INCLUDES

- Course framework
- Instructional section
- Sample exam questions

AP® Biology

COURSE AND EXAM DESCRIPTION

Effective
Fall 2025

AP®

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Effective
Fall 2025

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.

What AP® Stands For

Thousands of Advanced Placement teachers have contributed to the principles articulated here. These principles are not new; they are, rather, a reminder of how AP already works in classrooms nationwide. The following principles are designed to ensure that teachers' expertise is respected, that required course content is understood, and that students are academically challenged and free to make up their own minds.

1. AP stands for clarity and transparency. Teachers and students deserve clear expectations. The Advanced Placement Program makes public its course frameworks and sample assessments. Confusion about what is permitted in the classroom disrupts teachers and students as they navigate demanding work.
2. AP is an unflinching encounter with evidence. AP courses enable students to develop as independent thinkers and to draw their own conclusions. Evidence and the scientific method are the starting place for conversations in AP courses.
3. AP opposes censorship. AP is animated by a deep respect for the intellectual freedom of teachers and students alike. If a school bans required topics from their AP courses, the AP Program removes the AP designation from that course and its inclusion in the AP Course Ledger provided to colleges and universities. For example, the concepts of evolution are at the heart of college biology, and a course that neglects such concepts does not pass muster as AP Biology.
4. AP opposes indoctrination. AP students are expected to analyze different perspectives from their own, and no points on an AP Exam are awarded for agreement with any specific viewpoint. AP students are not required to feel certain ways about themselves or the course content. AP courses instead develop students' abilities to assess the credibility of sources, draw conclusions, and make up their own minds.

   As the AP English Literature course description states: "AP students are not expected or asked to subscribe to any one specific set of cultural or political values, but are expected to have the maturity to analyze perspectives different from their own and to question the meaning, purpose, or effect of such content within the literary work as a whole."
5. AP courses foster an open-minded approach to the histories and cultures of different peoples. The study of different nationalities, cultures, religions, races, and ethnicities is essential within a variety of academic disciplines. AP courses ground such studies in primary sources so that students can evaluate experiences and evidence for themselves.
6. Every AP student who engages with evidence is listened to and respected. Students are encouraged to evaluate arguments but not one another. AP classrooms respect diversity in backgrounds, experiences, and viewpoints. The perspectives and contributions of the full range of AP students are sought and considered. Respectful debate of ideas is cultivated and protected; personal attacks have no place in AP.
7. AP is a choice for parents and students. Parents and students freely choose to enroll in AP courses. Course descriptions are available online for parents and students to inform their choice. Parents do not define which college-level topics are suitable within AP courses; AP course and exam materials are crafted by committees of professors and other expert educators in each field. AP courses and exams are then further validated by the American Council on Education and studies that confirm the use of AP scores for college credits by thousands of colleges and universities nationwide.

The AP Program encourages educators to review these principles with parents and students so they know what to expect in an AP course. Advanced Placement is always a choice, and it should be an informed one. AP teachers should be given the confidence and clarity that once parents have enrolled their child in an AP course, they have agreed to a classroom experience that embodies these principles.

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Acknowledgements

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About AP

The 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 40 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—Progress Checks—that teachers can assign throughout the year to measure student progress as they acquire content knowledge and develop skills.

Enrolling Students: Access, Opportunity, and Readiness

The AP Program welcomes all students willing to challenge themselves with college-level coursework and career preparation. We strongly encourage educators to invite students into AP classes, including students from ethnic, racial, socioeconomic, geographic, or other groups not broadly participating in a school's AP program. We believe that readiness for AP is attainable, and that educators can expand readiness by opening access to Pre-AP course work. We commit to support educators and communities in their efforts to make AP courses widely available, advancing students in their plans for college and careers.

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 the **AP Course Audit** website 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 **AP Central®**.

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 and/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 multiplechoice 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.
- Performance that researchers have found to be predictive of an AP student succeeding when placed into a subsequent higher-level college course.
- The number of points college faculty indicate, after reviewing each AP question, that they expect is necessary to achieve each AP grade level.

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, use the search engine available on the **AP Credit Policy Search** page.

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 the **AP Reader** site 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 the **Become an AP Reader** site 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.

PROGRESS CHECKS

Formative AP questions for every unit provide feedback to students on the areas where they need to focus. Available online, 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 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.*

REPORTS

Reports provides teachers with a one-stop shop for student results on all assignment types, including Progress Checks. 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.

QUESTION BANK

The Question Bank is a searchable library of all AP questions that teachers use to build custom practice for their students. Teachers can create and assign assessments with formative topic questions or questions from practice or released AP Exams.

Class Section Setup and Enrollment

- 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 information upon joining their first class section.

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

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.

- As you teach each topic, use **AP Classroom** to assign student **Topic Questions** as a way to continuously check student understanding and provide just-in-time feedback.
- At the end of each unit, use **AP Classroom** to assign students **Progress Checks,** as homework or an in-class task.
- Provide question-level feedback to students through answer rationales; provide formative feedback using **Reports**.
- 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, genetic 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.

Inquiry-based laboratory experiences support the AP Biology course and AP Course Audit curricular requirements by providing opportunities for students to engage in the science practices as they design plans for experiments, make predictions, collect and analyze data, apply mathematical routines, develop explanations, and communicate about their work.

Colleges may require students to present their laboratory materials from AP science courses before granting college credit for laboratory work, so students should be encouraged to retain their laboratory notebooks, reports, and other materials.

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Course Framework

Introduction

Given the speed with which scientific discoveries and research continuously expand scientific knowledge, 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 essential, 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 and depth of content in the AP Biology course defines concepts, science practices, and understandings required by representative colleges and universities for granting college credit and/or placement. Illustrative examples are provided to offer a variety of optional instructional contexts to help students achieve deeper understanding. Content that is outside the scope of the course and exam is also identified within the exclusion statements in the framework.

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. The framework specifies what students should know, be able to do, and understand to qualify for college credit and/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 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 be proficient in 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.

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AP BIOLOGY

Science Practices

The table that follows presents the science practices that students should develop during the AP Biology course. These practices and skills form the basis of the tasks on the AP Biology Exam. While many different skills can be applied to any one content topic, the framework supplies skill focus recommendations for each topic to help assure skill distribution and repetition throughout the course.

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 apply those skills when taking the AP Biology Exam.

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

AP BIOLOGY

Science Practices

Science Practice 1

Concept Explanation 1

Explain biological concepts and processes presented in written format.

Science Practice 2

Visual Representations 2

Analyze visual representations of biological concepts and processes.

Science Practice 3

Questions and Methods 3

Determine scientific questions and methods.

SKILLS

1.A Describe biological concepts and processes.

1.B Explain biological concepts and processes.

1.C Explain biological concepts and processes in applied contexts.

2.A Describe characteristics of visual representations of biological concepts and processes.

2.B Explain relationships between characteristics of biological models in both theoretical and applied contexts.

2.C Explain how biological models relate to larger principles, concepts, processes, systems, or theories.

2.D Represent relationships within biological models, including mathematical models, diagrams, flowcharts, and systems.

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

3.B State the null hypothesis or predict the results of an experiment.

3.C Identify experimental procedures that align with the question, including:

i. identifying dependent and independent variables

ii. identifying appropriate controls

iii. justifying appropriate controls

3.D Propose a new investigation based on an evaluation of the experimental design or evidence.

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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 to represent the data, including: x-y graphs (bar, histogram, line, log scale, dual y), scatter plot, box and whisker plot, and pie chart. The graph should include the following components:

i. type of graph appropriate for the data

ii. axis labeling, including appropriate units and legend

iii. scaling

iv. accurately plotted data (including error bars when appropriate)

v. trend line (when appropriate)

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

i. identifying specific data points

ii. describing trends and patterns in the data

iii. describing relationships between variables

5.A Perform mathematical calculations, including:

i. mathematical equations in the curriculum

ii. means

iii. rates

iv. ratios

v. percentages and percent changes

5.B Use confidence intervals and error bars to estimate whether sample means are statistically different.

5.C Perform chi-square hypothesis testing.

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

6.A Make a scientific claim.

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

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Course Content

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 coursework in biology and its integration into a wide variety of STEM fields.

Big Ideas

The big ideas, often, are abstract concepts or themes that allow students to create meaningful connections among course concepts. 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

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.

BIG IDEA 2: ENERGETICS

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

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

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 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 a Glance provide suggestions for how to teach the required course content and administer the 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, adjust the pacing based on the needs of your students, alternate schedules (e.g., block scheduling), or your school's academic calendar.

TOPICS

Each unit is divided into teachable segments called topics. The topic pages (starting on p. 32) contain all required content for each topic.

Units	Exam Weighting
Unit 1: Chemistry of Life	**8–11%**
Unit 2: Cells	**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 throughout the course by showing the units in which each big idea appears.

Big Ideas	Unit 1 *Chemistry of Life*	Unit 2 *Cells*	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		✓			✓		✓	✓
Energetics	✓	✓	✓	✓				✓
Information Storage and Transmission	✓			✓	✓	✓		✓
Systems Interactions	✓	✓			✓		✓	✓

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Course at a Glance

Plan

The course at a glance provides a useful visual organization of the AP Biology 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 spiral 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

Assess

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

UNIT 1 Chemistry of Life

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

Science Practices	Topic
2	1.1 Structure of Water and Hydrogen Bonding
2	1.2 Elements of Life
2	1.3 Introduction to Macromolecules
1	1.4 Carbohydrates
6	1.5 Lipids
2	1.6 Nucleic Acids
6	1.7 Proteins

Progress Check 1

Multiple-Choice: ~24 questions
Free-Response: 2 questions
- Conceptual Analysis (partial)
- Analyze Model or Visual Representation of a Biological Concept or Process (partial)

UNIT 2 Cells

~14-16 Class Periods | 10-13% AP Exam Weighting

Science Practices	Topic
1, 6	2.1 Cell Structure and Function
2, 5	2.2 Cell Size
2	2.3 Plasma Membrane
5	2.4 Membrane Permeability
3	2.5 Membrane Transport
6	2.6 Facilitated Diffusion
4	2.7 Tonicity and Osmoregulation
1	2.8 Mechanisms of Transport
6	2.9 Cell Compartmentalization
6	2.10 Origins of Cell Compartmentalization

Progress Check 2

Multiple-Choice: ~33 questions (2 parts)
Free-Response: 2 questions
- Interpreting and Evaluating Experimental Results (partial)
- Analyze Model or Visual Representation of a Biological Concept or Process (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

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

- 1, 3 — 3.1 Enzymes
- 6 — 3.2 Environmental Impacts on Enzyme Function
- 6 — 3.3 Cellular Energy
- 6 — 3.4 Photosynthesis
- 4 — 3.5 Cellular Respiration

Progress Check 3

Multiple-Choice: ~19 questions
Free-Response: 2 questions

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

UNIT 4 Cell Communication and Cell Cycle

~12-14 Class Periods | 10-15% AP Exam Weighting

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

Progress Check 4

Multiple-Choice: ~24 questions
Free-Response: 2 questions

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

UNIT 5 Heredity

~8-10 Class Periods | 8-11% AP Exam Weighting

- 1 — 5.1 Meiosis
- 3 — 5.2 Meiosis and Genetic Diversity
- 5, 6 — 5.3 Mendelian Genetics
- 5 — 5.4 Non-Mendelian Genetics
- 1 — 5.5 Environmental Effects on Phenotype

Progress Check 5

Multiple-Choice: ~23 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

~18-20 Class Periods | **12-16%** AP Exam Weighting

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

Progress Check 6

Multiple-Choice: ~25 questions

Free-Response: 2 questions

- Interpreting and Evaluating Experimental Results
- Analyze Model or Visual Representation of a Biological Concept or Process

UNIT 7 Natural Selection

~19-21 Class Periods | **13-20%** AP Exam Weighting

2	7.1 Introduction to Natural Selection
1	7.2 Natural Selection
4	7.3 Artificial Selection
3	7.4 Population Genetics
1, 5	7.5 Hardy–Weinberg Equilibrium
4	7.6 Evidence of Evolution
6	7.7 Common Ancestry
3	7.8 Continuing Evolution
2	7.9 Phylogeny
2, 6	7.10 Speciation
6	7.11 Variations in Populations
3	7.12 Origins of Life on Earth

Progress Check 7

Multiple-Choice: ~48 questions (2 parts)

Free-Response: 2 questions

- Interpreting and Evaluating Experimental Results with Graphing
- Analyze Data

UNIT 8 Ecology

~19-21 Class Periods | **10-15%** AP Exam Weighting

3	8.1 Responses to the Environment
6	8.2 Energy Flow Through Ecosystems
4	8.3 Population Ecology
5	8.4 Effect of Density on Populations
5	8.5 Community Ecology
6	8.6 Biodiversity
5	8.7 Disruptions in Ecosystems

Progress Check 8

Multiple-Choice: ~24 questions

Free-Response: 2 questions

- Interpreting and Evaluating Experimental Results with Graphing
- Scientific Investigation

AP BIOLOGY

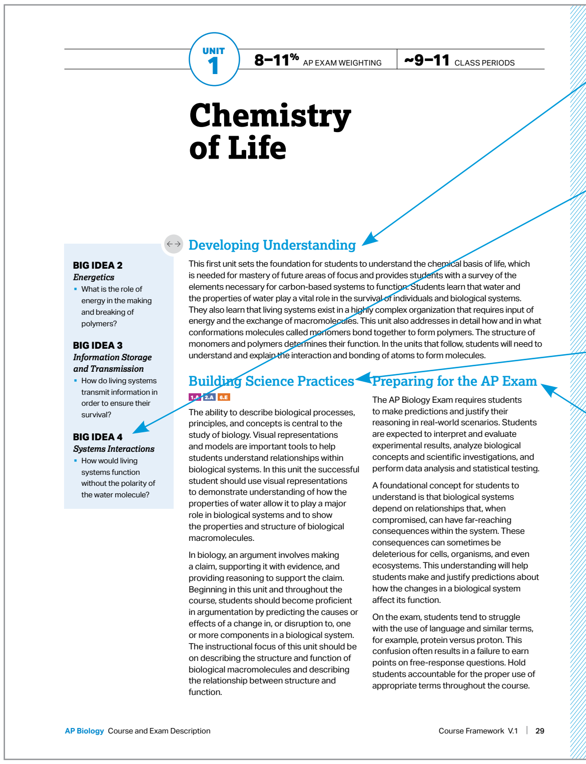
Unit Guides

Introduction

Developed with extensive input from the community of AP Biology educators, these unit guides offer teachers helpful guidance in building students' skills and content knowledge. The suggested sequence 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 that can be adopted or modified, rather than having to be built from scratch. An additional benefit is that these units enable the AP Program to provide interested teachers with formative assessments —the Topic Questions and Progress Checks—that can be assigned to students 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 | ~9–11 CLASS PERIODS

Chemistry of Life

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

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

BIG IDEA 4
Systems Interactions
- 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

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. Hold students accountable for the proper use of appropriate terms throughout the course.

