloration in flowers

IST-5.A.2.b

- Bird songs
- Pack behavior in animals
- Predator warnings
- Coloration

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TOPIC 8.1
Responses to the Environment

Required Course Content

ENDURING UNDERSTANDING

ENE-3

Timing and coordination of biological mechanisms involved in growth, reproduction, and homeostasis depend on organisms responding to environmental cues.

LEARNING OBJECTIVE

ENE-3.D

Explain how the behavioral and/or physiological response of an organism is related to changes in internal or external environment.

ESSENTIAL KNOWLEDGE

ENE-3.D.1

Organisms respond to changes in their environment through behavioral and physiological mechanisms.

EXCLUSION STATEMENT—*No specific behavioral or physiological mechanism is required for teaching this concept.*

ENE-3.D.2

Organisms exchange information with one another in response to internal changes and external cues, which can change behavior.

ENDURING UNDERSTANDING

IST-5

Transmission of information results in changes within and between biological systems.

LEARNING OBJECTIVE

IST-5.A

Explain how the behavioral responses of organisms affect their overall fitness and may contribute to the success of the population.

ESSENTIAL KNOWLEDGE

IST-5.A.1

Individuals can act on information and communicate it to others.

IST-5.A.2

Communication occurs through various mechanisms—

a. Organisms have a variety of signaling behaviors that produce changes in the behavior of other organisms and can result in differential reproductive success.

b. Animals use visual, audible, tactile, electrical, and chemical signals to indicate dominance, find food, establish territory, and ensure reproductive success.

IST-5.A.3

Responses to information and communication of information are vital to natural selection and evolution—

a. Natural selection favors innate and learned behaviors that increase survival and reproductive fitness.

b. Cooperative behavior tends to increase the fitness of the individual and the survival of the population.

EXCLUSION STATEMENT—*The details of the various communications and community behavioral systems are beyond the scope of the course and the AP Exam.*

ILLUSTRATIVE EXAMPLES

IST-5.A.3.a

- Parent and offspring interactions
- Courtship and mating behaviors
- Foraging in bees and other animals

IST-5.A.3.b

- Pack behavior in animals
- Herd, flock, and schooling behavior in animals
- Predator warning
- Colony and swarming behavior in insects
- Kin selection

SUGGESTED SKILL

Argumentation

6.D
Explain the relationship between experimental results and larger biological concepts, processes, or theories.

AVAILABLE RESOURCES
- AP Biology Lab Manual > **Energy Dynamics Lab**
- Classroom Resources > **Visualizing Information**

ILLUSTRATIVE EXAMPLES
- Seasonal reproduction in animals and plants
- Life-history strategy (biennial plants, reproductive diapause)

ENE-1.N.1
- Food chains/webs
- Trophic pyramids/diagrams

TOPIC 8.2
Energy Flow Through Ecosystems

Required Course Content

ENDURING UNDERSTANDING

ENE-1
The highly complex organization of living systems requires constant input of energy and the exchange of macromolecules.

LEARNING OBJECTIVE

ENE-1.M
Describe the strategies organisms use to acquire and use energy.

ESSENTIAL KNOWLEDGE

ENE-1.M.1
Organisms use energy to maintain organization, grow, and reproduce—

a. Organisms use different strategies to regulate body temperature and metabolism.
   i. Endotherms use thermal energy generated by metabolism to maintain homeostatic body temperatures.
   ii. Ectotherms lack efficient internal mechanisms for maintaining body temperature, though they may regulate their temperature behaviorally by moving into the sun or shade or by aggregating with other individuals.

b. Different organisms use various reproductive strategies in response to energy availability.

c. There is a relationship between metabolic rate per unit body mass and the size of multicellular organisms—generally, the smaller the organism, the higher the metabolic rate.

d. A net gain in energy results in energy storage or the growth of an organism.

e. A net loss of energy results in loss of mass and, ultimately, the death of an organism.

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LEARNING OBJECTIVE	ESSENTIAL KNOWLEDGE
ENE-1.N Explain how changes in energy availability affect populations and ecosystems.	**ENE-1.N.1** Changes in energy availability can result in changes in population size. **ENE.1.N.2** Changes in energy availability can result in disruptions to an ecosystem— a. A change in energy resources such as sunlight can affect the number and size of the trophic levels. b. A change in the producer level can affect the number and size of other trophic levels.
ENE-1.O Explain how the activities of autotrophs and heterotrophs enable the flow of energy within an ecosystem.	**ENE-1.O.1** Autotrophs capture energy from physical or chemical sources in the environment— a. Photosynthetic organisms capture energy present in sunlight. b. Chemosynthetic organisms capture energy from small inorganic molecules present in their environment, and this process can occur in the absence of oxygen. **ENE-1. O.2** Heterotrophs capture energy present in carbon compounds produced by other organisms. a. Heterotrophs may metabolize carbohydrates, lipids, and proteins as sources of energy by hydrolysis.

SUGGESTED SKILL

Representing and Describing Data

4.A

Construct a graph, plot, or chart.

AVAILABLE RESOURCES

- Classroom Resources > **Quantitative Skills in the AP Sciences (2018)**

TOPIC 8.3
Population Ecology

Required Course Content

ENDURING UNDERSTANDING

SYI-1

Living systems are organized in a hierarchy of structural levels that interact.

LEARNING OBJECTIVE

SYI-1.G

Describe factors that influence growth dynamics of populations.

ESSENTIAL KNOWLEDGE

SYI-1.G.1

Populations comprise individual organisms that interact with one another and with the environment in complex ways.

SYI-1.G.2

Many adaptations in organisms are related to obtaining and using energy and matter in a particular environment—

a. Population growth dynamics depend on a number of factors.

RELEVANT EQUATION

Population Growth—

$$\frac{dN}{dt} = B - D$$

where:

dt = chage in time

B = birth rate

D = death rate

N = population size

i. Reproduction without constraints results in the exponential growth of a population.

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LEARNING OBJECTIVE

SYI-1.G

Describe factors that influence growth dynamics of populations.

ESSENTIAL KNOWLEDGE

RELEVANT EQUATION

Exponential Growth—

$$\frac{dN}{dt} = r_{max} N$$

where:

dt = change in time

N = population size

r_{max} = maximum per capita growth rate of population

SUGGESTED SKILL

Statistical Tests and Data Analysis

5.A.c

Perform mathematical calculations, including rates.

TOPIC 8.4

Effect of Density of Populations

Required Course Content

ENDURING UNDERSTANDING

SYI-1

Living systems are organized in a hierarchy of structural levels that interact.

LEARNING OBJECTIVE

SYI-1.H

Explain how the density of a population affects and is determined by resource availability in the environment.

ESSENTIAL KNOWLEDGE

SYI-1.H.1

A population can produce a density of individuals that exceeds the system's resource availability.

SYI-1.H.2

As limits to growth due to density-dependent and density-independent factors are imposed, a logistic growth model generally ensues.

RELEVANT EQUATION

$$\frac{dN}{dt} = r_{max} N \left(\frac{K-N}{K} \right)$$

where:

dt = change in time

N = population size

r_{max} = maximum per capita growth rate of population

K = carrying capacity

TOPIC 8.5
Community Ecology

SUGGESTED SKILL

Statistical Tests and Data Analysis

5.B

Use confidence intervals and/or error bars (both determined using standard errors) to determine whether sample means are statistically different.

Required Course Content

ENDURING UNDERSTANDING

ENE-4

Communities and ecosystems change on the basis of interactions among populations and disruptions to the environment.

LEARNING OBJECTIVE

ENE-4.A

Describe the structure of a community according to its species composition and diversity.

ESSENTIAL KNOWLEDGE

ENE-4.A.1

The structure of a community is measured and described in terms of species composition and species diversity.

RELEVANT EQUATION

Simpson's Diversity Index—

$$\text{Diversity Index} = 1 - \Sigma\left(\frac{n}{N}\right)^2$$

n = the total number of organisms of a particular species

N = total number of organisms of all species

LEARNING OBJECTIVE

ENE-4.B

Explain how interactions within and among populations influence community structure.

ESSENTIAL KNOWLEDGE

ENE-4.B.1

Communities change over time depending on interactions between populations.

ENE-4.B.2

Interactions among populations determine how they access energy and matter within a community.

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LEARNING OBJECTIVE	ESSENTIAL KNOWLEDGE
ENE-4.B Explain how interactions within and among populations influence community structure.	**ENE-4.B.3** Relationships among interacting populations can be characterized by positive and negative effects and can be modeled. Examples include predator/prey interactions, trophic cascades, and niche partitioning. **ENE-4.B.4** Competition, predation, and symbioses, including parasitism, mutualism, and commensalism, can drive population dynamics.
ENE-4.C Explain how community structure is related to energy availability in the environment.	**ENE-4.C.1** Cooperation or coordination between organisms, populations, and species can result in enhanced movement of, or access to, matter and energy.

TOPIC 8.6
Biodiversity

SUGGESTED SKILL

Argumentation

6.E.c

Predict the causes or effects of a change in, or disruption to, one or more components in a biological system based on data.

Required Course Content

ENDURING UNDERSTANDING

SYI-3

Naturally occurring diversity among and between components within biological systems affects interactions with the environment.

LEARNING OBJECTIVE	ESSENTIAL KNOWLEDGE
SYI-3.F Describe the relationship between ecosystem diversity and its resilience to changes in the environment.	**SYI-3.F.1** Natural and artificial ecosystems with fewer component parts and with little diversity among the parts are often less resilient to changes in the environment. **SYI-3.F.2** Keystone species, producers, and essential abiotic and biotic factors contribute to maintaining the diversity of an ecosystem.
SYI-3.G Explain how the addition or removal of any component of an ecosystem will affect its overall short-term and long-term structure.	**SYI-3.G.1** The diversity of species within an ecosystem may influence the organization of the ecosystem. **SYI-3.G.2** The effects of keystone species on the ecosystem are disproportionate relative to their abundance in the ecosystem, and when they are removed from the ecosystem, the ecosystem often collapses.

SUGGESTED SKILLS

Statistical Tests and Data Analysis

5.D.a
Use data to evaluate a hypothesis (or prediction), including rejecting or failing to reject the null hypothesis.

5.D.b
Use data to evaluate a hypothesis (or prediction), including supporting or refuting the alternative hypothesis.

ILLUSTRATIVE EXAMPLES

SYI-2.A.2
- Kudzu
- Zebra mussels

SYI-2.B.2.a
- Dutch elm disease
- Potato blight

SYI-2.B.2.b
- Global climate change
- Logging
- Urbanization
- Mono-cropping

SYI-2.C.1
- El Niño
- Continental drift
- Meteor impact on dinosaurs

TOPIC 8.7
Disruptions to Ecosystems

Required Course Content

ENDURING UNDERSTANDING

EVO-1
Evolution is characterized by change in the genetic make-up of a population over time and is supported by multiple lines of evidence.