AP Biology Course and Exam Description | Course Framework V.1 | 29

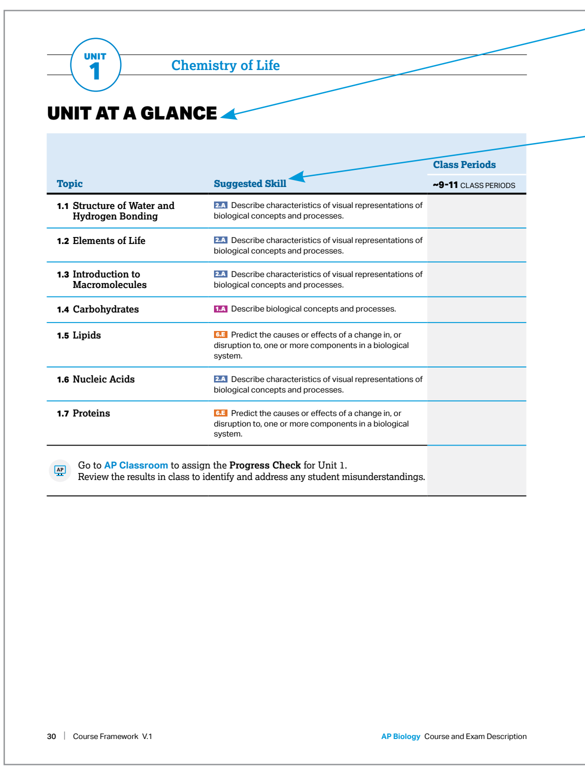
UNIT OPENERS

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 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 skills within 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

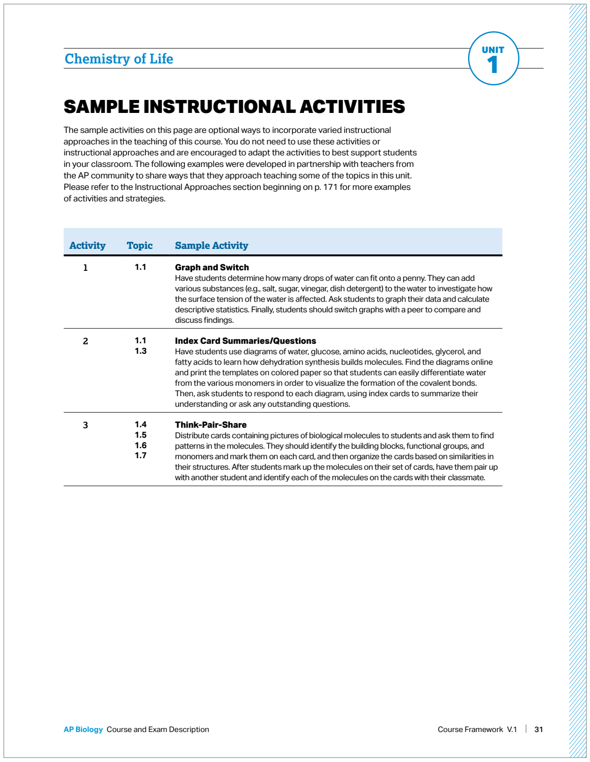
Topic	Suggested Skill	Class Periods ~9–11 CLASS PERIODS
1.1 Structure of Water and Hydrogen Bonding	2.A Describe characteristics of visual representations of biological concepts and processes.	
1.2 Elements of Life	2.A Describe characteristics of visual representations of biological concepts and processes.	
1.3 Introduction to Macromolecules	2.A Describe characteristics of visual representations of biological concepts and processes.	
1.4 Carbohydrates	1.A Describe biological concepts and processes.	
1.5 Lipids	6.E Predict the causes or effects of a change in, or disruption to, one or more components in a biological system.	
1.6 Nucleic Acids	2.A Describe characteristics of visual representations of biological concepts and processes.	
1.7 Proteins	6.E Predict the causes or effects of a change in, or disruption to, one or more components in a biological system.	
Go to AP Classroom to assign the **Progress Check** for Unit 1. Review the results in class to identify and address any student misunderstandings.		

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

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

The **suggested skills** for each topic 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 scaffolds the skills throughout the course. The questions on the 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

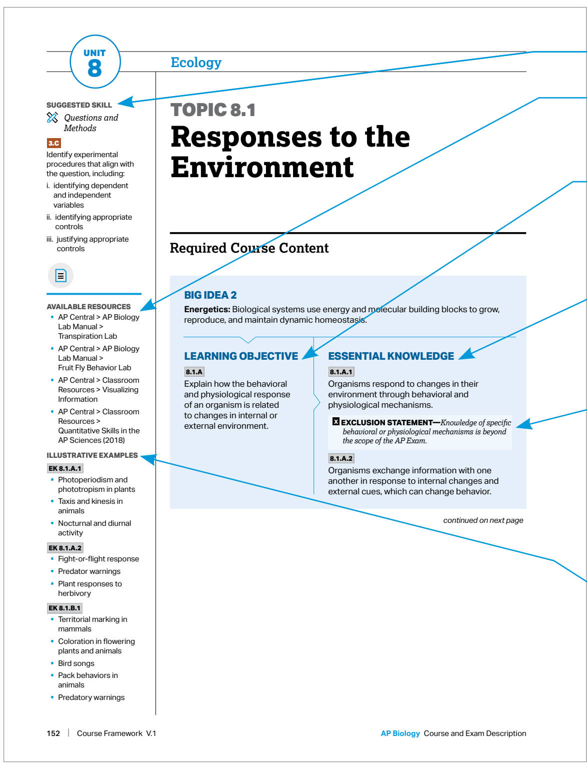
SAMPLE INSTRUCTIONAL ACTIVITIES

The sample activities on this page are optional 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 encouraged to adapt the activities to best support students in your classroom. 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** Have students determine how many drops of water can fit onto a penny. They can add various substances (e.g., salt, sugar, vinegar, dish detergent) to the water to investigate how the surface tension of the water is affected. Ask students to graph their data and calculate descriptive statistics. Finally, students should switch graphs with a peer to compare and discuss findings.
2	1.1 1.3	**Index Card Summaries/Questions** Have students use diagrams of water, glucose, amino acids, nucleotides, glycerol, and fatty acids to learn how dehydration synthesis builds molecules. Find the diagrams online and print the templates on colored paper so that students can easily differentiate water from the various monomers in order to visualize the formation of the covalent bonds. Then, ask students to respond to each diagram, using index cards to summarize their understanding or ask any outstanding questions.
3	1.4 1.5 1.6 1.7	**Think-Pair-Share** Distribute cards containing pictures of biological molecules to students and ask them to find patterns in the molecules. They should identify the building blocks, functional groups, and monomers and mark them on each card, and then organize the cards based on similarities in their structures. After students mark up the molecules on their set of cards, have them pair up with another student and identify each of the molecules on the cards with their classmate.

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

The **Sample Instructional Activities** include optional activities that can help tie together the content and skill for a particular topic.



UNIT 8

Ecology

SUGGESTED SKILL

Questions and Methods

3.C

Identify experimental procedures that align with the question, including:

i. identifying dependent and independent variables

ii. identifying appropriate controls

iii. justifying appropriate controls

AVAILABLE RESOURCES

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

ILLUSTRATIVE EXAMPLES

EK 8.1.A.1

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

EK 8.1.A.2

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

EK 8.1.B.1

- Territorial marking in mammals
- Coloration in flowering plants and animals
- Bird songs
- Pack behaviors in animals
- Predatory warnings

TOPIC 8.1

Responses to the Environment

Required Course Content

BIG IDEA 2

Energetics: Biological systems use energy and molecular building blocks to grow, reproduce, and maintain dynamic homeostasis.

LEARNING OBJECTIVE	ESSENTIAL KNOWLEDGE
8.1.A Explain how the behavioral and physiological response of an organism is related to changes in internal or external environment.	8.1.A.1 Organisms respond to changes in their environment through behavioral and physiological mechanisms. EXCLUSION STATEMENT—*Knowledge of specific behavioral or physiological mechanisms is beyond the scope of the AP Exam.* 8.1.A.2 Organisms exchange information with one another in response to internal changes and external cues, which can change behavior.

continued on next page

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

TOPIC PAGES

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

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

Learning objectives define what a student needs to be able to do with content knowledge in order to progress through the course.

Essential knowledge statements define the required content knowledge associated with each learning objective assessed on the AP Exam.

Exclusion statements provide guidance to teachers regarding the content exclusions of the AP Biology course. The content addressed in the exclusion statements will not be assessed on the AP Biology Exam. However, 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.

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AP BIOLOGY

UNIT 1

Chemistry of Life

8–11%
AP EXAM WEIGHTING

~9–11
CLASS PERIODS

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

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

Progress Check 1

Multiple-choice: ~24 questions
Free-response: 2 questions

- Conceptual Analysis (partial)
- Analyze Model or Visual Representation of a Biological Concept or Process (partial)

UNIT 1

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

Chemistry of Life

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

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

BIG IDEA 4
Systems Interactions
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SUGGESTED SKILL

Visual Representations

2.A

Describe characteristics of visual representations of biological concepts and processes.

TOPIC 1.1

Structure of Water and Hydrogen Bonding

Required Course Content

BIG IDEA 4

Systems Interactions: Biological systems interact, and these systems and their interactions exhibit complex properties.

LEARNING OBJECTIVE

1.1.A

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

ESSENTIAL KNOWLEDGE

1.1.A.1

Living systems depend on the properties of water to sustain life.

i. Water has polarity, because of the formation of polar covalent bonds between hydrogen and oxygen within water molecules. This polarity contributes to hydrogen bonding between and within biological molecules.

ii. Water has a high specific heat capacity, which allows for the maintenance of homeostatic body temperature within living organisms.

iii. Water has a high heat of vaporization, which allows for the evaporative cooling of the surrounding environment. In living organisms, this property allows for body temperature to be maintained.

1.1.A.2

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

TOPIC 1.2

Elements of Life

SUGGESTED SKILL

Visual Representations

2.A

Describe characteristics of visual representations of biological concepts and processes.

Required Course Content

BIG IDEA 2

Energetics: Biological systems use energy and molecular building blocks to grow, reproduce, and maintain dynamic homeostasis.

LEARNING OBJECTIVE

1.2.A

Describe the composition of macromolecules required by living organisms.

ESSENTIAL KNOWLEDGE

1.2.A.1

Atoms and molecules from the environment are necessary to build new molecules. Carbon, hydrogen, and oxygen are the most prevalent elements used to build biological molecules such as carbohydrates, proteins, lipids, and nucleic acids. Additionally:

i. Sulfur is used in the building of proteins.

ii. Phosphorus is used in the building of phospholipids (a type of lipid) and nucleic acids.

iii. Nitrogen is used in the building of nucleic acids.

SUGGESTED SKILL

Visual Representations

2.A

Describe characteristics of visual representations of biological concepts and processes.

AVAILABLE RESOURCE

- AP Central > Classroom Resources > Visualizing Information

TOPIC 1.3
Introduction to Macromolecules

Required Course Content

BIG IDEA 4

Systems Interactions: Biological systems interact, and these systems and their interactions exhibit complex properties.

LEARNING OBJECTIVE

1.3.A

Describe the chemical reactions that build and break biological macromolecules.

ESSENTIAL KNOWLEDGE

1.3.A.1

Hydrolysis is a chemical reaction involving the cleaving of covalent bonds. This type of reaction breaks down molecules into smaller molecules. When water is added to the bond between monomers in a polymer, the bond is broken. The hydrogen ion from a water molecule is added to one monomer and the hydroxyl group of the water molecule is added to the other monomer, completing the reaction.

1.3.A.2

Dehydration synthesis occurs when two smaller molecules are joined together through covalent bonding. A hydrogen ion is removed from one monomer and a hydroxyl group is removed from the other. This causes the loss of the equivalent of a water molecule from the reactants and the connection of the two remaining monomers. The connection of many monomers is known as polymerization.

TOPIC 1.4

Carbohydrates

SUGGESTED SKILL

Concept Explanation

1.A

Describe biological concepts and processes.

Required Course Content

BIG IDEA 4

Systems Interactions: Biological systems interact, and these systems and their interactions exhibit complex properties.

LEARNING OBJECTIVE

1.4.A

Describe the structure and function of carbohydrates.

ESSENTIAL KNOWLEDGE

1.4.A.1

Monosaccharides (simple sugars) are the monomers for polysaccharides (complex carbohydrates). These monomers are connected by covalent bonds to form polymers such as complex carbohydrates, which may be linear or branched.

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

ILLUSTRATIVE EXAMPLES

EK 1.4.A.1

- Cellulose
- Starch
- Glycogen

SUGGESTED SKILL

Argumentation

6.E

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

TOPIC 1.5
Lipids

Required Course Content

BIG IDEA 4

Systems Interactions: Biological systems interact, and these systems and their interactions exhibit complex properties.

LEARNING OBJECTIVE

1.5.A

Describe the structure and function of lipids.

ESSENTIAL KNOWLEDGE

1.5.A.1

Lipids are typically nonpolar, hydrophobic molecules whose structure and function are derived from the way their subcomponents are assembled. Fatty acids can be described as either saturated or unsaturated.

i. Saturated fatty acids contain only single bonds between carbon atoms.

ii. Unsaturated fatty acids contain at least one double bond between carbon atoms, which causes the carbon chain to kink.

iii. The more double bonds in a fatty acid tail, the more unsaturated the lipid becomes.

iv. The more unsaturated a lipid is, the more liquid it is at room temperature.

continued on next page

LEARNING OBJECTIVE

1.5.A

Describe the structure and function of lipids.

ESSENTIAL KNOWLEDGE

1.5.A.2

Lipids provide a variety of functions for living organisms. Some examples of lipids are fats, steroids including cholesterol, and phospholipids.

i. Fats provide energy storage and support cell function. In some cases, they can also provide insulation to help keep mammals warm.

ii. Steroids are hormones that support physiological functions including growth and development, energy metabolism, and homeostasis.

iii. Cholesterol provides essential structural stability to animal cell membranes.

iv. Phospholipids group together to form the lipid bilayers found in plasma and cell membranes.

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

SUGGESTED SKILL

Visual Representations

2.A

Describe characteristics of visual representations of biological concepts and processes.

TOPIC 1.6

Nucleic Acids

Required Course Content

BIG IDEA 3

Information Storage and Transmission: Living systems store, retrieve, transmit, and respond to information essential to life processes.

LEARNING OBJECTIVE

1.6.A

Describe the structure and function of DNA and RNA.

ESSENTIAL KNOWLEDGE

1.6.A.1

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

1.6.A.2

Nucleic acids have a linear sequence of nucleotides that have ends, defined by the 3′ (three prime) hydroxyl and 5′ (five prime) phosphates of the sugar in the nucleotide. During nucleic acid synthesis, nucleotides are added to the 3′ end of the growing strand, resulting in the formation of covalent bonds between nucleotides.

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

continued on next page

LEARNING OBJECTIVE	ESSENTIAL KNOWLEDGE
1.6.A Describe the structure and function of DNA and RNA.	**1.6.A.3** DNA is structured as an antiparallel double helix, with two strands of nucleotides running in opposite 5′ to 3′ orientation. In DNA, adenine nucleotides pair with thymine nucleotides via hydrogen bonds (A-T), and cytosine nucleotides pair with guanine nucleotides via hydrogen bonds (C-G). In RNA, adenine pairs with uracil (A-U).
	1.6.A.4 Structural differences between DNA and RNA include: i. DNA contains the sugar deoxyribose, and RNA contains the sugar ribose. ii. DNA contains the nitrogenous base thymine, and RNA contains the nitrogenous base uracil. iii. DNA is typically double stranded, while RNA is typically single stranded.

SUGGESTED SKILL

Argumentation

6.E

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

TOPIC 1.7

Proteins

Required Course Content

BIG IDEA 3

Information Storage and Transmission: Living systems store, retrieve, transmit, and respond to information essential to life processes.

LEARNING OBJECTIVE	ESSENTIAL KNOWLEDGE
1.7.A Describe the structure and function of proteins.	1.7.A.1 Proteins comprise linear chains of amino acids connected by the formation of covalent (peptide) bonds that form between a carboxyl group (–COOH) of one amino acid and an amine group ($-NH_2$) of the next amino acid, resulting in a growing peptide chain. 1.7.A.2 Amino acids are composed of a central carbon atom with a hydrogen atom, a carboxyl group, an amine group, and a variable R group covalently bound to it. The R group of an amino acid can be categorized by three possible chemical properties: hydrophobic/nonpolar, hydrophilic/polar, or ionic. The interactions of these R groups determine the structure and function of that region of the protein. 1.7.A.3 The specific sequence of amino acids in proteins determines the primary structure of a polypeptide as well as the overall shape of the protein. **EXCLUSION STATEMENT—***The molecular structure of amino acids is beyond the scope of the AP Exam.*

continued on next page

LEARNING OBJECTIVE

1.7.A

Describe the structure and function of proteins.

ESSENTIAL KNOWLEDGE

1.7.A.4

Secondary structures of proteins are made through the local folding that forms from interactions between atoms of the polypeptide backbone of the amino acid chain. Hydrogen bonding forms shapes such as alpha-helices and beta-pleated sheets.

1.7.A.5

The three-dimensional shape of the tertiary structure of a protein results from the formation of hydrogen bonds, hydrophobic interactions, ionic interactions, or disulfide bridges.

1.7.A.6

The quaternary structure arises from interactions between multiple polypeptides. All four levels of a protein structure determine the function of a protein.

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AP BIOLOGY

UNIT 2

Cells

10–13%
AP EXAM WEIGHTING

~14–16
CLASS PERIODS

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

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

Progress Check 2

Multiple-choice: ~33 questions (2 parts)

Free-response: 2 questions

- Interpreting and Evaluating Experimental Results (partial)
- Analyze Model or Visual Representation of a Biological Concept or Process (partial)

UNIT 2

10–13% AP EXAM WEIGHTING | **~14–16** CLASS PERIODS

Cells

BIG IDEA 1
Evolution
- Defend the origin of eukaryotic cells.

BIG IDEA 2
Energetics
- 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
- 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 2.A 2.D 3.D 4.A 5.A 5.D 6.A 6.B 6.E

A solid understanding of the origin and function of organelles is the foundation for understanding cell biology. Students should be able to 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

Topic	Suggested Skills	Class Periods ~14–16 CLASS PERIODS
2.1 Cell Structure and Function	1.A Describe biological concepts and processes. 6.A Make a scientific claim.	
2.2 Cell Size	2.D Represent relationships within biological models, including mathematical models, diagrams, flowcharts, and systems. 5.A Perform mathematical calculations, including: i. mathematical equations in the curriculum ii. means iii. rates iv. ratios v. percentages and percent changes	
2.3 Plasma Membrane	2.A Describe characteristics of visual representations of biological concepts and processes.	
2.4 Membrane Permeability	5.D Use data to evaluate a hypothesis or prediction, including rejecting or failing to reject the null hypothesis.	
2.5 Membrane Transport	3.D Propose a new investigation based on an evaluation of the experimental design or evidence.	
2.6 Facilitated Diffusion	6.E Predict the causes or effects of a change in, or disruption to, one or more components in a biological system.	
2.7 Tonicity and Osmoregulation	4.A Construct a graph to represent the data, including: x-y graphs (bar, histogram, line, log scale, dual y), scatter plot, box and whisker plot, and pie chart. The graph should include the following components: i. type of graph appropriate for the data ii. axis labeling, including appropriate units and legend iii. scaling iv. accurately plotted data (including error bars when appropriate) v. trend line (when appropriate)	
2.8 Mechanisms of Transport	1.B Explain biological concepts and processes.	

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UNIT AT A GLANCE *(cont'd)*

Topic	Suggested Skills	Class Periods ~14–16 CLASS PERIODS
2.9 Cell Compartmentalization	6.E Predict the causes or effects of a change in, or disruption to, one or more components in a biological system.	
2.10 Origins of Cell Compartmentalization	6.B Support a claim with evidence from biological principles, concepts, processes, and data.	

Go to **AP Classroom** to assign the **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 optional 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 encouraged to adapt the activities to best support students in your classroom. 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** Place students in groups and assign each group a cellular or subcellular component to study. Through their study, students should become "experts" on their topic. Ask students to then rotate through the expert stations to learn about the other cellular and subcellular components from their peers.
2	2.2	**Misconception Check** Provide students with agar cubes of different sizes that are soaked in phenolphthalein, and ask them to soak the cubes in vinegar. Have students make assumptions about which cubes will become clear first, then have them time 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. They can use their observations to determine how cell size affects cell function. Use this transport model to discuss any misconceptions students may still have about surface area-to-volume ratio and how it affects rates of cellular transport.
3	2.3 2.4 2.5	**One-Minute Essay** Before learning about 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 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 by writing a one-minute essay about the topic.

TOPIC 2.1
Cell Structure and Function

SUGGESTED SKILLS

Concept Explanation

1.A
Describe biological concepts and processes.

Argumentation

6.A
Make a scientific claim.

ILLUSTRATIVE EXAMPLE

EK 2.1.A.4
- Glycosylation and other chemical modifications of proteins that take place within the Golgi and determine protein function or targeting

Required Course Content

BIG IDEA 4

Systems Interactions: Biological systems interact, and these systems and their interactions exhibit complex properties.

LEARNING OBJECTIVE

2.1.A
Explain how the structure and function of subcellular components and organelles contribute to the function of cells.

ESSENTIAL KNOWLEDGE

2.1.A.1
Ribosomes are comprised of ribosomal RNA (rRNA) and protein. These non-membrane, subcellular structures are found in cells in all forms of life and reflect the common ancestry in all known life. Ribosomes synthesize proteins according to messenger RNA (mRNA) sequences.

2.1.A.2
The endomembrane system consists of a group of membrane-bound organelles and subcellular components (endoplasmic reticulum (ER), Golgi complex, lysosomes, vacuoles and transport vesicles, the nuclear envelope, and the plasma membrane) that work together to modify, package, and transport polysaccharides, lipids, and proteins intercellularly.

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LEARNING OBJECTIVE

2.1.A

Explain how the structure and function of subcellular components and organelles contribute to the function of cells.

ESSENTIAL KNOWLEDGE

2.1.A.3

Endoplasmic reticulum provides mechanical support by helping cells maintain shape and plays a role in intracellular transport.

i. Rough ER is associated with membrane-bound ribosomes, allows for the compartmentalization of cells, and helps carry out protein synthesis.

ii. Smooth ER functions include the detoxification of cells and lipid synthesis.

EXCLUSION STATEMENT—*Knowledge of the specific functions of smooth ER in specialized cells is beyond the scope of the AP Exam.*

2.1.A.4

The Golgi complex is a membrane-bound structure that consists of a series of flattened membrane sacs. Functions of the Golgi include:

i. Correctly folding and chemically modifying newly synthesized cellular products

ii. Packaging proteins for trafficking

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

2.1.A.5

Mitochondria have a double membrane that provides compartments for different metabolic reactions involved in aerobic cellular respiration. The outer membrane is smooth, while the inner membrane is highly convoluted, forming folds that enable ATP to be synthesized more efficiently.

2.1.A.6

Lysosomes are membrane-enclosed sacs that contain hydrolytic enzymes that digest material. Lysosomes also play a role in programmed cell death (apoptosis).

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LEARNING OBJECTIVE

2.1.A

Explain how the structure and function of subcellular components and organelles contribute to the function of cells.

ESSENTIAL KNOWLEDGE

2.1.A.7

Vacuoles are membrane-bound sacs that play many different roles.

i. In plant cells, a specialized large vacuole maintains turgor pressure through nutrient and water storage.
ii. In animal cells, vacuoles are smaller in size, are more plentiful than in plant cells, and store cellular materials.

2.1.A.8

Chloroplasts are specialized organelles that are found in plants and photosynthetic algae. Chloroplasts contain a double membrane and serve as the location for photosynthesis.

SUGGESTED SKILLS

Visual Representations

2.D

Represent relationships within biological models, including mathematical models, diagrams, flowcharts, and systems.

Statistical Tests and Data Analysis

5.A

Perform mathematical calculations, including:

i. mathematical equations in the curriculum
ii. means
iii. rates
iv. ratios
v. percentages and percent changes

ILLUSTRATIVE EXAMPLES

EK 2.2.A.1

- SA/V Ratios and Exchanges
  - Root hairs
  - Guard cells
  - Gut epithelial cells
- Cilia
- Stomata

TOPIC 2.2
Cell Size

Required Course Content

BIG IDEA 2

Energetics: Biological systems use energy and molecular building blocks to grow, reproduce, and maintain dynamic homeostasis.

LEARNING OBJECTIVE

2.2.A

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

ESSENTIAL KNOWLEDGE

2.2.A.1

Surface area-to-volume ratios affect the ability of a biological system to obtain necessary nutrients, 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: $V = s^3$

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

2.2.A

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

ESSENTIAL KNOWLEDGE

2.2.A.2

The surface area of the plasma membrane must be large enough to adequately exchange materials.

i. The surface area-to-volume ratio can restrict cell size and shape. Smaller cells typically have a higher surface area-to-volume ratio as well as a more efficient exchange of materials with the environment than do larger cells.

ii. As cells increase in volume, the surface area-to-volume ratio decreases and the demand for internal resources increases.

iii. More complex cellular structures (e.g., membrane folds) are necessary to adequately exchange materials with the environment.

iv. As organisms increase in size, their surface area-to-volume ratio decreases, affecting properties like rate of heat exchange with the environment. Smaller amounts of mass exchange proportionally more heat with the ambient environment than do larger masses. As mass increases, both the surface area-to-volume ratio and the rate of heat exchange decrease.

v. There is a relationship between metabolic rate per unit body mass and the size of multicellular organisms; typically, the smaller the organism, the higher the metabolic rate per unit body mass.

SUGGESTED SKILL

Visual Representations

2.A

Describe characteristics of visual representations of biological concepts and processes.

TOPIC 2.3
Plasma Membrane

Required Course Content

BIG IDEA 2

Energetics: Biological systems use energy and molecular building blocks to grow, reproduce, and maintain dynamic homeostasis.

LEARNING OBJECTIVE	ESSENTIAL KNOWLEDGE
2.3.A Describe the roles of each of the components of the cell membrane in maintaining the internal environment of the cell.	**2.3.A.1** Phospholipids have both hydrophilic and hydrophobic regions. The polar hydrophilic phosphate regions of the phospholipids are oriented toward the aqueous external or internal environment, while the nonpolar hydrophobic fatty acid regions face each other within the interior of the membrane. **2.3.A.2** Embedded proteins can be hydrophilic (with charged and polar side groups), hydrophobic (with nonpolar side groups), or both. i. Hydrophilic regions of the proteins are either inside the interior of the protein or exposed to the cytosol (cytoplasm). ii. Hydrophobic regions of proteins make up the protein surface that interacts with the fatty acids in the interior membrane.
2.3.B Describe the fluid mosaic model of cell membranes.	**2.3.B.1** Plasma membranes consist of a structural framework of phospholipid molecules embedded with proteins, steroids (such as cholesterol in vertebrate animals), glycoproteins, and glycolipids. All of these can move around the surface of the cell within the membrane, as illustrated by the fluid mosaic model.

TOPIC 2.4
Membrane Permeability

SUGGESTED SKILL

Statistical Tests and Data Analysis

5.D

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

Required Course Content

BIG IDEA 2

Energetics: Biological systems use energy and molecular building blocks to grow, reproduce, and maintain dynamic homeostasis.

LEARNING OBJECTIVE	ESSENTIAL KNOWLEDGE
2.4.A Explain how the structure of biological membranes influences selective permeability.	**2.4.A.1** Plasma membranes separate the internal environment of the cell from the external environment. Selective permeability is the result of the plasma membrane having a hydrophobic interior. **2.4.A.2** 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 channels and transport proteins. **2.4.A.3** The nonpolar hydrocarbon tails of phospholipids prevent the movement of ions and polar molecules across the membrane. Small polar, uncharged molecules, like H_2O or NH_3 (ammonia), pass through the membrane in small amounts.
2.4.B Describe the role of the cell wall in maintaining cell structure and function.	**2.4.B.1** Cell walls of Bacteria, Archaea, Fungi, and plants provide a structural boundary as well as a permeability barrier for some substances to the internal or external cellular environments and protection from osmotic lysis.

SUGGESTED SKILL

Questions and Methods

3.D

Propose a new investigation based on an evaluation of the experimental design or evidence.

TOPIC 2.5
Membrane Transport

Required Course Content

BIG IDEA 2

Energetics: Biological systems use energy and molecular building blocks to grow, reproduce, and maintain dynamic homeostasis.

LEARNING OBJECTIVE	ESSENTIAL KNOWLEDGE
2.5.A Describe the mechanisms that organisms use to maintain solute and water balance.	**2.5.A.1** The selective permeability of membranes allows for the formation of concentration gradients of solutes across the membrane. **2.5.A.2** Passive transport is the net movement of molecules from regions of high concentration to regions of low concentration without the direct input of metabolic energy. **2.5.A.3** Active transport requires the direct input of energy to move molecules. In some cases, active transport is utilized to move molecules from regions of low concentration to regions of high concentration.
2.5.B Describe the mechanisms that organisms use to transport large molecules across the plasma membrane.	**2.5.B.1** The processes of endocytosis and exocytosis require energy to move large substances or large amounts of substances into and out of cells. i. In endocytosis, the cell takes in large molecules and particulate matter by folding the plasma membrane in on itself and forming new (small) vesicles that engulf material from the external environment. ii. In exocytosis, internal vesicles release material from cells by fusing with the plasma membrane and secreting large molecules from the cell.

TOPIC 2.6
Facilitated Diffusion

SUGGESTED SKILL

Argumentation

6.E

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

Required Course Content

BIG IDEA 2

Energetics: Biological systems use energy and molecular building blocks to grow, reproduce, and maintain dynamic homeostasis.

LEARNING OBJECTIVE

2.6.A

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

ESSENTIAL KNOWLEDGE

2.6.A.1

Facilitated diffusion requires transport or channel proteins to enable the movement of charged ions across the membrane.

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

ii. Charged ions, including Na^+ (sodium) and K^+ (potassium), require channel proteins to move through the membrane.

2.6.A.2

Facilitated diffusion enables the movement of large polar molecules through membranes with no energy input. In this type of diffusion, substances move down the concentration gradient.

2.6.A.3

Aquaporins transport large quantities of water across membranes.

SUGGESTED SKILL

Representing and Describing Data

4.A

Construct a graph to represent the data, including: x-y graphs (bar, histogram, line, log scale, dual y), scatter plot, box and whisker plot, and pie chart. The graph should include the following components:

i. type of graph appropriate for the data

ii. axis labeling, including appropriate units and legend

iii. scaling

iv. accurately plotted data (including error bars when appropriate)

v. trend line (when appropriate)

AVAILABLE RESOURCES

- AP Central > Classroom Resources > Investigation 4: Diffusion and Osmosis
- AP Central > Classroom Resources > Visualizing Information

ILLUSTRATIVE EXAMPLES

EK 2.7.A.1

- Contractile vacuole in protists
- Central vacuole in plant cells

TOPIC 2.7

Tonicity and Osmoregulation

Required Course Content

BIG IDEA 2

Energetics: Biological systems use energy and molecular building blocks to grow, reproduce, and maintain dynamic homeostasis.

LEARNING OBJECTIVE	ESSENTIAL KNOWLEDGE
2.7.A Explain how concentration gradients affect the movement of molecules across membranes.	**2.7.A.1** External environments can be hypotonic, hypertonic, or isotonic to internal environments of cells. Movement of water can also be described as moving from hypotonic to hypertonic regions. Water moves by osmosis from regions of high water potential to regions of low water potential. **RELEVANT EQUATION** Water Potential: $\Psi = \Psi_p + \Psi_s$ where: Ψ_p = pressure potential Ψ_s = solute potential
2.7.B Explain how osmoregulatory mechanisms contribute to the health and survival of organisms.	**2.7.B.1** Growth and homeostasis are maintained by the constant movement of molecules across membranes.

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LEARNING OBJECTIVE

2.7.B

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

ESSENTIAL KNOWLEDGE

2.7.B.2

Osmoregulation maintains water balance and allows organisms to control their internal solute composition and water potential. Water moves from regions of low osmolarity or solute concentration to regions of high osmolarity or solute concentration.

RELEVANT EQUATION

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 processes.

TOPIC 2.8
Mechanisms of Transport

Required Course Content

BIG IDEA 2

Energetics: Biological systems use energy and molecular building blocks to grow, reproduce, and maintain dynamic homeostasis.

LEARNING OBJECTIVE

2.8.A

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

ESSENTIAL KNOWLEDGE

2.8.A.1

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

i. Membrane proteins are necessary for active transport.

ii. The Na^+/K^+ pump and ATPase contribute to the maintenance of the membrane potential.

TOPIC 2.9
Cell Compartmentalization

SUGGESTED SKILL

Argumentation

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

Required Course Content

BIG IDEA 2
Energetics: Biological systems use energy and molecular building blocks to grow, reproduce, and maintain dynamic homeostasis.

LEARNING OBJECTIVE	ESSENTIAL KNOWLEDGE
2.9.A Describe the membrane-bound structures of the eukaryotic cell.	**2.9.A.1** Membranes and membrane-bound organelles in eukaryotic cells compartmentalize intracellular metabolic processes and specific enzymatic reactions.
2.9.B Explain how internal membranes and membrane-bound organelles contribute to compartmentalization of eukaryotic cell functions.	**2.9.B.1** Internal membranes facilitate cellular processes by minimizing competing interactions and by increasing the surface area where reactions can occur.