LEARNING OBJECTIVE

EVO-1.0
Explain the interaction between the environment and random or preexisting variations in populations.

ESSENTIAL KNOWLEDGE

EVO-1.0.1
An adaptation is a genetic variation that is favored by selection and is manifested as a trait that provides an advantage to an organism in a particular environment.

EVO-1.0.2
Mutations are random and are not directed by specific environmental pressures.

ENDURING UNDERSTANDING

SYI-2
Competition and cooperation are important aspects of biological systems.

LEARNING OBJECTIVE

SYI-2.A
Explain how invasive species affect ecosystem dynamics.

ESSENTIAL KNOWLEDGE

SYI-2.A.1
The intentional or unintentional introduction of an invasive species can allow the species to exploit a new niche free of predators or competitors or to outcompete other organisms for resources.

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LEARNING OBJECTIVE	ESSENTIAL KNOWLEDGE
SYI-2.A Explain how invasive species affect ecosystem dynamics.	**SYI-2.A.2** The availability of resources can result in uncontrolled population growth and ecological changes.
SYI-2.B Describe human activities that lead to changes in ecosystem structure and/or dynamics.	**SYI-2.B.1** The distribution of local and global ecosystems changes over time. **SYI-2.B.2** Human impact accelerates change at local and global levels— a. The introduction of new diseases can devastate native species. b. Habitat change can occur because of human activity.
SYI-2.C Explain how geological and meteorological activity leads to changes in ecosystem structure and/or dynamics.	**SYI-2.C.1** Geological and meteorological events affect habitat change and ecosystem distribution. Biogeographical studies illustrate these changes.

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AP BIOLOGY

Laboratory Investigations

Lab Experiments

The AP Biology Exam directly assesses the learning objectives of the course framework, which means the inclusion of appropriate experiments aligned with those learning objectives is important for student success. Selecting experiments that provide students with the broadest laboratory experience possible is important when designing the course. You should plan to devote 25 percent of instructional time to lab investigations and have students conduct at least two investigations per big idea.

We encourage you to be creative in designing a lab program while ensuring students explore and develop understandings of core techniques. After completion, students should be able to explain how to collect data, use data to form conclusions, and apply their conclusions to larger biological concepts. Students should report recorded data and quantitative conclusions drawn from the data with appropriate precision (i.e., significant figures). Students should also develop an understanding of how changes in the design of the experiments would impact the validity and accuracy of their results. Many questions on the AP exam are written in an experimental context, so these skills will prove invaluable for both concept comprehension and exam performance.

Lab Materials

AP Biology is a college-level course, but the equipment and chemicals needed for the labs are comparable to those required for a high school-level biology course. A list of instruments, equipment, and chemicals for AP Biology can be found at the beginning of each investigation in the *AP Biology Investigative Labs: An Inquiry-Based Approach* lab manual. Most lab manuals provide a list of materials and equipment needed for each lab investigation. Before purchasing materials, consult your lab manual and calculate how much of a substance or material may be needed for the number of students you have.

Students will need access to basic lab equipment and glassware (e.g., beakers, graduated cylinders, and balances). Access to some specialized equipment, such as spectrophotometers, gel electrophoresis equipment and pH meters, may be needed to complete some of the investigations in the lab manual. None of the investigations in the lab manual require the use of probes or computer sensors for data collection, though they can be used if available. It is recommended that instructors have a computer and projector to show computer-based animations and simulations for pre-lab activities or post-lab discussions. However, a paper-based alternative can easily be provided if the equipment is unavailable. Students may use computers or graphing calculators to analyze data and present their findings, but they do not need to do so.

It is important that the AP Biology laboratory program be adapted to local conditions and funding even while it aims to offer the students a well-rounded experience with experimental biology. Adequate lab facilities should be provided so that each student has a work space where equipment and materials can be left overnight if necessary. Sufficient lab glassware for the anticipated enrollment and appropriate instruments (balances, and pH meters) should be provided.

Students in AP Biology will find it helpful to have access to computers with software appropriate for processing lab data and writing reports. A lab assistant in the form of a paid or unpaid aide may also be helpful; previous students may be able to earn credit by serving as assistants in the lab.

There are avenues you can explore as a means of obtaining access to more expensive equipment, such as computers, spectrophotometers, gel electrophoresis equipment, and probes. Spectrophotometers can often be rented for short periods of time from instrument suppliers. Chemical companies often have equipment that can be borrowed; company representatives should have this information. Alternatively, local colleges or universities may allow high school students to complete a lab as a field trip on their campus, or they may allow teachers to borrow their equipment. They may even donate their old equipment to your school. Some schools have partnerships with local businesses that can help with lab equipment and materials. It never hurts to ask for equipment and/or make your laboratory needs known. There are many grant programs that biology teachers can apply to for funds to purchase equipment and supplies, and you can also use online donation sites such as Donors Choose and Adopt-A-Classroom.

Lab Time

It is critical that lab work be an important part of an AP Biology course so that it is comparable to a college level course for biology majors. Data show that increased lab time is correlated with higher AP scores. Flexible or modular scheduling may be implemented in order to meet the time requirements identified in the course outline for lab and field experiences. You may find that at minimum, one double period a week is needed to allow adequate time for authentic lab experiences.

Lab Manuals

College Board publishes **AP Biology Investigative Labs: An Inquiry-Based Approach**, a manual that meets the curriculum requirement for inquiry-based laboratory experiences for students.

Both the teacher and the student manuals are free and available on the College Board website. Though this lab manual isn't required, it includes laboratory investigations that teachers can choose from to satisfy the guided inquiry lab component for the course. Some textbook publishers may provide a lab manual as an ancillary to the textbook, and most science classroom supply companies also offer lab manuals.

Lab Notebooks and Student Workbooks

Many publishers and science classroom material distributors offer affordable lab notebooks and student workbooks with associated practice problems and solutions. Students can use any type of notebook, even an online document, to fulfill the lab notebook requirement.

How to Set Up a Lab Program

Getting Students Started with Their Investigations

There are no prescriptive "steps" to the iterative process of inquiry-based investigations. However, there are some common characteristics of inquiry that will support students in designing their investigations. Often, this simply begins with using the learning objectives to craft a question for students to investigate. You may choose to give students a list of materials they are allowed to use in their experimental design or require that students request the equipment they feel they need to investigate the question. Working with learning objectives to craft questions may include:

- Selecting learning objectives from the course framework that relate to the subject currently under study, and which may set forth specific tasks, in the form of "Design an experiment to…"
- Rephrasing or refining the learning objectives that align to the unit of study to create an inquiry-based investigation for students.

Students should be given latitude to make design modifications or ask for additional equipment appropriate for their design. It is also helpful for individual groups to share with the class their basic design to elicit feedback on feasibility. During labs, students are encouraged to proceed independently, receiving only minor guidance from the teacher by the end of the course. Students should have many opportunities for post-lab reporting to share the successes and challenges of individual lab designs.

Students need instruction and multiple opportunities for practice with lab tools and techniques so that they can become more proficient investigators. Ensure that students understand how to choose an instrument that will help them gather the observations or measurements required to answer a question. Also ensure students know how to properly record, organize, display, and interpret the measurements made via the chosen instrument in order to support a conclusion or claim pertaining to a particular question. If access to instrumentation is a challenge, online and local university resources may be available.

Prior to performing lab experiments, you can provide meaning and purpose for students by giving them the opportunity to practice lab skills and scientific thinking. Pre-lab work that is acknowledged or checked can help determine what gaps students may have prior to engagement with the lab. Modeling lab skills and procedures is sometimes necessary for students to have a successful lab experience.

At the conclusion of each experiment, students should compose a lab report for which they receive feedback, identifying gaps in skills or lab procedures. Conducting post-lab discussions is an excellent strategy to ensure students are mastering lab and inquiry techniques and skills. These discussions also help students to connect the lab investigation to the enduring understandings.

The lab, as well as pre- and post-lab work should be extensions of student learning in the classroom rather than discrete activities. Design pre-lab exercises and discussions that prepare students for each lab experience and then follow up each investigation with a post-lab discussion to debrief procedures, errors, and conclusions. Test the students' understanding of biology concepts by asking them "what if" questions like "Predict what will happen if…." or "What should the next experiment be if…"

Observations and Data Manipulation

Students must practice making careful observations and accurately recording what they observe. Too frequently students confuse what they see with what they think they are supposed to see. They should be encouraged to be accurate reporters, even when their findings seem to conflict with what they are led to expect by the textbook or lab procedure. Proper interpretation of observations is also important. Students should be able to find evidence of change (growth, color change, temperature change, gas evolution, etc.) and its absence. Students should know how to make and interpret quantitative measurements correctly. This includes knowing the appropriate instrument for making the measurement.

In addition, it's important to emphasize a deep understanding of fundamental graphing skills (beyond line graphs and bar graphs) that will allow your students to make connections between the raw data they obtain from their investigations and the ways they communicate their results. Expect students to graph data correctly and appropriately for the investigation that was conducted, and consistently assess students' understanding and skill with all aspects of creating a graph including correct scaling and units.

Communication, Group Collaboration, and the Laboratory Record

Lab work is an excellent means through which students can develop and practice communication skills. Success in subsequent work in the field of biology depends heavily on an ability to communicate about observations, ideas, and conclusions. Working in a truly collaborative manner to plan and execute experiments will help students learn oral communication skills and practice teamwork. Students must be encouraged to take individual responsibility for the success or failure of the collaboration.

After students are given a question for investigation, they may report their findings to their teacher and/or their peers for feedback. Students should be encouraged to critique and challenge one another's claims based on the evidence collected during the investigation.

Lab Safety

A successful AP Biology lab program will instill in each student a lifelong "safety sense" that will ensure their safe transition into more advanced work in college or university lab or into the industrial workplace environment. It is important that certain concerns regarding lab safety be addressed in every biology course.

- All facilities should conform to federal, state, and local laws and guidelines pertaining to the safety of students and instructors.
- Teachers with a limited background in biology should receive additional safety training specific to biology labs before teaching AP Biology.
- Lab experiments and demonstrations should not be carried out if they could expose the students to unnecessary risks or hazards.
- Students should be fully informed of potential laboratory hazards relating to chemicals and equipment before performing specific experiments.
- Storage and disposal of hazardous chemicals must be done in accordance with local regulations and policies. Instructors and students should know what these regulations are.