SUGGESTED SKILL

Argumentation

6.B

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

TOPIC 2.10
Origins of Cell Compartmentalization

Required Course Content

BIG IDEA 1

Evolution: The process of evolution drives the diversity and unity of life.

LEARNING OBJECTIVE

2.10.A

Describe similarities and/or differences in compartmentalization between prokaryotic and eukaryotic cells.

ESSENTIAL KNOWLEDGE

2.10.A.1

Membrane-bound organelles such as mitochondria and chloroplasts evolved from once free-living prokaryotic cells via endosymbiosis.

2.10.A.2

Prokaryotes typically lack internal membrane-bound organelles but have internal regions with specialized structures and functions.

2.10.A.3

Eukaryotic cells maintain internal membranes that partition the cell into specialized regions.

AP BIOLOGY

UNIT 3

Cellular Energetics

12–16%
AP EXAM WEIGHTING

~12–14
CLASS PERIODS

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

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

Progress Check 3

Multiple-choice: ~19 questions
Free-response: 2 questions

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

UNIT 3

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

Cellular Energetics

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

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 provides students with the knowledge necessary to master the concepts of energy capture and usage. 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, which is knowledge they will use in Unit 6 while studying how cells use energy to fuel life processes.

Building Science Practices

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

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 concept 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, be able to predict how changes in reactants affect them, and be able to explain how organisms and ecosystems are affected by changes.

Common misconceptions include the following: 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 in order to predict and justify the effect of environmental changes on those processes.

On the exam, 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

Topic	Suggested Skills	Class Periods ~12–14 CLASS PERIODS
3.1 Enzymes	1.B Explain biological concepts and processes. 3.C Identify experimental procedures that align with the question, including: i. identifying dependent and independent variables ii. identifying appropriate controls iii. justifying appropriate controls	
3.2 Environmental Impacts on Enzyme Function	6.E Predict the causes or effects of a change in, or disruption to, one or more components in a biological system.	
3.3 Cellular Energy	6.C Provide reasoning to justify a claim by connecting evidence to biological theories.	
3.4 Photosynthesis	6.B Support a claim with evidence from biological principles, concepts, processes, and data.	
3.5 Cellular Respiration	4.A Construct a graph to represent the data, including: x-y graphs (bar, histogram, line, log scale, dual y), scatter plot, box and whisker plot, and pie chart. The graph should include the following components: i. the type of graph appropriate for the data ii. axis labeling, including appropriate units and legend iii. scaling iv. accurately plotted data (including error bars when appropriate) v. trend line (when appropriate)	

Go to **AP Classroom** to assign the **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 optional 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 encouraged to adapt the activities to best support students in your classroom. 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	**Error Analysis** Perform the "toothpickase" activity with students by placing 100 toothpicks onto a paper towel and asking them to use their fingers to break as many toothpicks as they can in 10-second intervals (without looking). Students should keep both the broken and unbroken toothpicks mixed together on the paper towel. Each toothpick can only be broken once. Have them continue breaking toothpicks for time intervals of 60, 120, and 180 seconds. Students then graph the number of toothpicks broken at each time interval. Once they have graphed their own data, allow students to pair up and compare graphs to determine whether errors have occurred based on expected outcomes in enzyme catalysis.
2	3.4	**Construct an Argument** Provide students with a visual representation of photosystems I and II and have them work in pairs to construct an argument about whether (or why) plants need both photosystems for photosynthesis to occur.
3	3.5	**Graph and Switch** Have students perform a yeast fermentation lab using the sucrose solutions from the Diffusion and Osmosis lab found in the AP Biology lab manual. Students should 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.

SUGGESTED SKILLS

Concept Explanation

1.B

Explain biological concepts and processes.

Questions and Methods

3.C

Identify experimental procedures that align with the question, including:

i. identifying dependent and independent variables

ii. identifying appropriate controls

iii. justifying appropriate controls

TOPIC 3.1
Enzymes

Required Course Content

BIG IDEA 2

Energetics: Biological systems use energy and molecular building blocks to grow, reproduce, and maintain dynamic homeostasis.

LEARNING OBJECTIVE	ESSENTIAL KNOWLEDGE
3.1.A Explain how enzymes affect the rate of biological reactions.	**3.1.A.1** The structure and function of enzymes contribute to the regulation of biological processes. Enzymes are proteins that are biological catalysts that facilitate chemical reactions in cells by lowering the activation energy. **3.1.A.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. This is illustrated by the enzyme-substrate complex model.

TOPIC 3.2
Environmental Impacts on Enzyme Function

SUGGESTED SKILL

Argumentation

6.E

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

AVAILABLE RESOURCES

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

Required Course Content

BIG IDEA 2
Energetics: Biological systems use energy and molecular building blocks to grow, reproduce, and maintain dynamic homeostasis.

LEARNING OBJECTIVE	ESSENTIAL KNOWLEDGE
3.2.A Explain how changes to the structure of an enzyme may affect its function.	**3.2.A.1** Change to the molecular structure of a component in an enzymatic system may result in a change to its function or efficiency. i. Denaturation of proteins, such as enzymes, occurs when the protein structure is disrupted by a change in temperature, pH, or chemical environment, eliminating the ability to catalyze reactions. ii. Environmental temperatures and pH outside the optimal range for a given enzyme will cause changes to its structure (by disrupting the hydrogen bonds), altering the efficiency with which it catalyzes reactions. **3.2.A.2** In some cases, enzyme denaturation is reversible, allowing the enzyme to regain activity.
3.2.B Explain how the cellular environment affects enzyme activity.	**3.2.B.1** The relative concentrations of substrates and products determine how efficiently an enzymatic reaction proceeds.

LEARNING OBJECTIVE	ESSENTIAL KNOWLEDGE
3.2.B Explain how the cellular environment affects enzyme activity.	**3.2.B.2** Higher environmental temperatures increase the average speed of movement of molecules in a solution, increasing the frequency of collisions between enzymes and substrates and therefore increasing the rate of reaction until the optimal temperature is achieved. **3.2.B.3** Competitive inhibitor molecules can bind reversibly to the active site of the enzyme. Noncompetitive inhibitors can bind to allosteric sites, changing the activity of the enzyme.

TOPIC 3.3
Cellular Energy

SUGGESTED SKILL

Argumentation

6.C

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

Required Course Content

BIG IDEA 2

Energetics: Biological systems use energy and molecular building blocks to grow, reproduce, and maintain dynamic homeostasis.

LEARNING OBJECTIVE

3.3.A

Describe the role of energy in living organisms.

ESSENTIAL KNOWLEDGE

3.3.A.1

All living systems require an input of energy.

3.3.A.2

Life requires a highly ordered system and does not violate the first and second laws of thermodynamics.

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

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

iii. Significant loss of order or energy flow results in death.

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

3.3.A.3

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

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LEARNING OBJECTIVE	ESSENTIAL KNOWLEDGE
3.3.B Explain how shared, conserved, and fundamental processes and features support the concept of common ancestry for all organisms.	**3.3.B.1** Core metabolic pathways (e.g., glycolysis, oxidative phosphorylation) are conserved across all currently recognized domains (Archaea, Bacteria, and Eukarya).

TOPIC 3.4
Photosynthesis

SUGGESTED SKILL

Argumentation

6.B

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

AVAILABLE RESOURCES

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

Required Course Content

BIG IDEA 2

Energetics: Biological systems use energy and molecular building blocks to grow, reproduce, and maintain dynamic homeostasis.

LEARNING OBJECTIVE

3.4.A

Describe the photosynthetic processes and structural features of the chloroplast that allow organisms to capture and store energy.

EXCLUSION STATEMENT—
Memorization of the steps in the Calvin cycle, the structure of the molecules, and the names of the enzymes involved, with the exception of ATP synthase, is beyond the scope of the AP Exam.

ESSENTIAL KNOWLEDGE

3.4.A.1

Photosynthesis is the series of reactions that use carbon dioxide (CO_2), water (H_2O), and light energy to make carbohydrates and oxygen (O_2).

i. Photosynthetic organisms capture energy from the sun and produce sugars that can be used in biological processes or stored.

ii. Photosynthesis first evolved in prokaryotic organisms.

iii. Scientific evidence supports the claim that prokaryotic (cyanobacterial) photosynthesis was responsible for the production of an oxygenated atmosphere.

iv. Prokaryotic photosynthetic pathways were the foundation of eukaryotic photosynthesis.

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LEARNING OBJECTIVE	ESSENTIAL KNOWLEDGE
3.4.A Describe the photosynthetic processes and structural features of the chloroplast that allow organisms to capture and store energy. **EXCLUSION STATEMENT—** *Memorization of the steps in the Calvin cycle, the structure of the molecules, and the names of the enzymes involved, with the exception of ATP synthase, is beyond the scope of the AP Exam.*	**3.4.A.2** Stroma and thylakoids are found within the chloroplast. i. The stroma is the fluid within the inner chloroplast membrane and outside the thylakoid. The carbon fixation (Calvin cycle) reactions of photosynthesis occur in the stroma. ii. The thylakoid membranes contain chlorophyll pigments organized into two photosystems, as well as electron transport proteins. iii. Thylakoids are organized in stacks called grana. The light reactions of photosynthesis occur in the grana. **3.4.A.3** The light 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 in the Calvin cycle. This provides energy for metabolic processes.
3.4.B Explain how cells capture energy from light and transfer it to biological molecules for storage and use.	**3.4.B.1** Electron transport chain (ETC) reactions occur in chloroplasts, in mitochondria, and across prokaryotic plasma membranes. In photosynthesis, electrons that pass through the thylakoid membrane are picked up and ultimately transferred to $NADP^+$ reducing it to NADPH in photosystem I. **EXCLUSION STATEMENT—** *The full names of the specific electron carriers in the electron transport chain are beyond the scope of the AP Exam.* **EXCLUSION STATEMENT—** *Specific steps, names of enzymes, and intermediates of the pathways for these processes are beyond the scope of this course and the AP Exam.* **3.4.B.2** During photosynthesis, chlorophylls absorb energy from light, boosting electrons to a higher energy level in photosystems I and II. Water then splits, supplying electrons to replace those lost from photosystem II.

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LEARNING OBJECTIVE

3.4.B

Explain how cells capture energy from light and transfer it to biological molecules for storage and use.

ESSENTIAL KNOWLEDGE

3.4.B.3

Photosystems I and II are embedded in the thylakoid membranes of chloroplasts and are connected by the transfer of electrons through an ETC.

3.4.B.4

When electrons are transferred between molecules in a series of oxidation/reduction reactions as they pass through the ETC, an electrochemical gradient of protons (hydrogen ions) is established across the thylakoid membrane. The membrane separates a region of low proton concentration outside the thylakoid membrane from a region of high proton concentration inside the thylakoid membrane.

3.4.B.5

The formation of the proton gradient is linked to the synthesis of ATP from ADP and inorganic phosphate via ATP synthase. 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 photophosphorylation.

3.4.B.6

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. This occurs in the stroma of the chloroplast.

SUGGESTED SKILL

Representing and Describing Data

4.A

Construct a graph to represent the data, including: x-y graphs (bar, histogram, line, log scale, dual y), scatter plot, box and whisker plot, and pie chart. The graph should include the following components:

i. the type of graph appropriate for the data

ii. axis labeling, including appropriate units and legend

iii. scaling

iv. accurately plotted data (including error bars when appropriate)

v. trend line (when appropriate)

AVAILABLE RESOURCES

- AP Central > AP Biology Lab Manual > Cellular Respiration Lab
- AP Central > Classroom Resources > Visualizing Information

TOPIC 3.5

Cellular Respiration

Required Course Content

BIG IDEA 2

Energetics: Biological systems use energy and molecular building blocks to grow, reproduce, and maintain dynamic homeostasis.

LEARNING OBJECTIVE

3.5.A

Describe the processes and structural features of mitochondria that allow organisms to use energy stored in biological macromolecules.

ESSENTIAL KNOWLEDGE

3.5.A.1

Cellular respiration uses energy from biological macromolecules to synthesize ATP. Respiration and fermentation are characteristic of all forms of life.

3.5.A.2

Aerobic cellular respiration in eukaryotes involves a series of coordinated enzyme-catalyzed reactions that capture energy from biological macromolecules.

3.5.A.3

The ETC transfers electrons in a series of oxidation-reduction reactions that establish an electrochemical gradient across membranes.

i. 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. Aerobic prokaryotes use oxygen as a terminal electron acceptor, while anaerobic prokaryotes use other molecules.

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LEARNING OBJECTIVE

3.5.A

Describe the processes and structural features of mitochondria that allow organisms to use energy stored in biological macromolecules.

ESSENTIAL KNOWLEDGE

ii. The transfer of electrons, through the ETC, is accompanied by the formation of a proton gradient across the inner mitochondrial membrane, with the membrane(s) separating a region of high proton concentration outside the membrane from a region of low proton concentration inside the membrane. The folding of the inner membrane increases the surface area, which allows for more ATP to be synthesized. In prokaryotes, the passage of electrons is accompanied by the movement of protons across the plasma membrane.

iii. 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 aerobic cellular respiration.

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

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

EXCLUSION STATEMENT—*Specific steps, names of enzymes, and intermediates of the pathways for these processes are beyond the scope of this course and the AP Exam.*

3.5.B

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

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, is beyond the scope of this course and the AP Exam.*

3.5.B.1

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

3.5.B.2

Pyruvate is transported from the cytosol to the mitochondrion where oxidation occurs. This process releases electrons during the Krebs (citric acid) cycle, reducing NAD^+ to NADH and FAD to $FADH_2$, and releasing CO_2.

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LEARNING OBJECTIVE

3.5.B

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

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, is beyond the scope of this course and the AP Exam.*

ESSENTIAL KNOWLEDGE

3.5.B.3

The Krebs cycle takes place in the mitochondrial matrix. During the Krebs cycle, carbon dioxide is released from organic intermediates, ATP is synthesized from ADP and inorganic phosphate, and electrons are transferred by the coenzymes NAD^+ and FAD.

3.5.B.4

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

3.5.B.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. The pH inside the mitochondrial matrix is higher than in the intermembrane space.

3.5.B.6

Fermentation allows glycolysis to proceed in the absence of oxygen and produces organic molecules such as alcohol and lactic acid.

AP BIOLOGY

UNIT 4

Cell Communication and Cell Cycle

10–15%
AP EXAM WEIGHTING

~12–14
CLASS PERIODS

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

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

Progress Check 4

Multiple-choice: ~24 questions
Free-response: 2 questions

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

UNIT 4

10–15% AP EXAM WEIGHTING | **~12–14** CLASS PERIODS

Cell Communication and Cell Cycle

BIG IDEA 2
Energetics

- In what ways do cells use energy to communicate with one another?

BIG IDEA 3
Information Storage and Transmission

- How does the cell cycle aid in the conservation of genetic information?
- How do different types of 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 4.B 5.A 6.C 6.E

Students build on their abilities to describe and explain biological concepts and processes by detailing 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 answer 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

Topic	Suggested Skills	Class Periods **~12–14** CLASS PERIODS
4.1 Cell Communication	1.B Explain biological concepts and processes.	
4.2 Introduction to Signal Transduction	1.A Describe biological concepts and processes.	
4.3 Signal Transduction Pathways	6.C Provide reasoning to justify a claim by connecting evidence to biological theories.	
4.4 Feedback	6.E Predict the causes or effects of a change in, or disruption to, one or more components in a biological system.	
4.5 Cell Cycle	4.B Describe data from a table or graph, including: i. identifying specific data points ii. describing trends and patterns in the data iii. describing relationships between variables 5.A Perform mathematical calculations, including: i. mathematical equations in the curriculum ii. means iii. rates iv. ratios v. percentages and percent changes	
4.6 Regulation of Cell Cycle	6.E Predict the causes or effects of a change in, or disruption to, one or more components in a biological system.	