Basic lab safety instruction should be an integral part of each laboratory experience. Topics that should be covered include:

- Simple first aid for cuts and thermal and chemical burns
- Use of safety goggles, eye washes, body showers, fire blankets, and fire extinguishers
- Safe handling of glassware, hot plates, burners and other heating devices, and electrical equipment
- Proper interpretation of Material Safety Data Sheets (MSDS) and hazard warning labels
- Proper use and reuse practices (including proper labeling of interim containers) for reagent bottles

AP BIOLOGY

Instructional Approaches

Selecting and Using Course Materials

You will need a wide variety of source materials to help students become proficient with science practices and develop a conceptual understanding of biology. In addition to using a textbook published within the past 10 years that will provide required course content, you should create opportunities for students to examine primary source material in different forms and engage in other types of scientific scholarship. Rich, diverse source material allows the teacher more flexibility in designing learning activities that develop the habits of scientific thinking that are essential for student success in the course.

Textbooks

Any textbook used in the course should be written at the college level and encourage a conceptual understanding of biology. Ideally, the textbook will include multiple examples and approaches to enable students to make connections across different domains within biology and between biology and other social and natural sciences.

College Board does not endorse any particular textbook, and the AP Biology Development Committee does not use any specific book when creating the exam. Therefore, when choosing a textbook, you should take into account many factors such as content, readability, learning level, and availability of ancillary materials. On the AP Central page for this course, you'll find an example textbooks list of college-level textbooks that meet the AP Biology Course Audit curricular requirements.

When planning instruction, it is advisable to consult multiple books and resources in addition to the selected textbook, to gain additional perspectives on the various concepts in the course that students need to learn.

Primary Sources

Many teachers may prefer to augment a textbook with journal articles and/or abstracts from the scientific literature. Students may find it useful to analyze primary source material regularly to deepen their understanding of the key concepts addressed by the textbook and to apply the science practices. While an increasing number of textbooks include primary source material, it is still important to introduce students to a wide variety of materials in order to provide opportunities to analyze data from diverse sources. These sources should include data tables, charts, graphs, and diagrams. You may also use the ancillary materials and website resources that accompany recently published textbooks to find quality materials to supplement classroom instruction.

Note: Lab manuals and other materials are also essential for AP Biology and are discussed on pages 167–168.

Guided Inquiry in AP Instruction

The process of following an experimental procedure to confirm a known outcome can build basic laboratory skills. However, authentic inquiry allows students opportunities to develop and refine higher-order scientific thinking skills. Inquiry skills are built through gradual release in lessons (scaffolding levels). Instead of seeking confirmation of concepts, inquiry-based labs and classroom activities allow students, with guidance, to observe phenomena, explore ideas, and find patterns. This allows students to answer questions they have developed themselves. You are encouraged to create opportunities for open-ended (inquiry-based) laboratory exercises where students can formulate questions, troubleshoot problems, and make appropriate adjustments.

The four levels of inquiry, according to "The Nature of Scientific Enquiry," are

1. **Confirmation:** Students confirm a principle through an activity in which the results are known in advance.
2. **Structured Inquiry:** Students investigate a teacher-presented question through a prescribed procedure.
3. **Guided Inquiry:** Students investigate a teacher-presented question using student-designed/selected procedures.
4. **Open Inquiry:** Students investigate topic-related questions that are student formulated through student-designed/selected procedures.[1]

For each level of inquiry, please see the table below for whether a question, procedure, and/or solution should be provided by you or generated by students.

Level of Inquiry	Question?	Procedure?	Solution?
1 Confirmation	Provided	Provided	Provided
2 Structured	Provided	Provided	Student generated
3 Guided	Provided	Student generated	Student generated
4 Open	Student generated	Student generated	Student generated

Some essential features of guided inquiry instruction in both the classroom and the laboratory are

- Learner selects among questions and poses new questions.
- Learner is directed to collect certain data.
- Learner is given data and asked to analyze it.
- Learner is given the data and told how to analyze it.
- Learner is guided in the process of formulating explanations from evidence.
- Learner is directed toward areas and sources of scientific knowledge.
- Learner is coached in the development of communication.

1 Marshall D. Herron, "The Nature of Scientific Enquiry," The School Review 79, no. 2 (Feb., 1971): 171–212.

Instructional Strategies

The *AP Biology* course framework outlines the concepts and skills students must master in order to be successful on the AP Exam. In order to address those concepts and skills effectively, you should incorporate a variety of instructional approaches into their daily lessons and activities. You can help students develop mastery of science practices by engaging them in learning activities that allow them to apply their understanding of course concepts. As you plan instruction, you may wish to consider the following strategies. The strategies and examples are meant to be suggestions only, and you may use or alter them as fits your needs.

Strategy	Definition	Purpose	Example
Ask the Expert (or Students as Experts)	Students are assigned as "experts" on problems they have mastered; groups rotate through the expert stations to learn about problems they have not yet mastered.	Provides opportunities for students to share their knowledge and learn from one another.	Assign students as "experts" on replication, transcription, post-transcriptional processing, translation, or post-translational processing. Students rotate through stations in groups, working with the station expert to complete a series of questions on the topic.
Construct an Argument	Students use scientific reasoning to present assumptions about biological situations, support conjectures with scientifically relevant and accurate data, and provide a logical progression of ideas leading to a conclusion that makes sense.	Helps develop the process of evaluating scientific information, developing reasoning skills, and enhancing communication skills in supporting conjectures and conclusions.	Present students with a written or visual scenario of the results of a laboratory investigation, then have them work together to draw conclusions about scientific investigations. Ask them to support their conclusions with data by having each student or group of students add a sentence to the conclusion. Once the conclusion is complete, read it (or show it on a screen), and then facilitate a class discussion.
Debate	Engaging in an informal or formal argumentation of an issue.	Gives students an opportunity to collect and orally present evidence supporting the affirmative and negative arguments of a proposition or issue.	Students can debate which line of evidence provides the strongest support for evolution.
Error Analysis	Students analyze an existing solution to determine whether (or where) errors have occurred.	Allows students to troubleshoot errors and focus on solutions that may arise when they perform the same procedures themselves.	Have students analyze their work to determine where there were errors in their calculations. For example, this can be done as part of the diffusion and osmosis lab, or when teaching chi-square or the Hardy-Weinberg principle.

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Strategy	Definition	Purpose	Example
Fishbowl	Some students form an inner circle and model appropriate discussion techniques, while an outer circle of students listens, responds, and evaluates.	Provides students with an opportunity to engage in a formal discussion and to experience the roles of both participant and active listener; students also have the responsibility of supporting their opinions and responses using specific evidence.	Divide students into two groups, and ask them for form two concentric circles. The inner circle can explain photosynthesis to the students in the outer circle, and the outer circle can explain cellular respiration to students in the inner circle.
Graph and Switch	Generating a graph to represent data and then switch papers to review each other's representations.	Allows students to practice creating different representations of data and both give and receive feedback on each other's work.	Give students a data table, and ask them to graph the data. They switch papers and then offer one another feedback. This can be scaffolded by distributing multiple data tables that require different types of graphs. Students can exchange papers and provide feedback on whether their classmate(s) graphed the data appropriately.
Idea Spinner	The teacher creates a spinner marked into four quadrants and labeled "Predict, Explain, Summarize, Evaluate." After new material is presented, the teacher spins the spinner and asks students to answer a question based on the location of the spinner. For example, if the spinner lands in the "Summarize" quadrant, the teacher might say, "List the key concepts just presented."	Functions as a formative assessment technique.	Present students with a written or visual scenario of the results of a laboratory investigation. Using the spinner, ask students to predict what would happen if one of the experimental conditions changed, explain the results, summarize the results, or evaluate the methods used.
Index Card Summaries/ Questions	Periodically, distribute index cards and ask students to write on both sides, with these instructions: (Side 1) Based on our study of (unit topic), list a big idea that you understand and word it as a summary statement. (Side 2) Identify something about (unit topic) that you do not yet fully understand and word it as a statement or question.	Functions as a formative assessment technique.	At the beginning or end of class, show students an image of a food chain or food web. On one side of an index card, students can summarize energy flow through ecosystems. On the other side of the index card, students can write a question about this topic. Collect the cards and read through them, noticing any trends in student responses. Address all questions that day (if done at the beginning of class) or the next day (if giving at the end of class).

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Strategy	Definition	Purpose	Example
Misconception Check	Present students with common or predictable misconceptions about a designated concept, principle, or process. Ask them whether they agree or disagree and to explain why. The misconception check can also be presented in the form of a multiple-choice or true-false quiz.	Functions as a formative assessment technique.	Provide students with a statement on the board, or on paper, such as "All mutations are bad." Ask them if the statement is true or false, and ask them to explain their reasoning. Address any misconceptions according to the answers they give.
One-Minute Essay	A one-minute essay question (or a one-minute question) is a focused question with a specific goal that can, in fact, be answered within a minute or two.	Functions as a formative assessment technique.	Give students one minute to respond to a prompt such as "Explain the relationship between photosynthesis at the cellular level and environmental carbon cycling."
QuickWrite	Writing for a short, specific amount of time about a designated topic related to a text.	Generates multiple ideas in a quick fashion that could be turned into longer pieces of writing at a later time (may be considered as part of the drafting process).	Prior to teaching about water and why it is so important as a biological molecule, ask students to take a few minutes to explain why they think water exhibits the properties of cohesion and adhesion. At the conclusion of the lesson, students can revisit their answer and revise it to reflect on what they have learned.
Think-Pair-Share	Considering and thinking about a topic or question and then writing what has been learned; pairing with a peer or a small group to share ideas; sharing ideas and discussion with a larger group.	Constructs meaning about a topic or question; tests thinking in relation to the ideas of others; prepares for a discussion with a larger group.	When teaching about biological molecules, for example, ask students to reflect on their current learning by asking them to think about the following prompt: "Explain why lipids are nonpolar and insoluble in water." Once students have had a minute or two to think about the question, they can turn to a neighbor or shoulder-partner and then share their answer. After two to three minutes of sharing, the teacher can engage the class in a whole-group discussion to ensure that students are building the necessary foundational understandings.

Developing the Science Practices

Throughout the AP Biology course, students will develop skills that are fundamental to the discipline of biology. Since these science practices represent the complex skills that adept biologists demonstrate, students will benefit from multiple opportunities to develop these skills in a scaffolded manner.

The science practices enable students to apply their content knowledge and establish lines of evidence, using them to develop and refine testable explanations and predictions of natural phenomena. The science practices that follow capture important aspects of the work that scientists engage in, at the level of competence expected of AP Biology students. These practices are effectively integrated with the course content and can be paired with a variety of learning objectives. You are strongly encouraged to design instruction with these science practices in mind.

Science Practice 1: Explain biological concepts, processes, and models presented in written format.

The ability to use verbal and/or written explanations that describe biological processes is an important learning outcome of the AP Biology course and will help students learn to construct and support their arguments. It is important to make clear the distinction between memorizing details and demonstrating an integrated understanding of how a concept or process relates to the overall function of the biological system. Students should have a deep enough understanding of the processes to predict the effects of environmental changes on those processes and justify their prediction (see Practice 6). Additionally, they should be able to use their understanding to explain the results of their own investigations.

Science Practice 1: *Concepts Explanation*

Skills	Tasks/Questions	Sample Activity	Instructional Strategies
1.A: *Describe biological concepts and/or processes.*	Describe characteristics, attributes, traits, and elements in defining terms and concepts. Classify concepts. Describe the components of a process. Describe how a process occurs. Describe structures and functions. Describe patterns and/or trends.	Have students describe how biological molecules are formed through dehydration synthesis and how they are dismantled through hydrolysis. Students should explain the role of water in both chemical reactions.	Index Card Summaries/Questions

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Science Practice 1: *Concepts Explanation (cont'd)*

Skills	Tasks/Questions	Sample Activity	Instructional Strategies
1.B: *Explain biological concepts and/or processes.*	Explain characteristics, attributes, traits, and elements in defining terms and concepts. Explain concepts. Explain the relationship between components of a process. Explain how a process occurs. Explain the relationship between structures and functions. Describe patterns and/or trends in a biological system.	Have students explain why molecules spontaneously move from areas of high concentration to areas of lower concentration, but not vice versa.	Misconception Check
1.C: *Explain biological concepts, processes, and/or models in applied contexts.*	Explain how biological concepts apply in real-world scenarios.	Have students explain how DNA sequences, metabolic processes, and morphological structures that arise through evolution connect the organisms that compose the tree of life.	One-Minute Essay

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Science Practice 2: Analyze visual representations of biological concepts and processes.

Visual representations are indispensable tools for learning and exploring scientific concepts and ideas. Students should create and use representations to illustrate biological processes and concepts, communicate information, make predictions, and describe systems to demonstrate their understanding. Students should also use and apply visual representations to make predictions and address scientific questions, as well as interpret and create graphs drawn from experimental data.

Science Practice 2: *Visual Representations*

Skills	Elements or Tasks	Sample Activity	Instructional Strategies
2.A: *Describe characteristics of a biological concept, process, or model represented visually.*	Describe the characteristics of a representation. Describe patterns or trends in the representation.	Using a graph or other visual data representations of experimental results, describe the relationship between the independent and dependent variables.	QuickWrite
2.B: *Explain relationships between different characteristics of biological concepts, processes, or models represented visually* **a.** *In theoretical contexts.* **b.** *In applied contexts.*	Compare patterns and/or trends in a representation. Explain the concept the model is representing. Predict patterns and/or trends based on a representation.	Using diagrams that illustrate chromosome movement in mitosis and meiosis, explain how information is passed from one generation to the next.	Ask the Expert (or Students as Experts)
2.C: *Explain how biological concepts or processes represented visually relate to larger biological principles, concepts, processes, or theories.*	Draw a conclusion based on the biological principles or concepts in the model or representation.	Demonstrate how chemical structures, such as the Watson and Crick model for DNA, link structure to function at the molecular level.	Construct an Argument
2.D: *Represent relationships within biological models, including* **a.** *Mathematical models.* **b.** *Diagrams.* **c.** *Flowcharts.*	Interact with a mathematical formula. Interact with a chemical equation. Diagram a biological process. Explain a biological process using a flowchart.	Use phylogenetic trees and/or cladograms to show connections and ancestry within and between species.	Index Card Summaries/ Questions

Science Practice 3: Determine scientific questions and methods.

To provide deeper understanding of the concepts, students should be able to pose, refine, and evaluate scientific questions about natural phenomena and investigate answers through experimentation, research, and information gathering and discussion. Suppose a student poses the question: "What happens to the rate of photosynthesis at very high temperatures?" This question can be addressed in a variety of ways, using literature searches, fact finding, and/or designing an experiment to investigate the effect of temperature on chloroplast function, including collecting data, making predictions, drawing conclusions, and refining the original question or approaches. Students need to learn to formulate good scientific questions that lend themselves to experimental approaches and can be evaluated using data and addressed through hypothesis testing. After identifying possible sources of error in an experimental procedure or data set, students should then revise the protocol to obtain more valid results. When presented with a range of data, students should identify outliers and propose an explanation for them as well as a justification for how they should be handled.

Science Practice 3: *Questions and Methods*

Skills	Elements or Tasks	Sample Activity	Instructional Strategies
3.A: *Identify or pose a testable question based on an observation, data, or a model.*	Pose, refine, and evaluate scientific questions about natural phenomena, and investigate answers through experimentation, research, and information gathering and discussion.	Have students discuss the scientific evidence that supports evolution by natural selection, and explain how this evidence is different from alternative ideas about evolution and the origin of life.	QuickWrite
3.B: *State the null or alternative hypotheses, or predict the results of an experiment.*	State the null hypothesis. State the alternative hypothesis. Predict the results of an experiment.	Given an experimental scenario, state the null or alternative hypotheses, or predict the results of an experiment.	Debate
3.C: *Identify experimental procedures that are aligned to the question, including* **a.** *Identifying dependent and independent variables.* **b.** *Identifying appropriate controls.* **c.** *Justifying appropriate controls.*	Identify the dependent variables in an experiment. Identify independent variables in an experiment. Identify the control group and the experimental groups. Justify the control group. Identify the environmental factors that must be controlled. Justify the environmental factors that must be controlled.	Have students design an experiment to test a hypothesis about an observation. They should identify the needed controls and develop an experimental protocol to collect the data. After the experiment, students should analyze their data and draw conclusions from the results that relate to a biological concept or process. Finally, students should describe the limitations of the investigation and their conclusions.	Misconception Check

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Science Practice 3: *Questions and Methods (cont'd)*

Skills	Elements or Tasks	Sample Activity	Instructional Strategies
3.D: *Make observations or collect data from representations of laboratory setups or results.*	Make observations from representations of laboratory setups or results. Collect data from representations of laboratory setups or results.	Give students a diagram of the polypeptide sequence that results from gene expression. The DNA, corresponding DNA, and mRNA sequences should be included in the diagram. Have them determine the phenotype that would occur if a mutation occurred in the DNA sequence.	One-Minute Essay
3.E: *Propose a new/next investigation based on* **a.** *An evaluation of the evidence from an experiment.* **b.** *An evaluation of the design/methods.*	Evaluate and refine scientific questions about natural phenomena, and investigate answers through experimentation, research, and information gathering and discussion.	After evaluating a data set to identify possible sources of error in an experimental procedure, students can revise the protocol to obtain more valid results.	Debate

Science Practice 4: Represent and describe data.

The analysis of different types of graphs is a skill that will help students to succeed in the course and on the AP Exam. Students should appropriately label a graph and correctly plot data. During this course, students should master the skill of communicating the data they collect during their investigations. They should learn not only how to create a graph but also how to create the appropriate graph for a given set of data. Frequent practice analyzing different types of data to identify patterns, connect variables, and perform statistical analysis is important for their success.

Science Practice 4: *Representing and Describing Data*

Skills	Elements or Tasks	Sample Activity	Instructional Strategies
4.A: *Construct a graph, plot, or chart* (X,Y; Log Y; Bar; Histogram; Line, Dual Y; Box and Whisker; Pie). **a.** *Orientation* **b.** *Labeling* **c.** *Units* **d.** *Scaling* **e.** *Plotting* **f.** *Type* **g.** *Trend line*	Construct a line graph showing correct a. Orientation b. Labeling c. Units d. Scaling e. Plotting f. Trend line Construct a line graph where the dependent variable is in a log scale showing correct a. Orientation b. Labeling c. Units d. Scaling e. Plotting f. Trend line Construct a line graph with a dual y-axis showing correct a. Orientation b. Labeling c. Units d. Scaling e. Plotting f. Trend line Construct a bar graph showing correct a. Orientation b. Labeling c. Units d. Scaling e. Plotting Construct a box and whisker chart showing correct a. Orientation b. Labeling c. Units d. Scaling e. Plotting	Give students a real or hypothetical data set. Students should identify the type of graph that should be constructed for the data set, and then they should graph the data.	Graph and Switch

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Science Practice 4: *Representing and Describing Data (cont'd)*

Skills	Elements or Tasks	Sample Activity	Instructional Strategies
	Construct a pie chart showing correct a. Orientation b. Labeling c. Units d. Scaling e. Plotting		
4.B: *Describe data from a table or graph, including* **a.** *Identifying specific data points.* **b.** *Describing trends and/or patterns in the data.* **c.** *Describing relationships between variables.*	Identify specific data points from a data table. Identify specific data points from a graph. Describe the trends and patterns in the data. Describe how the dependent variable changes in response to the independent variable.	Have students describe patterns or trends in a data table or graph of a data set (real or hypothetical), such as the increase in enzyme activity with an increase in temperature until reaching the optimum temperature, at which point enzyme activity decreases with increasing temperature.	Graph and Switch

Science Practice 5: Perform statistical tests and mathematical calculations to analyze and interpret data.

Students should be able to routinely use mathematics to solve problems, analyze experimental data, describe natural phenomena, make predictions, and describe processes symbolically. Students should also justify the selection of a particular mathematical routine and apply the routine to describe natural phenomena.

Students should also be able to analyze data collected from an experimental procedure or from a given source to determine whether the data support or do not support a conclusion or hypothesis. For example, if a student conducts an experiment to determine if light intensity affects the rate of photosynthesis, he or she can construct a graph based on the collected data and use the graph to formulate statements, conclusions, and possibly a hypothesis. Alternatively, students can draw conclusions from a provided data set. For example, given a graph depicting the percentage change in the mass of potato cores after exposure to different concentrations of sucrose, the student should be able to estimate the concentration of sucrose within the potato core. Students should also assess the validity of experimental evidence. Using the same example, if given hypothetical data showing that potato cores increase in mass when placed in solutions with lower water potential (a hypertonic solution), they should explain why the data (evidence) are likely invalid: Since potatoes contain sucrose, they should increase in mass only when placed in solutions with higher water potential (a hypotonic solution).