Go to **AP Classroom** to assign the **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 optional 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 encouraged to adapt the activities to best support students in your classroom. 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 conduct online research (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 a formative assessment of their understanding, such as, "Describe an example of communication between two cells."
2	4.2	**Ask the Expert** Divide students into three groups and assign them to complete one of the three sections of the Signal Transduction POGIL. After a debrief with each group to clarify misconceptions, students should rotate between groups. Student "experts" can share their understanding of the model they studied and answer any questions from their classmates. Clarify any outstanding misconceptions at the end of class.
3	4.4	**Fishbowl** Share the HHMI case study entitled "The Biochemistry and Cell Signaling Pathway of MC1R" with students. Ask them to read it and answer the questions that accompany the case study. Then set up a fishbowl for students to discuss what they learned from the case study and the applications to real life.

SUGGESTED SKILL

Concept Explanation

1.B

Explain biological concepts and processes.

AVAILABLE RESOURCE

- AP Central > Classroom Resources > Cell-to-Cell Communication – Cell Signaling

ILLUSTRATIVE EXAMPLES

EK 4.1.A.1

- Immune cells interact through cell-to-cell contact, antigen-presenting cells (APCs), helper T-cells, and killer T-cells.

EK 4.1.B.1

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

EK 4.1.B.2

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

TOPIC 4.1
Cell Communication

Required Course Content

BIG IDEA 3

Information Storage and Transmission: Living systems store, retrieve, transmit, and respond to information essential to life processes.

LEARNING OBJECTIVE	ESSENTIAL KNOWLEDGE
4.1.A Describe the ways that cells can communicate with one another.	**4.1.A.1** Cells communicate with one another through direct contact with other cells or from a distance via chemical signaling.
4.1.B Explain how cells communicate with one another over short and long distances.	**4.1.B.1** Cells communicate over short distances by using local regulators that target cells in the vicinity of the signal-emitting cell. **4.1.B.2** Signals released by one cell type can travel long distances to target cells of another type.

TOPIC 4.2

Introduction to Signal Transduction

SUGGESTED SKILL

Concept Explanation

1.A

Describe biological concepts and processes.

AVAILABLE RESOURCE

- AP Central > Classroom Resources > Cell-to-Cell Communication – Cell Signaling

Required Course Content

BIG IDEA 3

Information Storage and Transmission: Living systems store, retrieve, transmit, and respond to information essential to life processes.

LEARNING OBJECTIVE	ESSENTIAL KNOWLEDGE
4.2.A Describe the components of a signal transduction pathway.	**4.2.A.1** Signal transduction pathways link signal receptions with cellular responses. **4.2.A.2** Many signal transduction pathways include protein modifications and involve phosphorylation cascades.
4.2.B Describe the role of components of a signal transduction pathway in producing a cellular response.	**4.2.B.1** Signaling begins with the recognition of a chemical messenger—a ligand—by a receptor protein in a target cell. i. The ligand-binding domain of a receptor recognizes a specific chemical messenger, which can be a peptide (protein) or a small molecule. ii. G protein-coupled receptors are an example of a receptor protein in eukaryotes. iii. Receptors may be located on the surface of a target cell or in the cytoplasm or nucleus of the target cell.

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LEARNING OBJECTIVE

4.2.B

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

ESSENTIAL KNOWLEDGE

4.2.B.2

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

i. After the ligand binds, the intracellular domain of a receptor protein changes shape, initiating transduction of the signal.
ii. Enzymes and second messengers such as cyclic AMP (cAMP) relay and amplify the intracellular signal.
iii. Hormones are an example of a signaling messenger that can travel long distances in the bloodstream.
iv. The binding of ligands to ligand-gated channels can cause the channel to open or close.

TOPIC 4.3

Signal Transduction Pathways

Required Course Content

BIG IDEA 3

Information Storage and Transmission: Living systems store, retrieve, transmit, and respond to information essential to life processes.

LEARNING OBJECTIVE

4.3.A

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

4.3.B

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

ESSENTIAL KNOWLEDGE

4.3.A.1

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

4.3.B.1

Changes in signal transduction pathways can alter cellular responses. 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.

4.3.B.2

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

SUGGESTED SKILL

Argumentation

6.C

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

AVAILABLE RESOURCE

- AP Central > Classroom Resources > Cell-to-Cell Communication – Cell Signaling

ILLUSTRATIVE EXAMPLES

EK 4.3.A.1

- 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

EK 4.3.B.1

- Cytokines regulate gene expression to allow for cell replication and division.
- Mating pheromones in yeast trigger mating gene expression.
- Ethylene levels cause changes in the production of different enzymes allowing fruits to ripen.
- HOX genes regulate animal body plans during embryonic development.

SUGGESTED SKILL

Argumentation

6.E

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

AVAILABLE RESOURCE

- AP Central > Classroom Resources > Cell-to-Cell Communication – Cell Signaling

ILLUSTRATIVE EXAMPLES

EK 4.4.A.1.i

- Blood sugar regulation by insulin/glucagon

EK 4.4.A.1.ii

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

TOPIC 4.4
Feedback

Required Course Content

BIG IDEA 2

Energetics: Biological systems use energy and molecular building blocks to grow, reproduce, and maintain dynamic homeostasis.

LEARNING OBJECTIVE

4.4.A

Explain how positive and negative feedback helps maintain homeostasis.

ESSENTIAL KNOWLEDGE

4.4.A.1

Organisms use feedback mechanisms to maintain their internal environments in response to internal and external changes.

i. Negative feedback mechanisms maintain homeostasis by reducing the initial stimulus to regulate physiological processes. If a system is perturbed or disrupted, negative feedback mechanisms return the system back to its target set point. These processes operate at the molecular, cellular, and organismal levels.

ii. Positive feedback mechanisms amplify responses and processes in biological organisms. The variable initiating the response is moved further away from the initial set point. Amplification occurs when the stimulus is further intensified, which, in turn, initiates an additional response that produces system change.

TOPIC 4.5
Cell Cycle

Required Course Content

BIG IDEA 3

Information Storage and Transmission: Living systems store, retrieve, transmit, and respond to information essential to life processes.

LEARNING OBJECTIVE

4.5.A

Describe the events that occur in the cell cycle.

ESSENTIAL KNOWLEDGE

4.5.A.1

The cell cycle is a highly regulated series of events that controls the growth and reproduction of eukaryotic cells.

i. The cell cycle consists of sequential stages of interphase (G1, S, G2), mitosis, and cytokinesis.

ii. G1 phase: The cell is metabolically active, duplicating organelles and cytosolic components.

iii. S phase: DNA is in the form of chromatin and replicates to form two sister chromatids connected at a centromere.

iv. G2 phase: Protein synthesis occurs, ATP is produced in large quantities, and centrosomes replicate.

v. A cell can enter a stage (G0) in which it no longer divides, but it can reenter the cell cycle in response to appropriate cues.

vi. Nondividing cells may exit the cell cycle or be held at a particular stage in the cell cycle.

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SUGGESTED SKILLS

Representing and Describing Data

4.B

Describe data from a table or graph, including:

i. identifying specific data points

ii. describing trends and patterns in the data

iii. describing relationships between variables

Statistical Tests and Data Analysis

5.A

Perform mathematical calculations, including:

i. mathematical equations in the curriculum

ii. means

iii. rates

iv. ratios

v. percentages and percent changes

AVAILABLE RESOURCE

- AP Central > AP Biology Lab Manual > Mitosis Lab

LEARNING OBJECTIVE

4.5.B

Explain how mitosis results in the transmission of chromosomes from one generation of cells to the next.

ESSENTIAL KNOWLEDGE

4.5.B.1

Mitosis is a process that ensures the transfer of a complete genome from a parent cell to two genetically identical daughter cells in eukaryotes.

i. Mitosis plays a role in growth, tissue repair, and asexual reproduction.

ii. Mitosis occurs in sequential steps (prophase, metaphase, anaphase, telophase) and alternates with interphase in the cell cycle.

iii. Prophase: Sister chromatids condense, mitotic spindle begins to form, and centrosomes move to opposite poles of the cell.

iv. Metaphase: Spindle fibers align chromosomes along the equator of the cell.

v. Anaphase: Paired sister chromatids separate as spindle fibers pull chromatids toward poles.

vi. Telophase: Mitotic spindle breaks down, a new nuclear envelope develops, and then the cytoplasm divides.

vii. Cytokinesis: A cleavage furrow forms in animal cells or a cell plate forms in plant cells, resulting in two new daughter cells.

TOPIC 4.6

Regulation of Cell Cycle

SUGGESTED SKILL

Argumentation

6.E

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

Required Course Content

BIG IDEA 3

Information Storage and Transmission: Living systems store, retrieve, transmit, and respond to information essential to life processes.

LEARNING OBJECTIVE	ESSENTIAL KNOWLEDGE
4.6.A Describe the role of checkpoints in regulating the cell cycle.	**4.6.A.1** A number of internal controls or checkpoints regulate progression through the cell cycle. **4.6.A.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 AP Exam.*
4.6.B Describe the effects of disruptions to the cell cycle on the cell or organism.	**4.6.B.1** Disruptions to the cell cycle may result in cancer or apoptosis (programmed cell death).

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AP BIOLOGY

UNIT 5

Heredity

8–11%
AP EXAM WEIGHTING

~8–10
CLASS PERIODS

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

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

Progress Check 5

Multiple-choice: ~23 questions
Free-response: 2 questions

- Interpreting and Evaluating Experimental Results with Graphing
- Conceptual Analysis

UNIT 5

8–11% AP EXAM WEIGHTING | **~8–10** CLASS PERIODS

Heredity

BIG IDEA 1
Evolution
- How is our understanding of evolution influenced by our knowledge of genetics?

BIG IDEA 3
Information Storage and Transmission
- Why is it important that not all inherited characteristics get expressed in the next generation?
- How might Mendel's laws have been affected if he had studied a different type of plant?

BIG IDEA 4
Systems Interactions
- 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 learn how non-Mendelian genetics describes patterns of inheritance that seem to violate Mendel's laws. This unit also covers the roles 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.A 5.C 6.E

Data can convey important information about biological systems. To understand this information, students need to practice describing data and identifying patterns and trends that might make the data meaningful for the researcher. This analysis could 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 or solutions to problems in biological systems.

Students should understand the value and application of the chi-square test in contexts beyond genetics, but also that chi-square hypothesis testing is not always an appropriate statistical test for the data being analyzed. Students should learn how to state a null hypothesis of an experiment, and more importantly, that the null hypothesis is related to the experimental variables in question.

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 the haploid results of meiosis or a mistake in crossing over.

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 can expect to calculate a chi-square value and explain its meaning in a given scenario. On the exam, students commonly fail to identify the null hypothesis rather than an alternate hypothesis. Provide them with 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 placed on helping students understand when to reject or fail to reject the null hypothesis.

UNIT AT A GLANCE

Topic	Suggested Skills	Class Periods ~8–10 CLASS PERIODS
5.1 Meiosis	1.B Explain biological concepts and processes.	
5.2 Meiosis and Genetic Diversity	3.A Identify or pose a testable question based on an observation, data, or a model.	
5.3 Mendelian Genetics	5.C Perform chi-square hypothesis testing. 6.E Predict the causes or effects of a change in, or disruption to, one or more components in a biological system.	
5.4 Non-Mendelian Genetics	5.A Perform mathematical calculations, including: i. mathematical equations in the curriculum ii. means iii. rates iv. ratios v. percentages and percent changes 5.C Perform chi-square hypothesis testing.	
5.5 Environmental Effects on Phenotype	1.C Explain biological concepts and processes in applied contexts.	

Go to **AP Classroom** to assign the **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 optional 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 encouraged to adapt the activities to best support students in your classroom. 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** Have students construct simulated chromosomes with pop beads or pipe cleaners and manipulate them through the stages of meiosis. As students model the process, ask them to 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. Then, have students turn to a classmate to share their sketches or photographs and discuss what they now understand about meiosis in humans. Conduct a whole-class discussion where one student from each pair shares their collective understanding.
2	5.3	**Construct an Argument** Instruct students that they can use genetically modified corn to apply the chi-square test to a dihybrid cross. First, students should calculate the expected genotypic and phenotypic ratios using a Punnett square. They should then formulate null hypotheses for the cross and perform a chi-square test. Have them conclude the exercise by stating whether they should reject or fail to reject the null hypothesis and ask that they justify their reasoning.
3	5.5	**One-Minute Essay** Direct students to read an article about an organism that exhibits phenotypic plasticity. After reading, provide a prompt about this inheritance process, and ask them to respond to it in one minute or less.

SUGGESTED SKILL

Concept Explanation

1.B

Explain biological concepts and processes.

AVAILABLE RESOURCE

- AP Central > AP Biology Lab Manual > Meiosis Lab

TOPIC 5.1
Meiosis

Required Course Content

BIG IDEA 3

Information Storage and Transmission: Living systems store, retrieve, transmit, and respond to information essential to life processes.

LEARNING OBJECTIVE

5.1.A

Explain how meiosis results in the transmission of chromosomes from one generation to the next.

ESSENTIAL KNOWLEDGE

5.1.A.1

Meiosis is a process that ensures the formation of haploid gamete cells, sometimes referred to as daughter cells, in sexually reproducing diploid organisms.

5.1.A.2

Meiosis I involves the following steps:

i. Prophase I: Homologous chromosomes pair up and condense, synapsis occurs and then chiasmata may form, meiotic spindle begins to form, centrosomes move to opposite poles of the cell, and the nuclear envelope breaks down.

ii. Metaphase I: Meiotic spindle fibers align homologous pairs of chromosomes along the equator of the cell at the metaphase plate.

iii. Anaphase I: Homologous chromosomes separate, while sister chromatids remain attached, as meiotic spindle fibers pull chromosomes toward poles.

iv. Telophase I: Meiotic spindle breaks down, a new nuclear envelope develops, a cleavage furrow (animal cell) or cell plate (plant cell) forms, and cytokinesis occurs. Two haploid daughter cells are formed (at the end of meiosis I).

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LEARNING OBJECTIVE	ESSENTIAL KNOWLEDGE
5.1.A Explain how meiosis results in the transmission of chromosomes from one generation to the next.	**5.1.A.3** Meiosis II involves the following steps: i. Prophase II: Meiotic spindle forms; sister chromatids connected at the centromere attach to meiotic spindle. ii. Metaphase II: Chromosomes align along the metaphase plate; the kinetochore of each chromatid is attached to a microtubule extending from the poles. iii. Anaphase II: Proteins at the centromeres break down, and sister chromatids are pulled apart and toward opposite poles in the cell. iv. Telophase II: Meiotic spindle breaks down, a new nuclear envelope develops, a cleavage furrow (animal cell) or a cell plate (plant cell) forms, chromatids begin to decondense, and cytokinesis occurs. Four haploid daughter cells are formed, each with an unduplicated chromatid.
5.1.B Describe similarities and differences between the phases and outcomes of mitosis and meiosis.	**5.1.B.1** Mitosis and meiosis are similar in the use of a spindle apparatus to move chromosomes but differ in the number of cells produced and the genetic content of the daughter cells.

SUGGESTED SKILL

Questions and Methods

3.A

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

AVAILABLE RESOURCE

- AP Central > AP Biology Lab Manual > Meiosis Lab

TOPIC 5.2
Meiosis and Genetic Diversity

Required Course Content

BIG IDEA 3

Information Storage and Transmission: Living systems store, retrieve, transmit, and respond to information essential to life processes.

LEARNING OBJECTIVE

5.2.A

Explain how the process of meiosis generates genetic diversity.

ESSENTIAL KNOWLEDGE

5.2.A.1

Correct separation of the homologous chromosomes in meiosis I and sister chromatids in meiosis II ensures that each gamete receives a haploid (1n) set of chromosomes that comprises an assortment of both maternal and paternal chromosomes. When incorrect separation occurs (nondisjunction), gametes are no longer haploid.

5.2.A.2

During prophase I of meiosis, non-sister chromatids exchange genetic material via a process called crossing over (recombination), which increases genetic diversity among the resultant gametes.

5.2.A.3

Sexual reproduction in eukaryotes increases genetic variation, including crossing over, random assortment of chromosomes during meiosis, and subsequent fertilization of gametes.

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

TOPIC 5.3
Mendelian Genetics

SUGGESTED SKILLS

Statistical Tests and Data Analysis

5.C

Perform chi-square hypothesis testing.