Science Practice 5: *Statistical Tests and Data Analysis*

Skills	Elements or Tasks	Sample Activity	Instructional Strategies
5.A: *Perform mathematical calculations, including* **a.** *Mathematical equations in the curriculum.* **b.** *Means.* **c.** *Rates.* **d.** *Ratios.* **e.** *Percentages.*	Calculate one or more of the components of Hardy-Weinberg equation. Calculate the mean of a data set. Calculate the rate of a reaction. Calculate a ratio. Calculate a percent change.	Have students complete a teacher-selected Hardy-Weinberg lab. Students can use their data to predict changes in gene frequencies in the population they studied.	Error Analysis
5.B: *Use confidence intervals and/or error bars (both determined using standard errors) to determine whether sample means are statistically different.*	Draw standard error bars, ± 1 SEM or ±2 SEM. Draw error bars for the 95% confidence interval. Determine if there is overlap between the bars of two or more sample means.	After completing an investigation such as the Diffusion and Osmosis lab, collect class data. The students graph the class data and calculate the descriptive statistics and then use the standard error bars to determine if two sample means are statistically different.	Graph and Switch

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Science Practice 5: *Statistical Tests and Data Analysis (cont'd)*

Skills	Elements or Tasks	Sample Activity	Instructional Strategies
5.C: *Perform chi-square hypothesis testing.*	Calculate the chi-square value of a given set of data. Determine the *p*-value for a given set of data. Draw conclusions about the experiment based on the comparison of the chi-square value to the *p*-value.	Have students perform the animal behavior lab of your choice. They should formulate the null and alternative hypotheses and then calculate the chi-square test statistic. Once the chi-square statistic has been calculated, students compare it to the *p*-value in order to compare the observed versus the predicted patterns in animal behavior.	Misconception Check
5.D: *Use data to evaluate a hypothesis (or prediction), including* **a.** *Rejecting or failing to reject the null hypothesis.* **b.** *Supporting or refuting the alternative hypothesis.*	Make a prediction using the data, and then justify the prediction. Given data and a prediction, justify the prediction. Given a null hypothesis and a graph, determine if the null hypothesis should be rejected.	Give students data from an experiment that can be found on a website such as **datanuggets.org/**. Have the students graph the data (or give them a graph), and ask them to make a prediction about what might happen if one of the environmental factors changed or if something about the experimental group changed.	Idea Spinner

Science Practice 6: Develop and justify scientific arguments using evidence.

Students should be able to write and evaluate scientific descriptions, explanations, and theories that describe biological phenomena and processes. Students should be able to call upon current knowledge and historical experiments and draw inferences from their explorations to justify claims with evidence. For example, students should cite evidence drawn from the different scientific disciplines that support natural selection and evolution, such as the geological record, antibiotic resistance in bacteria, herbicide resistance in plants, or how a population bottleneck changes Hardy-Weinberg equilibrium. Essential skills include the ability to analyze, interpret, and make predictions from a model or the data obtained in an experiment and the ability to justify the reasoning for a prediction and/or explanation. For example, when given a sequence of DNA containing a designated mutational change, students can predict the effect of the mutation on the encoded polypeptide and propose a possible resulting phenotype. Students can also evaluate the merits of alternative scientific explanations or conclusions.

Science Practice 6: *Argumentation*

Skills	Elements or Tasks	Sample Activity	Instructional Strategies
6.A: *Make a scientific claim.*	Describe what is being shown in the graph. Describe what is being shown in the data table. Draw conclusions from the experimental results of others. Draw conclusions from their own experimental results.	Give students a graph of a real or hypothetical data set, along with a description of the experiment that produced the results. Ask them to draw a conclusion about the experiment using a biological concept.	Fishbowl
6.B: *Support a claim with evidence from biological principles, concepts, processes, and/or data.*	Explain how the claim is supported by biological evidence.	Provide students with a scientific paper to read. Select a paper that is appropriate for their reading level and content knowledge. Have students identify the conclusions of the research and then support the conclusions with evidence in the paper. As the year progresses, you may also ask students to refute the conclusions using evidence from the data or from biological concepts.	Construct an Argument

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Science Practice 6: *Argumentation (cont'd)*

Skills	Elements or Tasks	Sample Activity	Instructional Strategies
6.C: *Provide reasoning to justify a claim by connecting evidence to biological theories.*	Explain how the data relate to a biological theory. Explain how reasoning supports a claim.	Have students read the brief article, "**Peppered Moths Re-examined**". They should then explain—using biological concepts and data—the conclusions from the peppered moth experiment and the reasoning behind the controversy about the experiment. They should then describe Marjerus's work and explain how well it supports the original experiment. Students can then propose additional experiments to support or refute the original conclusion.	Construct an Argument
6.D: *Explain the relationship between experimental results and larger biological concepts, processes, or theories.*	Explain how the results of an investigation explain a biological principle. Connect observational data to a broader theory.	Have students read excerpts from the article "**On the Origin of Mitosing Cells**" by Lynn Sagan (Margulis), and identify the claims made in the article about endosymbiosis and the evidence to support the claim. (Note: The article is long, so it is not advisable for students to read it in its entirety.) Students should then learn about the work of Schwartz and Dayhoff, who obtained experimental results to support Margulis's claim, and then explain how the results support the theory of endosymbiosis.	Construct an Argument

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Science Practice 6: *Argumentation (cont'd)*

Skills	Elements or Tasks	Sample Activity	Instructional Strategies
6.E: *Predict the causes or effects of a change in, or disruption to, one or more components in a biological system based on* **a.** *Biological concepts or processes.* **b.** *A visual representation of a biological concept, process, or model.* **c.** *Data.*	Describe what happens when an organism is removed from a food web. Describe how temperature affects the rate of photosynthesis. Use a visual representation to describe how cells respond to changing salinity levels in the external environment.	When given a sequence of DNA containing a designated mutational change, the student can predict the effect of the mutation on the encoded polypeptide and propose a possible resulting phenotype.	Construct an Argument

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AP BIOLOGY

Exam Information

Exam Overview

The AP Biology Exam assesses student understanding of the science practices and learning objectives outlined in the course framework. The exam is 3 hours long and includes 60 multiple-choice questions and 6 free-response questions. A four-function, scientific, or graphing calculator is allowed on both sections of the exam. The details of the exam, including exam weighting and timing, can be found below:

Section	Question Type	Number of Questions	Exam Weighting	Timing
I	**Multiple-choice questions**	**60**	**50%**	**90 minutes**
II	**Free-response questions**	**6**	**50%**	**90 minutes**
	Question 1: Interpreting and Evaluating Experimental Results (8–10 pts)			
	Question 2: Interpreting and Evaluating Experimental Results with Graphing (8–10 pts)			
	Question 3: Scientific Investigation (4 pts)			
	Question 4: Conceptual Analysis (4 pts)			
	Question 5: Analyze Model or Visual Representation (4 pts)			
	Question 6: Analyze Data (4 pts)			

The exam assesses content from each of four big ideas for the course:
1. Evolution
2. Energetics
3. Information Storage and Transmission
4. Systems Interactions

The exam also assesses each of the eight units of the course with the following exam weightings on the multiple-choice section of the AP Exam:

Unit	Exam Weighting
1: Chemistry of Life	**8–11%**
2: Cell Structure and Function	**10–13%**
3: Cellular Energetics	**12–16%**
4: Cell Communication and Cell Cycle	**10–15%**
5: Heredity	**8–11%**
6: Gene Expression and Regulation	**12–16%**
7: Natural Selection	**13–20%**
8: Ecology	**10–15%**

How Student Learning Is Assessed on the AP Exam

All six AP Biology science practices are assessed on every AP Exam in the multiple-choice and free-response sections as detailed below.

Science Practice	Multiple-Choice Section	Free-Response Section
1: Concept Explanation	Individual and/or set-based multiple-choice questions assess students' ability to explain biological concepts, processes, and models presented in written format. Students will need to describe and explain these concepts, processes, and models in both conceptual and applied contexts.	Free-response questions 1, 2, 3, 4, and 5 include one or two points per question that assess Science Practice 1.
2: Visual Representations	Individual and/or set-based multiple-choice questions will assess students' ability to analyze visual representations of biological concepts and processes. Students will need to describe characteristics of a biological concept, process, or model represented visually, as well as explain relationships between these different characteristics. Additionally, students will need to explain how biological concepts or processes represented visually relate to larger biological principles, concepts, processes, or theories.	Free-response question 5 focuses primarily on Science Practice 2.
3: Questions and Methods	Individual and/or set-based multiple-choice questions will assess students' ability to determine scientific questions and methods. Students will need to identify or pose a testable question, state the null or alternative hypotheses or predict the results of an experiment, identify experimental procedures, and/or propose new investigations.	Free-response questions 1 and 3 focus on Science Practice 3, with approximately half of the points for each question assessing this practice.

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Science Practice	Multiple-Choice Section	Free-Response Section
4: Representing and Describing Data	Individual and/or set-based multiple-choice questions will assess students' ability to describe data from a table or graph. Students will need to identify specific data points, describe trends or patterns, and describe relationships between variables	Free-response questions 2 and 6 focus on Science Practice 4, with approximately half of the points for each question assessing this practice. Free-response question 1 also assesses this practice in one or two points.
5: Statistical Tests and Data Analysis	Individual and/or set-based multiple-choice questions will assess students' ability to perform statistical tests and mathematical calculations to analyze and interpret data. Students will need to perform mathematical calculations, use confidence intervals, perform chi-square hypothesis testing, and use data to evaluate a hypothesis or prediction.	Free-response question 1 or 2 assess students' ability to perform a mathematical calculation. Free-response question 6 assesses students' ability to use data to evaluate a hypothesis or prediction.
6: Argumentation	Individual and/or set-based multiple-choice questions will assess students' ability to develop and justify scientific arguments using evidence. Students will need to make scientific claims, support claims with evidence, and provide reasoning to justify claims. Additionally, students will need to explain relationships between experimental results and larger biological concepts, processes, or theories. Finally, students will need to predict the causes or effects of a change in, or disruption to, one or more components in a biological system.	Free-response questions 1, 2, 3, 4, and 6 include one, two, or occasionally three points per question that assess Science Practice 6.

Section I: Multiple-Choice

The first section of the AP Biology Exam includes 60 multiple-choice questions appearing either as individual questions or in sets of typically four to five questions per set. All six AP Biology science practices are assessed in the multiple-choice section with the following exam weightings:

Science Practice	Exam Weighting
1: Concept Explanation	**25–33%**
2: Visual Representations	**16–24%**
3: Questions and Methods	**8–14%**
4: Representing and Describing Data	**8–14%**
5: Statistical Tests and Data Analysis	**8–14%**
6: Argumentation	**20–26%**

Section II: Free-Response

The second section of the AP Biology Exam includes two long questions, and four short-answer questions. Each of the four short-answer questions will focus on a different big idea and a different unit of instruction.

Free-response question 1: Interpreting and Evaluating Experimental Results is an 8 to 10-point question that presents students with an authentic scenario accompanied by data in a table and/or graph. This question assesses student ability to do the following in four question parts:

- Part A (1 to 2 points): Describe and explain biological concepts, processes, or models.
- Part B (3 to 4 points): Identify experimental design procedures.
- Part C (1 to 3 points): Analyze data.
- Part D (2 to 4 points): Make and justify predictions.

Free-response 2: Interpreting and Evaluating Experimental Results with Graphing is an 8 to 10-point question that presents students with an authentic scenario accompanied by data in a table. This question assesses students' ability to do the following in four question parts:

- Part A (1 to 2 points): Describe and explain biological concepts, processes, or models.
- Part B (4 points): Construct a graph, plot or chart and use confidence intervals or error bars.
- Part C (1 to 3 points): Analyze data.
- Part D (1 to 3 points): Make and justify predictions.

Free-response question 3: Scientific Investigation is a 4-point question that presents students with a description of a lab investigation scenario. This question assesses students' ability to do the following in four question parts:

- Part A (1 point): Describe biological concepts or processes.
- Part B (1 point): Identify experimental procedures.
- Part C (1 point): Predict results.
- Part D (1 point): Justify predictions.

Free-response question 4: Conceptual Analysis is a 4-point question that presents students with an authentic scenario describing a biological phenomenon with a disruption. This question assesses students' ability to do the following in four question parts:

- Part A (1 point): Describe biological concepts or processes.
- Part B (1 point): Explain biological concepts or processes.
- Part C (1 point): Predict the causes or effects of a change in a biological system.
- Part D (1 point): Justify predictions.

Free-response question 5: Analyze Model or Visual Representation is a 4-point question that presents students with a description of an authentic scenario accompanied by a visual model or representation. This question assesses students' ability to do the following in four question parts:

- Part A (1 point): Describe characteristics of a biological concept, process, or model represented visually.
- Part B (1 point): Explain relationships between different characteristics of a biological concept or process represented visually.
- Part C (1 point): Represent relationships within a biological model.
- Part D (1 point): Explain how a biological concept or process represented visually relates to a larger biological principle, concept, process, or theory.

Free-response question 6: Analyze Data is a 4-point question that presents students with data in a graph, table, or other visual representation. This question assesses students' ability to do the following in four question parts:

- Part A (1 point): Describe data.
- Part B (1 point): Describe data.
- Part C (1 point): Use data to evaluate a hypothesis or prediction.
- Part D (1 point): Explain how experimental results relate to biological principles, concepts, processes, or theories.

Task Verbs Used in Free-Response Questions

The following **task verbs** are commonly used in the free-response questions:

Calculate: Perform mathematical steps to arrive at a final answer, including algebraic expressions, properly substituted numbers, and correct labeling of units and significant figures.

Construct/Draw: Create a diagram, graph, representation, or model that illustrates or explains relationships or phenomena. Labels may or may not be required.

Describe: Provide relevant characteristics of a specified topic.

Determine: Decide or conclude after reasoning, observation, or applying mathematical routines (calculations).

Evaluate: Judge or determine the significance or importance of information, or the quality or accuracy of a claim.

Explain: Provide information about how or why a relationship, process, pattern, position, situation, or outcome occurs, using evidence and/or reasoning to support or qualfiy a claim. Explain "how" typically requires analyzing the relationship, process, pattern, position, situation, or outcome; whereas explain "why" typically requires analysis of motivations or reasons for the relationship, process, pattern, position, situation, or outcome.

Identify: Indicate or provide information about a specified topic, without elaboration or explanation.

Justify: Provide evidence to support, qualify, or defend a claim, and/or provide reasoning to explain how that evidence supports or qualifies the claim.

Make a claim: Make an assertion that is based on evidence or knowledge.

Predict/Make a prediction: Predict the causes or effects of a change in, or disruption to, one or more components in a relationship, pattern, process, or system.

Represent: Use appropriate graphs, symbols, words, illustrations, and/or tables of numerical values to describe biological concepts, characteristics, and/or relationships.

State (the null/alternative hypothesis): Indicate or provide a hypothesis to support or defend a claim about a scientifically testable question.

Support a claim: Provide reasoning to explain how evidence supports or qualifies a claim.

Sample Exam Questions

The sample exam questions that follow illustrate the relationship between the course framework and AP Biology Exam and serve as examples of the types of questions that appear on the exam. After the sample questions you will find a table that shows which skill, learning objective(s), and unit each question relates to. The table also provides the answers to the multiple-choice questions.

Section I: Multiple-Choice Questions

The following are examples of the kinds of multiple-choice questions found on the exam.

1. Insulin is a protein hormone that is secreted in response to elevated blood glucose levels. When insulin binds to its receptors on liver cells, the activated receptors stimulate phosphorylation cascades that cause the translocation of glucose transporters to the plasma membrane.

   Based on the information provided, which of the following best describes the role of insulin in this liver cell signal transduction pathway?

   (A) It acts as a ligand.

   (B) It acts as a receptor.

   (C) It acts as a secondary messenger.

   (D) It acts as a protein kinase.

2. Humans have a diploid number ("2n") of 46. Which of the following statements best predicts the consequence if meiosis did not occur during gametogenesis?

   (A) The gametes would get larger from one generation to the next.

   (B) The chromosome number would double with each generation.

   (C) The chromosome number would be halved with each generation.

   (D) The chromosome number would triple with each generation.

3. Mutations in the *MYO6* and *POU4F3* genes have been associated with a form of hereditary hearing loss in humans. Researchers studying the genes have proposed that *POU4F3* encodes a transcription factor that influences the regulation of *MYO6*.

   Which of the following questions will best help guide the researchers toward a direct test of their proposal?

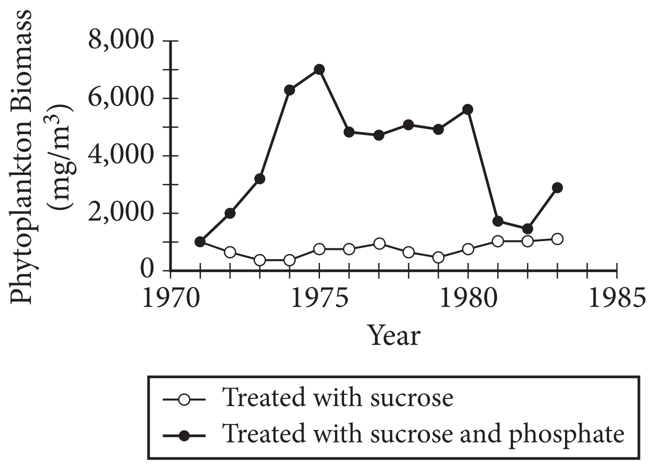
   (A) Have mutations in other genes also been associated with hearing loss?

   (B) In what types of cells are the mutant forms of the *POU4F3* gene expressed?

   (C) Are mutations in the *MYO6* and *POU4F3* genes also found in mice?

   (D) Do mutations in the *POU4F3* gene affect *MYO6* mRNA levels in cells?

Questions 4–7 refer to the following material.



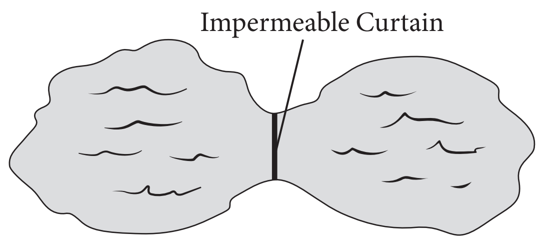


Figure 1. Phytoplankton biomass in two sides of a small lake that is divided by an impermeable curtain

In the early 1970s, researchers hypothesized that carbon was the limiting nutrient in many aquatic ecosystems. To test this hypothesis, the researchers divided a small lake in two roughly equal halves with an impermeable curtain that was fastened and sealed to the bedrock of the lake. Beginning in 1971 the researchers treated one side of the lake with sucrose and the other side with both sucrose and phosphate. From 1971 to 1983 the researchers monitored the phytoplankton biomass in both parts of the lake. The results are shown in Figure 1.

4. Which of the following claims is best supported by the data?
   (A) Carbon was a limiting factor for phytoplankton in the lake.
   (B) Phosphate was a limiting factor for phytoplankton in the lake.
   (C) Both carbon and phosphate were limiting factors for phytoplankton in the lake.
   (D) Neither carbon nor phosphate was a limiting factor for phytoplankton in the lake.

5. The average growth rate of the phytoplankton population from 1971 to 1975 in the side of the lake treated with sucrose and phosphate is closest to which of the following?
   (A) 125 (mg/m^3)/year
   (B) 1,000 (mg/m^3)/year
   (C) 1,500 (mg/m^3)/year
   (D) 6,000 (mg/m^3)/year

6. Which of the following treatments would have been the best control treatment for the experiment?
   (A) An untreated section of the lake
   (B) A section of the lake that was treated with phosphate but not sucrose
   (C) A different lake that was treated with sucrose and phosphate
   (D) A small pool of the lake water maintained in a controlled laboratory environment

7. Which of the following was most likely a direct consequence of the addition of phosphate to the lake?
   (A) The amount of biomass in the first trophic level decreased.
   (B) The amount of biomass in the second trophic level decreased.
   (C) The amount of energy available to producers in the lake increased.
   (D) The amount of energy available to consumers in the lake increased.

8. The enzyme trypsin aids in protein digestion in the small intestine. The relative activity of trypsin at different pH values is shown in Figure 1.

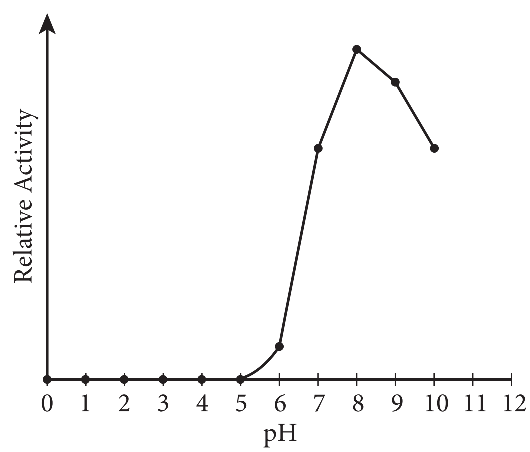


Figure 1. Effect of pH on the activity of trypsin

Which of the following statements best explains the activity levels of trypsin shown in Figure 1?
   (A) The small intestine releases inhibitor molecules that block the activity of trypsin unless it is at its optimum pH.
   (B) The number of effective collisions between trypsin and its substrate increase at higher pH values.
   (C) As pH values increase, the substrate concentration decreases, leading to an eventual decline in the rate of the trypsin-catalyzed reaction.
   (D) At extremely low pH values, trypsin is denatured and cannot function efficiently.

Different photosynthetic organisms have different types of chlorophyll molecules. The distribution of chlorophylls in several different groups of organisms is shown in Table 1. A plus sign (+) in the table indicates the presence of a chlorophyll, while a minus sign (–) indicates its absence.

Table 1. The distribution of chlorophylls in several groups of organisms

	Chlorophyll *a*	Chlorophyll *b*	Chlorophyll *c*	Chlorophyll *d*
Flowering plants	+	+	–	–
Green algae	+	+	–	–
Brown algae	+	–	+	–
Red algae	+	–	–	+
Cyanobacteria	+	–	–	–

9. Based on the data, which of the following most likely describes the evolutionary relationship among the organisms?
   (A) Because brown algae, red algae, and cyanobacteria lack chlorophyll *b*, they evolved before green algae and flowering plants did.
   (B) Because green algae and flowering plants contain chloroplasts, they evolved more recently than brown algae, red algae, and cyanobacteria did.
   (C) Because increasingly complex forms of chlorophyll are found in red algae, brown algae, green algae, and flowering plants, respectively, this reflects the order of their appearance.
   (D) Because all of the organisms contain chlorophyll *a*, the organisms share a common ancestor.