Argumentation

6.E

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

Required Course Content

BIG IDEA 1

Evolution: The process of evolution drives the diversity and unity of life.

BIG IDEA 3

Information Storage and Transmission: Living systems store, retrieve, transmit, and respond to information essential to life processes.

LEARNING OBJECTIVE

5.3.A

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

ESSENTIAL KNOWLEDGE

5.3.A.1

Mendel's laws of segregation and independent assortment can be applied to genes that are on different chromosomes.

5.3.A.2

In most cases, 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.

i. Rules of probability can be applied to analyze the passing of single-gene traits from parent to offspring.

ii. Monohybrid, dihybrid, and test crosses can be used to determine whether alleles are dominant or recessive.

iii. An organism's genotype is the set of alleles inherited for one or more genes by an individual organism. An organism's genotype can be homozygous or heterozygous for each gene.

iv. An organism's phenotype is the observable expression of the inherited traits.

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LEARNING OBJECTIVE

5.3.A

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

ESSENTIAL KNOWLEDGE

v. Patterns of inheritance (autosomal, genetically linked, sex-linked) and whether an allele is dominant or recessive can often be predicted from data, including pedigrees. Punnett squares can be used to predict the genotypes and phenotypes of parents and offspring.

RELEVANT EQUATIONS

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

TOPIC 5.4
Non-Mendelian Genetics

Required Course Content

BIG IDEA 3
Information Storage and Transmission: Living systems store, retrieve, transmit, and respond to information essential to life processes.

LEARNING OBJECTIVE

5.4.A

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

ESSENTIAL KNOWLEDGE

5.4.A.1

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

i. Genes located on the same chromosome are referred to as being genetically linked. The probability that these linked genes segregate together during meiosis can be used to calculate the map distance (or map units) between them on a chromosome. This calculation is called gene or genetic mapping.

ii. Codominance occurs when the phenotype from both alleles is expressed such that the heterozygote would have a different phenotype than either homozygote.

iii. Incomplete dominance occurs when neither allele of a gene can mask the other, so the phenotype of the heterozygote is a blended version of the dominant and recessive phenotypes.

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SUGGESTED SKILLS

Statistical Tests and Data Analysis

5.A

Perform mathematical calculations, including:

i. mathematical equations in the curriculum
ii. means
iii. rates
iv. ratios
v. percentages and percent changes

5.C

Perform chi-square hypothesis testing.

ILLUSTRATIVE EXAMPLES

EK 5.4.A.2

- Sex-linked traits (X- or Y-linked) reside on sex chromosomes.
- Sex-linked traits (X- or Y-linked) are inherited at higher rates in XY individuals than they are in XX individuals.
- In certain species, the chromosomal basis of sex determination is not based on X and Y chromosomes (e.g., ZW in birds, haplodiploidy in bees).

LEARNING OBJECTIVE

5.4.A

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

ESSENTIAL KNOWLEDGE

5.4.A.2

Some traits, known as sex-linked traits (X- or Y-linked), are determined by genes on sex chromosomes. The pattern of inheritance of sex-linked traits can often be predicted from data, including pedigrees, indicating the genotypes and phenotypes of both parents and offspring.

5.4.A.3

Pleiotropy is a phenomenon in which the expression of a single gene results in multiple traits or effects; these traits therefore do not segregate independently.

5.4.A.4

Some traits result from non-nuclear inheritance.

i. 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.

ii. In animals, mitochondria are usually transmitted by the egg and not by sperm; thus, traits determined by the mitochondrial DNA are typically maternally inherited.

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

TOPIC 5.5

Environmental Effects on Phenotype

SUGGESTED SKILL

Concept Explanation

1.C

Explain biological concepts and processes in applied contexts.

Required Course Content

BIG IDEA 4

Systems Interactions: Biological systems interact, and these systems and their interactions exhibit complex properties.

LEARNING OBJECTIVE

5.5.A

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

ESSENTIAL KNOWLEDGE

5.5.A.1

Environmental conditions influence gene expression and can lead to phenotypic plasticity (e.g., the ability of individual genotypes to produce different phenotypes).

ILLUSTRATIVE EXAMPLES

EK 5.5.A.1

- 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

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AP BIOLOGY

UNIT 6

Gene Expression and Regulation

12–16%
AP EXAM WEIGHTING

~18–20
CLASS PERIODS

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

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

Progress Check 6

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

- Interpreting and Evaluating Experimental Results
- Analyze Model or Visual Representation of a Biological Concept or Process

UNIT 6

12–16% AP EXAM WEIGHTING | **~18–20** CLASS PERIODS

Gene Expression and Regulation

BIG IDEA 3
Information Storage and Transmission

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

Developing Understanding

Progressing from the continuity of life to gene expression, students gain in-depth knowledge about nucleic acids and their role in gene expression in this unit. There is also 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 their phenotype, thus emphasizing the importance of protein synthesis (transcription and translation) in 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 2.C 2.D 6.A 6.B 6.D 6.E

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

Throughout the course, students should be given multiple opportunities to make a claim, support it with evidence, and provide 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 when 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 could 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

Topic	Suggested Skills	Class Periods ~18–20 CLASS PERIODS
6.1 DNA and RNA Structure	1.C Explain biological concepts and processes in applied contexts.	
6.2 DNA Replication	2.B Explain relationships between characteristics of biological models in both theoretical and applied contexts.	
6.3 Transcription and RNA Processing	2.B Explain relationships between characteristics of biological models in both theoretical and applied contexts.	
6.4 Translation	2.D Represent relationships within biological models, including mathematical models, diagrams, flowcharts, and systems. 6.E Predict the causes or effects of a change in, or disruption to, one or more components in a biological system.	
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 data.	
6.7 Mutations	2.C Explain how biological models relate to larger principles, concepts, processes, systems, or theories.	
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 **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 optional 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 encouraged to adapt the activities to best support students in your classroom. 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** Distribute diagrams of nucleotides (which can be found on the internet and photocopied), and ask students to model the process of replication, explaining what is happening as they go. Circulate around the room as they're working and observe the results of replication that students produce. Correct any misunderstandings when you see them.
2	6.3	**Think-Pair-Share** Have students build a model of transcription using pool noodles (which can usually be purchased at a dollar store). Instruct pairs of students to use everyday materials, such as tape, colored paper, yarn (or string), and markers to identify the promoter region, TATA box, transcription start site, and terminal sequence. They should describe the process of transcription from the initial binding of the transcription factors to the production of the transcript. At the end of class, invite one student from each pair to share their model with the whole class.
3	6.4	**Construct an Argument** Ask students to 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.

SUGGESTED SKILL

Concept Explanation

1.C

Explain biological concepts and processes in applied contexts.

AVAILABLE RESOURCES

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

TOPIC 6.1

DNA and RNA Structure

Required Course Content

BIG IDEA 3

Information Storage and Transmission: Living systems store, retrieve, transmit, and respond to information essential to life processes.

LEARNING OBJECTIVE

6.1.A

Describe the structures involved in passing hereditary information from one generation to the next.

ESSENTIAL KNOWLEDGE

6.1.A.1

Genetic information is stored in and passed to subsequent generations through DNA molecules and, in some cases, RNA molecules.

i. Prokaryotic organisms typically have circular chromosomes.

ii. Eukaryotic organisms typically have multiple linear chromosomes that are comprised of DNA. These chromosomes are condensed using histones and associated proteins.

6.1.A.2

Prokaryotes and eukaryotes can contain plasmids, which are extra-chromosomal circular molecules of DNA.

LEARNING OBJECTIVE

6.1.B

Describe the characteristics of DNA that allow it to be used as hereditary material.

ESSENTIAL KNOWLEDGE

6.1.B.1

Nucleic acids exhibit specific nucleotide base pairing that is conserved through evolution.

i. Purines (guanine and adenine) have a double ring structure.

ii. Pyrimidines (cytosine, thymine, and uracil) have a single ring structure.

iii. Purines pair with pyrimidines: adenine with thymine (or uracil in RNA) and guanine with cytosine.

TOPIC 6.2

DNA Replication

SUGGESTED SKILL

Visual Representations

2.B

Explain relationships between characteristics of biological models in both theoretical and applied contexts.

AVAILABLE RESOURCE

- AP Central > Classroom Resources > From Gene to Protein – A Historical Perspective

Required Course Content

BIG IDEA 3

Information Storage and Transmission: Living systems store, retrieve, transmit, and respond to information essential to life processes.

LEARNING OBJECTIVE

6.2.A

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

ESSENTIAL KNOWLEDGE

6.2.A.1

DNA replication ensures continuity of hereditary information.

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

ii. Replication is a semiconservative process, meaning one strand of DNA serves as the template for a new strand of complementary DNA.

iii. Helicase unwinds the DNA strands.

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

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

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

vii. Ligase joins the fragments on the lagging strand.

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

SUGGESTED SKILL

Visual Representations

2.B
Explain relationships between characteristics of biological models in both theoretical and applied contexts.

AVAILABLE RESOURCE
- AP Central > Classroom Resources > From Gene to Protein—A Historical Perspective

TOPIC 6.3
Transcription and RNA Processing

Required Course Content

BIG IDEA 3
Information Storage and Transmission: Living systems store, retrieve, transmit, and respond to information essential to life processes.

LEARNING OBJECTIVE

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

ESSENTIAL KNOWLEDGE

6.3.A.1
The sequence of the RNA bases, together with the structure of the RNA molecule, determines RNA function.

i. Messenger RNA (mRNA) molecules carry information from DNA in the nucleus to the ribosome in the cytoplasm.

ii. Distinct transfer RNA (tRNA) molecules bind specific amino acids and have anticodon sequences that base pair with the codons of mRNA. tRNA is recruited to the ribosome during translation to generate the primary peptide sequence based on the mRNA sequence.

iii. Ribosomal RNA (rRNA) molecules are functional building blocks of ribosomes.

6.3.A.2
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

6.3.A

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

ESSENTIAL KNOWLEDGE

6.3.A.3

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.

6.3.A.4

In eukaryotic cells the mRNA transcript undergoes a series of enzyme-mediated modifications.

i. The addition of a poly-A tail makes mRNA more stable.

ii. The addition of a GTP cap helps with ribosomal recognition.

iii. The excision of introns, along with the splicing and retention of exons, generates different versions of the resulting mature mRNA molecule. This process is known as alternative splicing.

SUGGESTED SKILLS

Visual Representations

2.D

Represent relationships within biological models, including mathematical models, diagrams, flowcharts, and systems.

Argumentation

6.E

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

AVAILABLE RESOURCE

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

TOPIC 6.4
Translation

Required Course Content

BIG IDEA 3

Information Storage and Transmission: Living systems store, retrieve, transmit, and respond to information essential to life processes.

LEARNING OBJECTIVE

6.4.A

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

ESSENTIAL KNOWLEDGE

6.4.A.1

Translation of the mRNA to generate a polypeptide occurs on ribosomes that are present in the cytoplasm of both prokaryotic and eukaryotic cells, as well as the cytoplasmic surface of the rough ER of eukaryotic cells.

6.4.A.2

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

6.4.A.3

Translation involves many sequential steps, including initiation, elongation, and termination. The salient features of translation include:

i. Translation is initiated when the rRNA in the ribosome interacts with the mRNA at the start codon (AUG, coding for the amino acid methionine).

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

iii. 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.

iv. Nearly all living organisms use the same genetic code, which is evidence for the common ancestry of all living organisms.

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LEARNING OBJECTIVE

6.4.A

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

ESSENTIAL KNOWLEDGE

v. tRNA brings the correct amino acid to the place specified by the codon on the mRNA.

vi. The amino acid is transferred to the growing polypeptide chain.

vii. The process continues along the mRNA until a stop codon is reached.

viii. Translation terminates with the release of the newly synthesized protein.

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

EXCLUSION STATEMENT—*Memorization of the genetic code, with the exception of the start codon AUG, is beyond the scope of the AP Exam.*

6.4.A.4

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 is transcribed and translated for the assembly of new viral progeny.

SUGGESTED SKILL

Argumentation

6.A

Make a scientific claim

AVAILABLE RESOURCE

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

TOPIC 6.5

Regulation of Gene Expression

Required Course Content

BIG IDEA 3

Information Storage and Transmission: Living systems store, retrieve, transmit, and respond to information essential to life processes.

LEARNING OBJECTIVE

6.5.A

Describe the types of interactions that regulate gene expression.

ESSENTIAL KNOWLEDGE

6.5.A.1

Regulatory sequences are stretches of DNA that interact with regulatory proteins to control transcription. Some genes are constitutively expressed, and others are inducible.

6.5.A.2

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

6.5.A.3

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

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

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

iii. The function and amount of gene products determine the phenotype of organisms.

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LEARNING OBJECTIVE

6.5.B

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

ESSENTIAL KNOWLEDGE

6.5.B.1

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

i. Prokaryotes regulate operons in an inducible or repressible system.

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

SUGGESTED SKILL

Argumentation

6.B

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

AVAILABLE RESOURCE

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

TOPIC 6.6

Gene Expression and Cell Specialization

Required Course Content

BIG IDEA 3

Information Storage and Transmission: Living systems store, retrieve, transmit, and respond to information essential to life processes.

LEARNING OBJECTIVE	ESSENTIAL KNOWLEDGE
6.6.A Explain how the binding of transcription factors to promoter regions affects gene expression and the phenotype of the organism.	**6.6.A.1** RNA polymerase and transcription factors bind to promoter or enhancer DNA sequences to initiate transcription. These sequences can be upstream or downstream of the transcription start site. **6.6.A.2** Negative regulatory molecules inhibit gene expression by binding to DNA and blocking transcription.
6.6.B Explain the connection between the regulation of gene expression and phenotypic differences in cells and organisms.	**6.6.B.1** Gene regulation results in differential gene expression and influences cell products and functions. **6.6.B.2** Certain small RNA molecules have roles in regulating gene expression.

TOPIC 6.7
Mutations

SUGGESTED SKILL

Visual Representations

2.C

Explain how biological models relate to larger principles, concepts, processes, systems, or theories.

AVAILABLE RESOURCE

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

ILLUSTRATIVE EXAMPLES

EK 6.7.A.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.

EK 6.7.C.1

- Sickle cell anemia

Required Course Content

BIG IDEA 3

Information Storage and Transmission: Living systems store, retrieve, transmit, and respond to information essential to life processes.

LEARNING OBJECTIVE

6.7.A

Describe the various types of mutation.

ESSENTIAL KNOWLEDGE

6.7.A.1

Alterations in a DNA sequence are mutations that can cause changes in the type or amount of the protein produced and the consequent phenotype. DNA mutations can be beneficial, detrimental, 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.

i. Point mutations occur when one nucleotide has been substituted for a different nucleotide.

ii. Frameshift mutations occur when one or more nucleotides are inserted or deleted, causing the reading frame to be shifted.

iii. Nonsense mutations occur when there is a point mutation that causes a premature stop.

iv. Silent mutations occur when the change in the nucleotide sequence has no effect on the amino acid sequence.

X EXCLUSION STATEMENT—*Knowledge of specific mutations and their effects is beyond the scope of the AP Exam.*

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LEARNING OBJECTIVE	ESSENTIAL KNOWLEDGE
6.7.B Explain how changes in genotype may result in changes in phenotype.	**6.7.B.1** Errors in DNA replication or DNA repair mechanisms as well as external factors, including radiation and reactive chemicals, can cause random mutations in the DNA. i. Whether a mutation is beneficial, detrimental, or neutral depends on the environmental context. ii. Mutations are a source of genetic variation. **6.7.B.2** Errors in mitosis or meiosis can result in changes in phenotype. i. Changes in chromosome number resulting from nondisjunction often result in new phenotypes caused by triploidy (aneuploidy). ii. Changes in chromosome number often result in disorders with developmental limitations. iii. Alterations in chromosome structure lead to genetic disorders. **EXCLUSION STATEMENT**—*Knowledge of specific disorders related to changes in chromosome number is beyond the scope of the AP Exam.*
6.7.C Explain how alterations in DNA sequences contribute to variation that can be subject to natural selection.	**6.7.C.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. i. The horizontal acquisitions of genetic information in prokaryotes via transformation (uptake of 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 genetic variation. ii. Related viruses can recombine genetic information if they infect the same host cell. iii. Reproductive processes that increase genetic variation are evolutionarily conserved and are shared by various organisms.