10. A student used a microscope to observe a wet-mount slide of red onion epidermal cells that were suspended in a 1% NaCl solution. The student then added a 15% NaCL solution to the slide and observed the changes that occurred. The student's observations are represented in Figure 1.

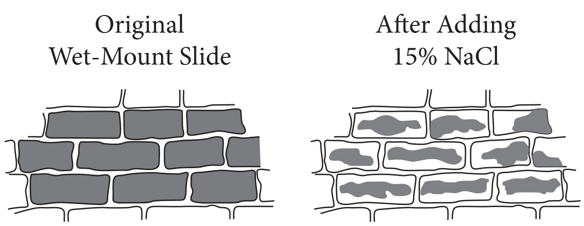


Figure 1. Student's observations of onion cells

Which of the following most directly explains the changes in the cells?
   (A) The degradation of DNA in the nuclei of the cells
   (B) The lysis of chloroplasts in the cells
   (C) The movement of water from the central vacuoles of the cells into the solution
   (D) The movement of NaCl from the solution into the cytoplasm of the cells

11. The human *TPM1* gene encodes members of the tropomyosin family of cytoskeletal proteins. Which of the following best explains how different proteins can be made in different cell types from the one *TPM1* gene?

(A) Different introns are selectively converted to exons.

(B) Different exons are retained or spliced out of the primary transcript.

(C) The GTP cap is selectively added to and activates different exons.

(D) Different portions of the primary transcript remain bound to the template DNA.

12. Scientists examined the folded structure of a purified protein resuspended in water and found that amino acids with nonpolar R groups were primarily buried in the middle of the protein, whereas amino acids with polar R groups were primarily on the surface of the protein. Which of the following best explains the location of the amino acids in the folded protein?

(A) Polar R groups on the surface of the protein can form ionic bonds with the charged ends of the water molecules.

(B) Polar R groups are too bulky to fit in the middle of the protein and are pushed toward the protein's surface.

(C) Nonpolar R groups that cannot form hydrogen bonds with water are pushed into the middle of the protein.

(D) Nonpolar R groups from different parts of the protein form covalent bonds with each other to maintain the protein's structure.

13. The apple maggot fly, *Rhagoletis pomonella*, is native to North America and originally fed on fruit of the wild hawthorn. Since the mid-1800s, a population of flies has emerged that instead feed on domesticated apples. Apple maggot flies typically mate on or near the fruit of their host plants. Many varieties of apples ripen three to four weeks before the hawthorn fruits do.

The different fruit preferences of the two fly populations will most likely have which of the following effects?

(A) The flies that eat hawthorn fruit will increase in number, while the flies that eat apples will decrease in number because of the use of insecticides on apple trees.

(B) The single fly species will evolve into two distinct species because of the lack of gene flow between the two populations.

(C) The ability to survive on a diet of two different fruits will help the flies learn to eat many more types of fruit.

(D) The flies that eat hawthorn fruit will lay some of their eggs on the earlier-ripening apples to minimize competition among the larvae.

Platelets are fragments of larger cells and normally circulate in the blood without adhering to blood vessel walls. When the wall of a blood vessel is damaged, collagen fibers in the wall are exposed to the interior of the blood vessel. The exposed fibers and chemicals released from the endothelial cells that line the blood vessel attract platelets, which start to form a plug and release other chemicals (Figure 1).

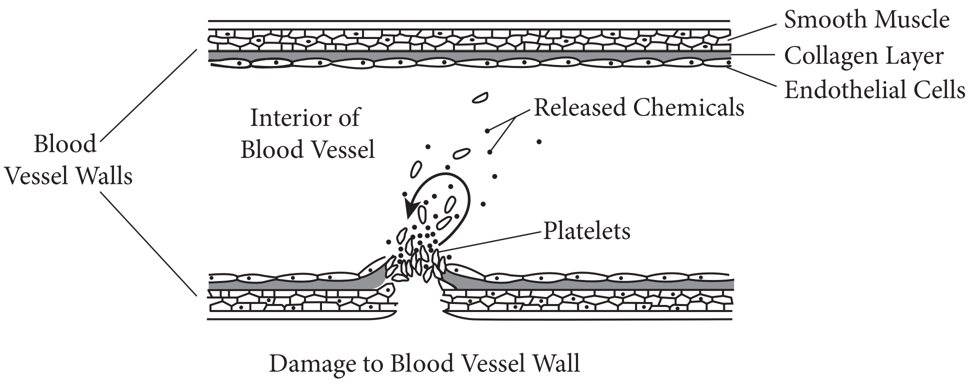


Figure 1. Formation of a platelet plug in a damaged blood vessel wall

14. Which of the following best explains the feedback mechanism illustrated in Figure 1?
    (A) This is an example of positive feedback, because the few platelets that initially bind attract more platelets to the damaged area.
    (B) This is an example of positive feedback, because it results from the interactions among collagen, endothelial cells, and platelets.
    (C) This is an example of negative feedback, because a large clump of platelets can block the blood vessel and prevent blood flow through it.
    (D) This is an example of negative feedback, because the accumulation of platelets returns the open blood vessel wall to a closed state.

15. It is estimated that oxygen production first evolved in photosynthetic prokaryotes approximately 2.7 billion years ago. The first photosynthetic prokaryotes are presumed to be similar to today's cyanobacteria.

Which of the following best supports the claim that photosynthetic prokaryotes were responsible for the oxygen in Earth's atmosphere?
    (A) The light reactions of photosynthesis split carbon dioxide into carbon and oxygen.
    (B) The light reactions of photosynthesis split water into hydrogen ions and oxygen.
    (C) The Calvin cycle splits glucose into carbon, hydrogen, and oxygen.
    (D) The Calvin cycle splits water into hydrogen ions and oxygen.

Section II: Free-Response Questions

The following are examples of the kinds of free-response questions found on the exam. Note that on the actual AP Exam, there will be two long questions and four short-answer questions.

Read each question carefully. Write your response in the space provided for each part of each question. Answers must be written out in paragraph form. Outlines, bulleted lists, or diagrams alone are not acceptable and will not be scored.

Interpreting and Evaluating Experimental Results (Question 1 on the AP Exam)

In many countries, *Anopheles gambiae* mosquitoes are responsible for transmitting the parasite that causes malaria to people through their bites. A primary tool for mosquito control is the use of insecticidal nets sprayed with chemicals known as pyrethroids, which are relatively safe for people but toxic to mosquitoes. However, mosquito resistance to pyrethroids has now become widespread. Pyrethroids interfere with the function of a transmembrane sodium channel found in cells of the mosquitoes (Figure 1). In one common mutation to the channel protein, a phenylalanine is substituted for a leucine at amino acid position 1014. Scientists hypothesize that this mutation is responsible for some cases of pyrethroid resistance.

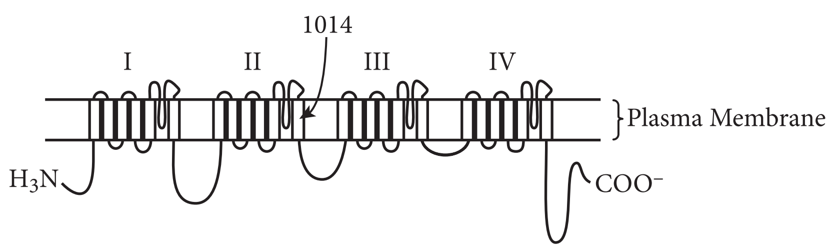


Figure 1. Schematic drawing of the transmembrane sodium channel targeted by pyrethroids and other insecticides. The arrow points to the position of amino acid 1014.

To investigate pyrethroid resistance, mosquitoes were collected four times over a two-year period from the following two regions.

- Region A: a southern vegetable-growing region where large amounts of insecticide are applied for crop protection
- Region B: a northern rice-growing region where very little insecticide is applied for rice protection

Scientists exposed the collected mosquitoes to filter papers soaked in two different pyrethroid insecticides, deltamethrin and permethrin, and the percent mortality of the mosquitoes was determined after 24 hours (Figure 2). The scientists simultaneously determined whether leucine or phenylalanine was encoded at position 1014 by each of the two copies of the sodium channel gene (Table 1).

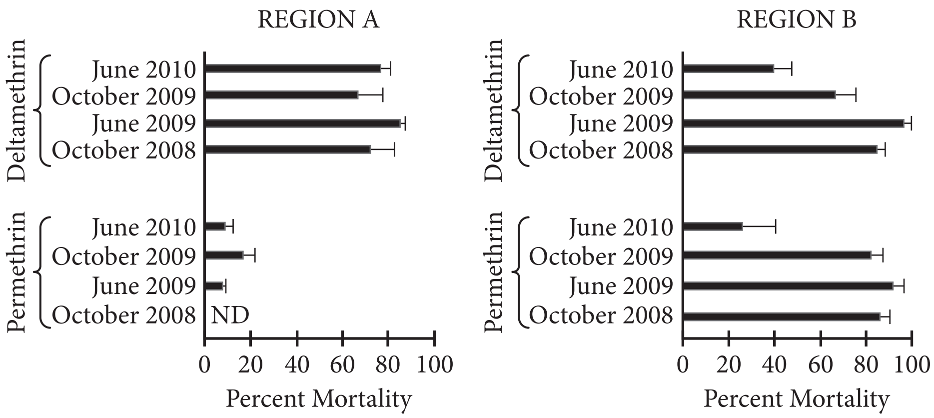


Figure 2. Susceptibility of *A. gambiae* mosquitoes from two regions to the pyrethroids deltamethrin and permethrin. A mosquito strain that is susceptible to the insecticides displayed at least 95% mortality in all experiments, and mosquitoes exposed to untreated filter paper displayed less than 10% mortality. Error bars represent standard deviation. "ND" means no data are available.

Table 1. Frequencies of leucine and phenylalanine at position 1014 of the sodium channel

Region	Date	Total Mosquitoes Tested	Homozygous for Leucine	Heterozygous for Leucine and Phenylalanine	Homozygous for Phenylalanine
A	October 2008	39	3	5	31
A	June 2009	29	-	5	24
A	October 2009	28	-	1	27
A	June 2010	46	-	9	37
B	October 2008	27	20	5	2
B	June 2009	26	18	7	1
B	October 2009	34	20	8	6
B	June 2010	44	12	20	12

(a) **Describe** the most likely cause of the amino acid substitution in the sodium channel protein. **Explain** how the substitution of a single amino acid in the channel protein could cause pyrethroid resistance in mosquitoes.

(b) **Identify** the dependent variable in the experiment whose data are graphed in Figure 2. **Identify** the positive control in the experiment. **Justify** exposing some mosquitoes to untreated filter paper each time the experiment was performed.