TOPIC 6.8
Biotechnology

SUGGESTED SKILL

Argumentation

6.D

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

AVAILABLE RESOURCES

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

ILLUSTRATIVE EXAMPLES

EK 6.8.A.1

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

Required Course Content

BIG IDEA 3

Information Storage and Transmission: Living systems store, retrieve, transmit, and respond to information essential to life processes.

LEARNING OBJECTIVE

6.8.A

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

ESSENTIAL KNOWLEDGE

6.8.A.1

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

i. Gel electrophoresis is a process that separates DNA fragments by size and charge.

ii. During polymerase chain reaction (PCR), DNA fragments are amplified by denaturing DNA, annealing primers to the original strand, and extending the new DNA molecule.

iii. Bacterial transformation introduces foreign DNA into bacterial cells.

iv. DNA sequencing technology determines the order of nucleotides in a DNA molecule. Typically, these techniques result in a DNA fingerprint that allows for the comparison of DNA sequences from various samples.

EXCLUSION STATEMENT—*Knowledge of the details of each of these genetic engineering techniques is beyond the scope of the AP Exam.*

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AP BIOLOGY

UNIT 7

Natural Selection

13–20%
AP EXAM WEIGHTING

~19–21
CLASS PERIODS

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

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

Progress Check 7

Multiple-choice: ~48 questions (2 parts)

Free-response: 2 questions

- Interpreting and Evaluating Experimental Results with Graphing
- Analyze Data

UNIT 7

13–20% AP EXAM WEIGHTING | **~19–21** CLASS PERIODS

Natural Selection

BIG IDEA 1
Evolution

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

BIG IDEA 4
Systems Interactions

- 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. Natural selection is 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. The biological principles studied here and in previous units will carry over into Unit 8, which focuses on ecology.

Building Science Practices

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

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 by communicating the biological meaning it represents. Mastery is demonstrated when students can create or use models such as cladograms and phylogenetic trees to analyze and discuss biological phenomena or solve new problems.

Hardy–Weinberg equations are used with respect to a specific gene. 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 appear 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 to 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. Students should be given opportunities to work with different models of isolation mechanisms to gain a better understanding.

UNIT AT A GLANCE

Topic	Suggested Skills	Class Periods ~19–21 CLASS PERIODS
7.1 Introduction to Natural Selection	2.A Describe characteristics of visual representations of biological concepts and processes.	
7.2 Natural Selection	1.B Explain biological concepts and processes.	
7.3 Artificial Selection	4.B Describe data from a table or graph, including: i. identifying specific data points ii. describing trends and patterns in the data iii. describing relationships between variables	
7.4 Population Genetics	3.B State the null hypothesis or predict the results of an experiment.	
7.5 Hardy–Weinberg Equilibrium	1.C Explain biological concepts and processes in applied contexts. 5.A Perform mathematical calculations, including: i. mathematical equations in the curriculum ii. means iii. rates iv. ratios v. percentages and percent changes	
7.6 Evidence of Evolution	4.B Describe data from a table or graph, including: i. identifying specific data points ii. describing trends and patterns in the data iii. describing relationships between variables	

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UNIT AT A GLANCE *(cont'd)*

Topic	Suggested Skills	Class Periods ~19–21 CLASS PERIODS
7.7 Common Ancestry	6.E Predict the causes or effects of a change in, or disruption to, one or more components in a biological system.	
7.8 Continuing Evolution	3.D Propose a new investigation based on an evaluation of the experimental design or evidence.	
7.9 Phylogeny	2.D Represent relationships within biological models, including mathematical models, diagrams, flowcharts, and systems.	
7.10 Speciation	2.B Explain relationships between characteristics of biological models in both theoretical and applied contexts. 6.E Predict the causes or effects of a change in, or disruption to, one or more components in a biological system.	
7.11 Variations in Populations	6.C Provide reasoning to justify a claim by connecting evidence to biological theories.	
7.12 Origins of Life on Earth	3.B State the null hypothesis or predict the results of an experiment.	

Go to **AP Classroom** to assign the **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 optional 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 encouraged to adapt the activities to best support students in your classroom. 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	7.2	**Misconception Check** Using one of many available online resources, have students learn about the work of Peter and Rosemary Grant. Using data from the Grants' work, help students to build their graphing and statistical analysis skills. This is a good opportunity for students to practice explaining trends in data and supporting their claims with evidence. Through their work of supporting their claims, misconceptions will come up and can be corrected.
2	7.3	**Graph and Switch** Place students into groups of 3–5 and have them perform a brine shrimp lab, placing groups of brine shrimp eggs in petri dishes with various concentrations of salt in the water. They should monitor the number of eggs and swimming shrimp in the petri dishes at regular time intervals over a period of 2–3 days. Ask students to then calculate the hatching viability in each petri dish and graph their data. Chi-square can be used to analyze the null hypothesis. Have students then switch graphs with classmates to compare findings.
3	7.5	**Construct an Argument** Have students use one of the Rock Pocket Mice activities available online to learn the principles of the Hardy–Weinberg equilibrium and to calculate allele frequencies in a population. Once students have completed their calculations, have them construct an argument about whether and how the mice populations are evolving.
4	7.10	**Ask the Expert** Show students a cartoon image of an isolating mechanism that leads to speciation. Discuss with them what is happening in the cartoon and how it relates to speciation. Place students into groups and have them conduct research on other isolating mechanisms and draw their own cartoons to illustrate what they learned. Ask students to move around to other groups, sharing their cartoons and answering any questions from their classmates.

TOPIC 7.1

Introduction to Natural Selection

SUGGESTED SKILL

Visual Representations

2.A

Describe characteristics of visual representations of biological concepts and processes.

AVAILABLE RESOURCES

- AP Central > Classroom Resources > Visualizing Information
- AP Central > Classroom Resources > Evolution and Change

Required Course Content

BIG IDEA 1

Evolution: The process of evolution drives the diversity and unity of life.

LEARNING OBJECTIVE	ESSENTIAL KNOWLEDGE
7.1.A Describe the causes of natural selection.	**7.1.A.1** Natural selection is a major mechanism of evolution. **7.1.A.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 on those favorable traits to subsequent generations.
7.1.B Explain how natural selection affects populations.	**7.1.B.1** Evolutionary fitness is measured by reproductive success. **7.1.B.2** Biotic and abiotic environments can fluctuate, affecting 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 processes.

AVAILABLE RESOURCE

- AP Central > Classroom Resources > Evolution and Change

ILLUSTRATIVE EXAMPLES

EK 7.2.A.2

- Flowering time in relation to global climate change

EK 7.2.A.3

- Sickle cell anemia
- DDT resistance in insects

TOPIC 7.2

Natural Selection

Required Course Content

BIG IDEA 1

Evolution: The process of evolution drives the diversity and unity of life.

LEARNING OBJECTIVE	ESSENTIAL KNOWLEDGE
7.2.A Describe the importance of phenotypic variation in a population.	**7.2.A.1** Natural selection acts on phenotypic variations in populations. **7.2.A.2** Environments change and apply selective pressures to populations. **7.2.A.3** Some phenotypic variations can increase or decrease the fitness of an organism in particular environments.
7.2.B Explain how variation in molecules within cells connects to the fitness of an organism.	**7.2.B.1** Variation in the number and types of molecules within cells can provide populations a greater ability to survive and reproduce in different environments.

TOPIC 7.3
Artificial Selection

Required Course Content

BIG IDEA 1
Evolution: The process of evolution drives the diversity and unity of life.

LEARNING OBJECTIVE
7.3.A
Explain how humans can affect diversity within a population.

ESSENTIAL KNOWLEDGE
7.3.A.1
Through artificial selection, humans affect variation in other species.

SUGGESTED SKILL

Representing and Describing Data

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

i. identifying specific data points
ii. describing trends and patterns in the data
iii. describing relationships between variables

AVAILABLE RESOURCES

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

SUGGESTED SKILL

Questions and Methods

3.B
State the null hypothesis or predict the results of an experiment.

AVAILABLE RESOURCE
- AP Central > Classroom Resources > Evolution and Change

TOPIC 7.4
Population Genetics

Required Course Content

BIG IDEA 1
Evolution: The process of evolution drives the diversity and unity of life.

LEARNING OBJECTIVE

7.4.A
Explain how random occurrences affect the genetic makeup of a population.

ESSENTIAL KNOWLEDGE

7.4.A.1
Evolution is also driven by random occurrences.

i. Mutation is a random process that adds new genetic variation to a population.
ii. Genetic drift is a change in allele frequencies attributable to a nonselective process occurring in small populations.
iii. The bottleneck effect is a type of genetic drift that occurs when a population size is reduced to a small number of individuals for at least one generation.
iv. The founder effect is a type of genetic drift that occurs when a population is separated from other members of the population. The frequency of genes and traits will shift based on the genes in this new founder population.
v. Migration can result in gene flow (the addition or removal of alleles from a population).

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LEARNING OBJECTIVE	ESSENTIAL KNOWLEDGE
7.4.B Describe the role of random processes in the evolution of specific populations.	**7.4.B.1** Random processes can lead to changes in allele frequencies in a population. i. Mutations result in genetic variation, which provides phenotypes on which natural selection acts. ii. Genetic drift can allow a small population to diverge from other populations of the same species. iii. Gene flow between two populations prevents them from diverging into separate species.
7.4.C Describe the change in the genetic makeup of a population over time.	**7.4.C.1** Changes in allele frequencies provide evidence for the occurrence of evolution in a population.

SUGGESTED SKILLS

Concept Explanation

1.C

Explain biological concepts and processes in applied contexts.

Statistical Tests and Data Analysis

5.A

Perform mathematical calculations, including:

i. mathematical equations in the curriculum
ii. means
iii. rates
iv. ratios
v. percentages and percent changes

AVAILABLE RESOURCES

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

ILLUSTRATIVE EXAMPLE

EK 7.5.A.2

- Graphic analysis of allele frequencies in a population

TOPIC 7.5

Hardy–Weinberg Equilibrium

Required Course Content

BIG IDEA 1

Evolution: The process of evolution drives the diversity and unity of life.

LEARNING OBJECTIVE

7.5.A

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

ESSENTIAL KNOWLEDGE

7.5.A.1

The Hardy–Weinberg Equilibrium is a model for describing and predicting allele frequencies in a non-evolving population. Conditions for a population or an allele to be in Hardy–Weinberg equilibrium are:

i. A large population size
ii. No migration
iii. No new mutations
iv. Random mating
v. No natural selection

These conditions are never met, but they provide a valuable null hypothesis.

7.5.A.2

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

RELEVANT EQUATIONS

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

TOPIC 7.6
Evidence of Evolution

Required Course Content

BIG IDEA 1
Evolution: The process of evolution drives the diversity and unity of life.

LEARNING OBJECTIVE	ESSENTIAL KNOWLEDGE
7.6.A Describe the types of data that provide evidence for evolution.	**7.6.A.1** Evolution is supported by scientific evidence from many disciplines (geographical, geological, physical, biochemical, and mathematical data).
7.6.B Explain how morphological, biochemical, and geological data provide evidence that organisms have changed over time.	**7.6.B.1** Molecular, morphological, and genetic evidence from extant and extinct organisms adds to our understanding of evolution. i. Fossils can be dated by a variety of methods. These include 1) the age of the rocks where a fossil is found; 2) the rate of decay of isotopes including carbon-14; and 3) geographical data. ii. Morphological homologies, including vestigial structures, provide evidence of common ancestry. **7.6.B.2** A comparison of DNA nucleotide sequences and protein amino acid sequences provides evidence for evolution and common ancestry.

SUGGESTED SKILL

Representing and Describing Data

4.B
Describe data from a table or graph, including:
- i. identifying specific data points
- ii. describing trends and patterns in the data
- iii. describing relationships between variables

AVAILABLE RESOURCE
- AP Central > Classroom Resources > Evolution and Change

SUGGESTED SKILL

Argumentation

6.E

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

AVAILABLE RESOURCE

- AP Central > Classroom Resources > Evolution and Change

TOPIC 7.7

Common Ancestry

Required Course Content

BIG IDEA 1

Evolution: The process of evolution drives the diversity and unity of life.

LEARNING OBJECTIVE

7.7.A

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

ESSENTIAL KNOWLEDGE

7.7.A.1

Structural and functional evidence indicates common ancestry of all eukaryotes. This evidence includes:

i. Membrane-bound organelles

ii. Linear chromosomes

iii. Genes that contain introns

TOPIC 7.8
Continuing Evolution

Required Course Content

BIG IDEA 1
Evolution: The process of evolution drives the diversity and unity of life.

LEARNING OBJECTIVE

7.8.A

Explain how evolution is an ongoing process in all living organisms.

ESSENTIAL KNOWLEDGE

7.8.A.1

All species have evolved and continue to evolve. Examples include:

i. Genomic changes over time
ii. Continuous change in the fossil record
iii. Evolution of resistance to antibiotics, pesticides, herbicides, or chemotherapy drugs
iv. Pathogens evolving and causing emergent diseases

SUGGESTED SKILL

Questions and Methods

3.D

Propose a new investigation based on an evaluation of the experimental design or evidence.

AVAILABLE RESOURCE

- AP Central > Classroom Resources > Evolution and Change

SUGGESTED SKILL

Visual Representations

2.D

Represent relationships within biological models, including mathematical models, diagrams, flowcharts, and systems.

AVAILABLE RESOURCE

- AP Central > Classroom Resources > Evolution and Change

TOPIC 7.9
Phylogeny

Required Course Content

BIG IDEA 1

Evolution: The process of evolution drives the diversity and unity of life.

LEARNING OBJECTIVE	ESSENTIAL KNOWLEDGE
7.9.A Describe the types of evidence that can be used to infer an evolutionary relationship.	**7.9.A.1** Phylogenetic trees and cladograms show hypothetical evolutionary relationships among lineages that can be tested. **7.9.A.2** Phylogenetic trees show the amount of change over time calibrated by fossils or a molecular clock, whereas cladograms do not show time scale or the evolutionary difference between groups. **7.9.A.3** Traits that are either gained or lost during evolution can be used to construct phylogenetic trees and cladograms. The out-group represents the lineage that is least closely related to the remainder of the organisms in the phylogenetic tree or cladogram. i. Shared derived characters can be present in more than one lineage and indicate common ancestry. These are informative for the construction of phylogenetic trees and cladograms. ii. 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
7.9.B Explain how phylogenetic trees and cladograms can be used to infer evolutionary relatedness.	**7.9.B.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. **7.9.B.2** Phylogenetic trees and cladograms can be constructed from morphological similarities of living or fossil species and from DNA and protein sequence similarities. **7.9.B.3** Phylogenetic trees and cladograms represent hypotheses that are constantly being revised based on evidence.

SUGGESTED SKILLS

Visual Representations

2.B

Explain relationships between characteristics of biological models in both theoretical and applied contexts.

Argumentation

6.E

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

AVAILABLE RESOURCE

- AP Central > Classroom Resources > Evolution and Change

ILLUSTRATIVE EXAMPLES

LO 7.10.C

- Hawaiian *Drosophila*
- Caribbean *Anolis*
- Apple maggot *Rhagoletis*

TOPIC 7.10
Speciation

Required Course Content

BIG IDEA 1

Evolution: The process of evolution drives the diversity and unity of life.

LEARNING OBJECTIVE	ESSENTIAL KNOWLEDGE
7.10.A Describe the conditions under which new species may arise.	**7.10.A.1** Speciation occurs when two populations become reproductively isolated from each other. **7.10.A.2** The biological species concept provides a commonly used definition of a 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.
7.10.B Describe the rate of evolution and speciation under different ecological conditions.	**7.10.B.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. **7.10.B.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. **7.10.B.3** Convergent evolution occurs when similar selective pressures result in similar phenotypic adaptations in different populations or species.

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LEARNING OBJECTIVE

7.10.C

Explain the processes and mechanisms that drive speciation.

ESSENTIAL KNOWLEDGE

7.10.C.1

Sympatric speciation occurs in populations with geographic overlap. Allopatric speciation occurs in populations that are geographically isolated.