(c) Based on the data in Figure 2, **describe** whether mosquitoes from region A or from region B are more likely to exhibit greater evolutionary fitness if exposed to permethrin in their native environment over the time period of the experiment. Based on the data in Figure 2, **describe** any significant change in the susceptibility of mosquitoes from region B to each of the two insecticides over the two-year period. Use the data in Table 1 to **calculate** the frequency of the allele coding for phenylalanine in each population of mosquitoes in October 2008. Round your answers to two decimal places.

(d) Using mosquitoes from insecticide-free areas, the scientists developed mosquito strains with amino acid substitutions at other positions in the sodium channel protein. They exposed the mosquito strains to nonpyrethroid insecticides. **Predict** the susceptibility of the mosquitoes to the insecticides. The scientists claim that the mosquito population of region B evolved resistance over the period of the experiment and that resistance arose as a result of the immigration of resistant mosquitoes from other regions. Based on the data in Table 1 and the information provided, **provide evidence** to support the scientists' claim.

Analyze Model or Visual Representation (Question 5 on AP Exam)

In humans, the gene that determines a particular condition has only two alleles, one of which (*B*) is completely dominant to the other (*b*). The phenotypes of three generations of a family with respect to the condition are shown in the pedigree in Figure 1. Individuals are numbered.

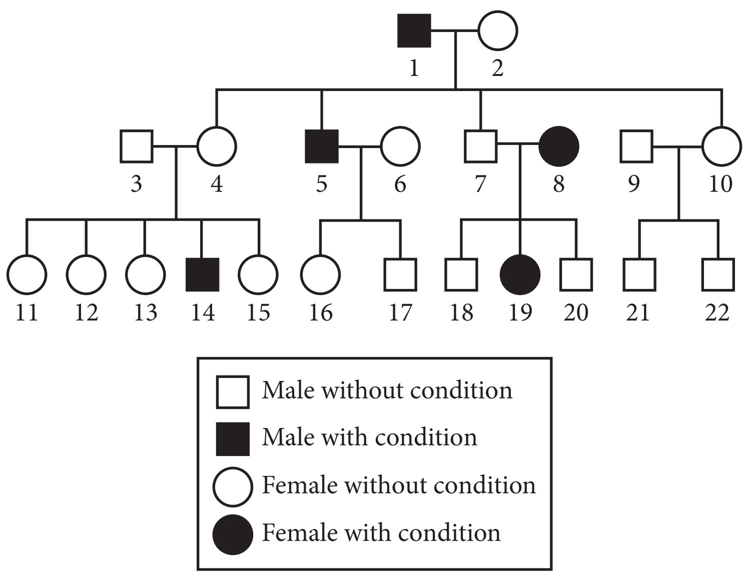
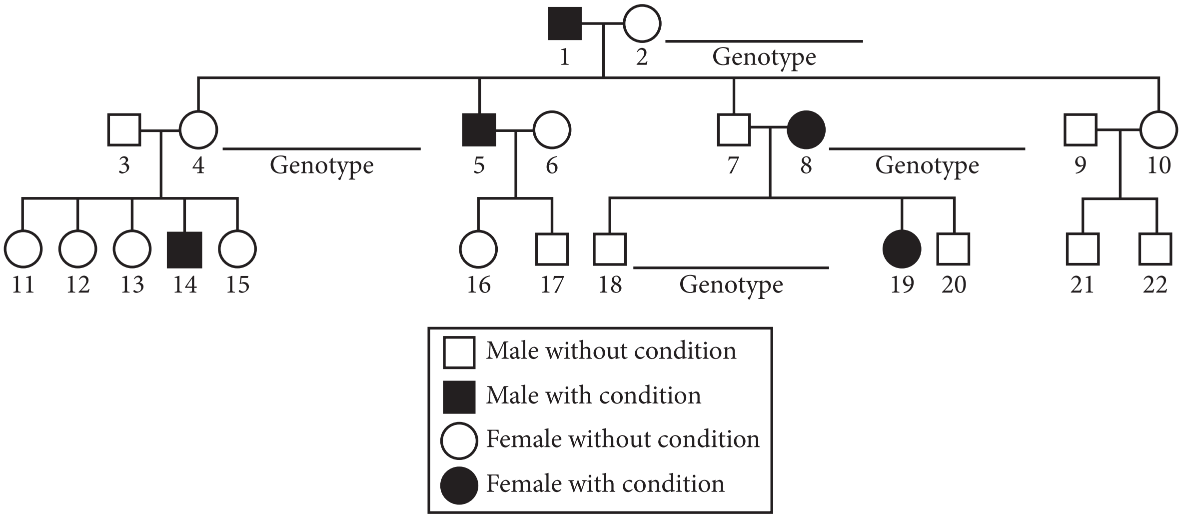


Figure 1. Inheritance of a particular condition over three generations of a family

(a) **Describe** the process in eukaryotes that ensures that the number of chromosomes will not double from parent to offspring when gametes fuse during fertilization.

(b) **Explain** how any one chromosome in individual 16 contains DNA that came from both individuals 1 and 2.

(c) **Use the template** figure of the pedigree and the allele designations *B* and *b* to **indicate** the genotypes of individuals 2, 4, 8, and 18.



(d) Based on the pedigree, **explain** whether the inheritance pattern of the condition is sex-linked or autosomal <u>and</u> dominant or recessive.

Answer Key and Question Alignment to Course Framework

Multiple-Choice Question	Answer	Skill	Learning Objective	Unit
1	A	1.A	IST-3.B	4
2	B	6.E.a	IST-1.F	5
3	D	3.A	IST-2.C	6
4	B	4.B.c	SYI-1.G	8
5	C	5.A.c	SYI-1.G	8
6	A	3.C.b	SYI-1.G	8
7	D	6.E.a	ENE-1.N	8
8	D	2.B.b	ENE-1.F	3
9	D	4.B.b	EVO-2.B	7
10	C	2.B.b	ENE-2.H	2
11	B	1.C	IST-1.N	6
12	C	1.B	SYI-1.B	1
13	B	1.C	EVO-3.F	7
14	A	2.C	ENE-3.C	4
15	B	6.B	ENE-1.I	3

Free-Response Question	Question Type	Skill	Learning Objective	Unit
1	Interpreting and Evaluating Experimental Results	1.A, 1.C, 3.B, 3.C.a, 3.C.b, 3.C.c, 4.B.b, 4.B.c, 5.A.a, 6.B	EVO-1.E, EVO-1.H, EVO-1.L, IST-2.E, SYI-1.C	1, 6, 7
5	Analyze Model or Visual Representation	1.A, 2.B.b, 2.D.b, 2.C	IST-1.H, IST-1.I	5

The scoring information for the questions within this course and exam description, along with further exam resources, can be found on the **AP Biology Exam Page** on AP Central.

AP BIOLOGY

Appendix

AP BIOLOGY

Equations and Formulas

AP® BIOLOGY EQUATIONS AND FORMULAS

Statistical Analysis and Probability

Mean

$$\bar{x} = \frac{1}{n}\sum_{i=1}^{n} x_i$$

Standard Deviation

$$s = \sqrt{\frac{\sum (x_i - \bar{x})^2}{n-1}}$$

Standard Error of the Mean

$$SE_{\bar{x}} = \frac{s}{\sqrt{n}}$$

Chi-Square

$$\chi^2 = \sum \frac{(o-e)^2}{e}$$

Chi-Square Table

p value	Degrees of Freedom							
	1	2	3	4	5	6	7	8
0.05	3.84	5.99	7.81	9.49	11.07	12.59	14.07	15.51
0.01	6.63	9.21	11.34	13.28	15.09	16.81	18.48	20.09

$\bar{x}$ = sample mean

n = sample size

s = sample standard deviation (i.e., the sample-based estimate of the standard deviation of the population)

o = observed results

e = expected results

Σ = sum of all

Degrees of freedom are equal to the number of distinct possible outcomes minus one.

Laws of Probability

If A and B are mutually exclusive, then:

$$P(\text{A or B}) = P(\text{A}) + P(\text{B})$$

If A and B are independent, then:

$$P(\text{A and B}) = P(\text{A}) \times P(\text{B})$$

Hardy-Weinberg Equations

$$p^2 + 2pq + q^2 = 1$$

$$p + q = 1$$

p = frequency of allele 1 in a population

q = frequency of allele 2 in a population

Metric Prefixes

Factor	Prefix	Symbol
10^9	giga	G
10^6	mega	M
10^3	kilo	k
10^{-2}	centi	c
10^{-3}	milli	m
10^{-6}	micro	μ
10^{-9}	nano	n
10^{-12}	pico	p

Mode = value that occurs most frequently in a data set

Median = middle value that separates the greater and lesser halves of a data set

Mean = sum of all data points divided by number of data points

Range = value obtained by subtracting the smallest observation (sample minimum) from the greatest (sample maximum)

Rate and Growth

Rate

$$\frac{dY}{dt}$$

Population Growth

$$\frac{dN}{dt} = B - D$$

Exponential Growth

$$\frac{dN}{dt} = r_{max}N$$

Logistic Growth

$$\frac{dN}{dt} = r_{max}N\left(\frac{K - N}{K}\right)$$

dY = amount of change

dt = change in time

B = birth rate

D = death rate

N = population size

K = carrying capacity

r_{max} = maximum per capita growth rate of population

Simpson's Diversity Index

$$\text{Diversity Index} = 1 - \sum\left(\frac{n}{N}\right)^2$$

n = total number of organisms of a particular species

N = total number of organisms of all species

Water Potential (Ψ)

$$\Psi = \Psi_P + \Psi_S$$

Ψ_P = pressure potential

Ψ_S = solute potential

The water potential will be equal to the solute potential of a solution in an open container because the pressure potential of the solution in an open container is zero.

The Solute Potential of a Solution

$$\Psi_S = -iCRT$$

i = ionization constant (1.0 for sucrose because sucrose does not ionize in water)

C = molar concentration

R = pressure constant (R = 0.0831 liter bars/mole K)

T = temperature in Kelvin (ºC + 273)

pH = – log[H^+]

Surface Area and Volume

Surface Area of a Sphere

$$SA = 4\pi r^2$$

Surface Area of a Rectangular Solid

$$SA = 2lh + 2lw + 2wh$$

Surface Area of a Cylinder

$$SA = 2\pi rh + 2\pi r^2$$

Surface Area of a Cube

$$SA = 6s^2$$

Volume of a Sphere

$$V = \frac{4}{3}\pi r^3$$

Volume of a Rectangular Solid

$$V = lwh$$

Volume of a Cylinder

$$V = \pi r^2 h$$

Volume of a Cube

$$V = s^3$$

r = radius

l = length

h = height

w = width

s = length of one side of a cube

SA = surface area

V = volume

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