7.10.C.2

Various pre-zygotic and post-zygotic mechanisms can maintain reproductive isolation and prevent gene flow between populations.

SUGGESTED SKILL

Argumentation

6.C

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

AVAILABLE RESOURCE
- AP Central > Classroom Resources > Evolution and Change

ILLUSTRATIVE EXAMPLES

EK 7.11.A.1
- 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 7.11
Variations in Populations

Required Course Content

BIG IDEA 4

Systems Interactions: Biological systems interact, and these systems and their interactions exhibit complex properties.

LEARNING OBJECTIVE

7.11.A

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

ESSENTIAL KNOWLEDGE

7.11.A.1

The level of variation in a population affects population dynamics.

i. The ability of a population 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.

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

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

TOPIC 7.12
Origins of Life on Earth

SUGGESTED SKILL

Questions and Methods

3.B

State the null hypothesis or predict the results of an experiment.

AVAILABLE RESOURCE

- AP Central > Classroom Resources > Evolution and Change

Required Course Content

BIG IDEA 4

Systems Interactions: Biological systems interact, and these systems and their interactions exhibit complex properties.

LEARNING OBJECTIVE

7.12.A

Describe the scientific evidence that supports models of the origin of life on Earth.

ESSENTIAL KNOWLEDGE

7.12.A.1

The origin of life on Earth is supported by scientific evidence.

i. Geological evidence reinforces models of the origin of life on Earth.

ii. Earth formed approximately 4.6 billion years ago (bya). The environment was too hostile for life until about 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 for the origin of life.

7.12.A.2

The RNA world hypothesis proposes that RNA could have been the earliest genetic material. There are three assumptions:

i. At some point in time, genetic continuity was assured by the replication of RNA.

ii. Base-pairing is necessary for replication.

iii. Genetically encoded proteins were not involved as catalysts.

AP BIOLOGY

UNIT 8

Ecology

10–15%
AP EXAM WEIGHTING

~19–21
CLASS PERIODS

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

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

Progress Check 8

Multiple-choice: ~24 questions
Free-response: 2 questions

- Interpreting and Evaluating Experimental Results with Graphing
- Scientific Investigation

UNIT 8

10–15% AP EXAM WEIGHTING | **~19–21** CLASS PERIODS

Ecology

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

BIG IDEA 2
Energetics
- 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
- How does a disruption of a biological system affect genetic information storage and transmission?

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

Developing Understanding

The content in Unit 8 brings together student learning from all previous units as it shows 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 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 course, a student should be able to accurately determine what happens within biological systems when disruptions occur.

Building Science Practices

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

Designing research to test biological systems is at the heart of this course. Students need 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; be sure students understand how to modify a procedure to collect data and test a hypothesis.

Preparing for the AP Exam

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. Ensure student understanding of the relationship between organisms and their environment by having them construct and analyze food chains, food webs, and trophic diagrams. 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 have practiced providing support for their claims about biological systems. Making connections to ecology are fundamental and will help students to build this skill.

UNIT AT A GLANCE

Topic	Suggested Skill	Class Periods ~19–21 CLASS PERIODS
8.1 Responses to the Environment	3.C Identify experimental procedures that align with the question, including: i. identifying dependent and independent variables ii. identifying appropriate controls iii. justifying appropriate controls	
8.2 Energy Flow Through Ecosystems	6.D Explain the relationship between experimental results and larger biological concepts, processes, or theories.	
8.3 Population Ecology	4.A Construct a graph to represent the data, including: x-y graphs (bar, histogram, line, log scale, dual y), scatter plot, box and whisker plot, and pie chart. The graph should include the following components: i. type of graph appropriate for the data ii. axis labeling, including appropriate units and legend iii. scaling iv. accurately plotted data (including error bars when appropriate) v. trend line (when appropriate)	
8.4 Effect of Density on Populations	5.A Perform mathematical calculations, including: i. mathematical equations in the curriculum ii. means iii. rates iv. ratios v. percentages and percent changes	
8.5 Community Ecology	5.B Use confidence intervals and error bars to estimate whether sample means are statistically different.	
8.6 Biodiversity	6.E Predict the causes or effects of a change in, or disruption to, one or more components in a biological system.	
8.7 Disruptions in Ecosystems	5.D Use data to evaluate a hypothesis or prediction, including rejecting or failing to reject the null hypothesis.	

Go to **AP Classroom** to assign the **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 optional 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 encouraged to adapt the activities to best support students in your classroom. 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	**Construct an Argument** Have students perform an animal behavior lab using pill bugs. They should use choice chambers to study the responses of pill bugs to the levels of moisture in the given chambers, creating different environments on either side of the choice chamber and placing the same number of pill bugs on both sides. Have them 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 evaluate the null hypothesis. Once a hypothesis is evaluated, students can construct arguments in support of ways to keep pill bugs out of places where they are unwanted.
2	8.5	**Graph and Switch** Ask students to read about the moose and wolves of Isle Royale to obtain background information on the two organisms. Then have them download a data spreadsheet from the internet and use it to graph data about the two populations. They should 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** To facilitate the hula hoop diversity activity, divide students into groups and give each group a hula hoop and a magnifying glass. Ask students to place their hula hoops in a grassy, woodsy, or garden area and make observations and collect a variety of data about the plants, animals, and abiotic factors inside the hula hoop area. They should record their observations, collected data, and any questions on index cards. Once students have collected all their data and made their observations, have them predict what will happen to organisms in an ecosystem when its biodiversity changes. As a class, discuss the relationship between biodiversity and species endangerment, and predict what changes might occur in an ecosystem when a biotic or abiotic factor changes.

SUGGESTED SKILL

Questions and Methods

3.C

Identify experimental procedures that align with the question, including:

i. identifying dependent and independent variables

ii. identifying appropriate controls

iii. justifying appropriate controls

AVAILABLE RESOURCES

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

ILLUSTRATIVE EXAMPLES

EK 8.1.A.1

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

EK 8.1.A.2

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

EK 8.1.B.1

- Territorial marking in mammals
- Coloration in flowering plants and animals
- Bird songs
- Pack behaviors in animals
- Predatory warnings

TOPIC 8.1
Responses to the Environment

Required Course Content

BIG IDEA 2

Energetics: Biological systems use energy and molecular building blocks to grow, reproduce, and maintain dynamic homeostasis.

LEARNING OBJECTIVE

8.1.A

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

ESSENTIAL KNOWLEDGE

8.1.A.1

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

EXCLUSION STATEMENT—*Knowledge of specific behavioral or physiological mechanisms is beyond the scope of the AP Exam.*

8.1.A.2

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

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BIG IDEA 3

Information Storage and Transmission: Living systems store, retrieve, transmit, and respond to information essential to life processes.

LEARNING OBJECTIVE

8.1.B

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

ESSENTIAL KNOWLEDGE

8.1.B.1

Organisms communicate through various mechanisms (visual, audible, tactile, electrical, and/or chemical signals).

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

ii. Animals use signals to indicate dominance, find food, establish territory, and ensure reproductive success.

X EXCLUSION STATEMENT—*Knowledge of specific mechanisms of communication is beyond the scope of the AP Exam.*

8.1.B.2

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

i. Fitness favors innate and learned behaviors that increase survival and reproductive success.

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

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

ILLUSTRATIVE EXAMPLES

EK 8.1.B.2.i

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

EK 8.1.B.2.ii

- Pack behavior in animals
- Herd, flock, and schooling behavior in animals
- Predator warnings
- 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 Central > AP Biology Lab Manual > Energy Dynamics Lab
- AP Central > Classroom Resources > Visualizing Information

ILLUSTRATIVE EXAMPLES

LO 8.2.A

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

EK 8.2.C.1

- Food chains/webs
- Trophic pyramids/diagrams

TOPIC 8.2
Energy Flow Through Ecosystems

Required Course Content

BIG IDEA 2

Energetics: Biological systems use energy and molecular building blocks to grow, reproduce, and maintain dynamic homeostasis.

LEARNING OBJECTIVE

8.2.A

Describe the strategies organisms use to acquire and use energy.

ESSENTIAL KNOWLEDGE

8.2.A.1

Organisms use energy to organize, grow, reproduce, and maintain homeostasis.

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

ii. A net gain in energy results in energy storage, the growth of an organism, and increased reproductive output.

iii. A net loss of energy results in loss of mass, a decrease in reproductive output, and, eventually, the death of an organism.

8.2.A.2

Different organisms use various reproductive strategies in response to energy availability. Some organisms alternate between asexual and sexual reproduction in response to energy availability.

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LEARNING OBJECTIVE	ESSENTIAL KNOWLEDGE
8.2.B Explain how energy flows and matter cycles through trophic levels.	**8.2.B.1** Ecological levels of organization include populations, communities, ecosystems, and biomes. **8.2.B.2** Energy flows through ecosystems, while matter and nutrients cycle between the environment and organisms via biogeochemical cycles. The cycles are essential for life, and each cycle demonstrates the conservation of matter. The cycles are interdependent. **8.2.B.3** Biogeochemical cycles include abiotic and biotic reservoirs, as well as processes that cycle matter between reservoirs. **8.2.B.4** The hydrologic (water) cycle involves water movement and storage within the hydrosphere. Reservoirs include oceans, surface water, the atmosphere, and living organisms. Processes include evaporation, condensation, precipitation, and transpiration. **8.2.B.5** The carbon cycle involves recycling carbon atoms through Earth's biosphere into organisms as carbohydrates and back into the atmosphere as carbon dioxide $\left(CO_2\right)$. At the highest levels of organization, the carbon cycle can be simplified into four parts: photosynthesis, cellular respiration, decomposition, and combustion. **8.2.B.6** The nitrogen cycle involves several steps, including nitrogen fixation, assimilation, ammonification, nitrification, and denitrification. These steps are performed by microorganisms in the soil. The largest reservoir of nitrogen is the atmosphere. In nitrogen fixation, nitrogen gas $\left(N_2\right)$ is fixed into ammonia $\left(NH_3\right)$, which ionizes to ammonium (NH_4^+) by acquiring hydrogen ions from the soil solution.

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LEARNING OBJECTIVE	ESSENTIAL KNOWLEDGE
8.2.B Explain how energy flows and matter cycles through trophic levels.	**8.2.B.7** The phosphorus cycle involves weathering rocks releasing phosphate $\left(PO_4^{3-}\right)$ into soil and groundwater. Producers take in phosphate, which is incorporated into biological molecules; consumers eat producers, transferring phosphate to animals. Phosphorus returns to the soil via decomposition of biomass, or excretion. Phosphate can also be incorporated back into the environment via decomposition of decaying organic matter.
8.2.C Explain how changes in energy availability affect populations, communities, and ecosystems.	**8.2.C.1** Changes in energy availability can result in changes in population size. **8.2.C.2** Changes in energy availability can result in disruptions to an ecosystem. i. A change in energy resources such as sunlight can affect the number and size of the trophic levels. Trophic levels include producers; primary, secondary, tertiary, and quaternary consumers; and decomposers. ii. A change in the biomass or number of producers in a given geographic area can affect the number and size of other trophic levels.
8.2.D Explain how the activities of autotrophs and heterotrophs enable the flow of energy within an ecosystem.	**8.2.D.1** Autotrophs capture energy from physical or chemical sources in the environment. i. Photosynthetic organisms capture energy present in sunlight contributing to primary productivity. ii. Chemosynthetic organisms capture energy from small inorganic molecules present in their environment, which can occur in the absence of oxygen. **8.2.D.2** Heterotrophs, which include carnivores, herbivores, omnivores, decomposers, and scavengers, metabolize carbohydrates, lipids, and proteins as sources of energy. Heterotrophs capture the energy present in carbon compounds by consuming organic matter derived from autotrophs incorporating matter into their tissues.

TOPIC 8.3

Population Ecology

Required Course Content

BIG IDEA 3

Information Storage and Transmission: Living systems store, retrieve, transmit, and respond to information essential to life processes.

LEARNING OBJECTIVE

8.3.A

Describe factors that influence growth dynamics of populations.

ESSENTIAL KNOWLEDGE

8.3.A.1

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

8.3.A.2

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

i. Population growth dynamics depend on birth rate, death rate, and population size.

RELEVANT EQUATION

Population Growth—

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

where

dt = chage in time

B = birth rate

D = death rate

N = population size

dN = change in population size

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SUGGESTED SKILL

Representing and Describing Data

4.A

Construct a graph to represent the data, including: x-y graphs (bar, histogram, line, log scale, dual y), scatter plot, box and whisker plot, and pie chart. The graph should include the following components:

i. type of graph appropriate for the data

ii. axis labeling, including appropriate units and legend

iii. scaling

iv. accurately plotted data (including error bars when appropriate)

v. trend line (when appropriate)

AVAILABLE RESOURCE

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

LEARNING OBJECTIVE

8.3.A

Describe factors that influence growth dynamics of populations.

ESSENTIAL KNOWLEDGE

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

RELEVANT EQUATION

Exponential Growth—

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

where

dt = change in time

N = population size

dN = change in population size

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

TOPIC 8.4

Effect of Density on Populations

SUGGESTED SKILL

Statistical Tests and Data Analysis

5.A

Perform mathematical calculations, including:

i. mathematical equations in the curriculum

ii. means

iii. rates

iv. ratios

v. percentages and percent changes

Required Course Content

BIG IDEA 4

Systems Interactions: Biological systems interact, and these systems and their interactions exhibit complex properties.

LEARNING OBJECTIVE

8.4.A

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

ESSENTIAL KNOWLEDGE

8.4.A.1

Carrying capacity is the sustainable abundance of a species that can be supported by the ecosystem's total available resources.

8.4.A.2

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

RELEVANT EQUATION

Logistical Growth—

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

where

dt = change in time

N = population size

dN = change in population size

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

K = carrying capacity

SUGGESTED SKILL

Statistical Tests and Data Analysis

5.B

Use confidence intervals and error bars to estimate whether sample means are statistically different.

TOPIC 8.5
Community Ecology

Required Course Content

BIG IDEA 2

Energetics: Biological systems use energy and molecular building blocks to grow, reproduce, and maintain dynamic homeostasis.

LEARNING OBJECTIVE	ESSENTIAL KNOWLEDGE
8.5.A Describe the structure of a community according to its species composition and diversity.	**8.5.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— Diversity Index $= 1 - \sum\left(\frac{n}{N}\right)^2$ where n = total number of organisms of a particular species N = total number of organisms of all species
8.5.B Explain how interactions within and among populations influence community structure.	**8.5.B.1** Communities are groups of interacting populations of different species that change over time based on the interactions between those populations. **8.5.B.2** Interactions among populations determine how they access energy and matter within a community.

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LEARNING OBJECTIVE

8.5.B

Explain how interactions within and among populations influence community structure.

ESSENTIAL KNOWLEDGE

8.5.B.3

Relationships among interacting populations can be characterized by positive and negative effects and can be modeled. Examples include predator/prey interactions, cooperation, trophic cascades, and niche partitioning.

8.5.B.4

Competition, predation, and symbioses, including parasitism, mutualism, and commensalism, can drive population dynamics.

SUGGESTED SKILL

Argumentation

6.E

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

TOPIC 8.6
Biodiversity

Required Course Content

BIG IDEA 4

Systems Interactions: Biological systems interact, and these systems and their interactions exhibit complex properties.

LEARNING OBJECTIVE	ESSENTIAL KNOWLEDGE
8.6.A Describe the relationship between ecosystem diversity and its resilience to changes in the environment.	**8.6.A.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. **8.6.A.2** Keystone species, producers, and essential abiotic and biotic factors contribute to maintaining the diversity of an ecosystem.
8.6.B Explain how the addition or removal of any component of an ecosystem will affect its overall short-term and long-term structure.	**8.6.B.1** The effects of keystone species on the ecosystem are disproportionate relative to their abundance in the ecosystem. When they are removed from the ecosystem, it often collapses.

TOPIC 8.7

Disruptions in Ecosystems

Required Course Content

BIG IDEA 1

Evolution: The process of evolution drives the diversity and unity of life.

LEARNING OBJECTIVE

8.7.A

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

ESSENTIAL KNOWLEDGE

8.7.A.1

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

8.7.A.2

Heterozygote advantage is when the heterozygous genotype has a higher relative fitness than either the homozygous dominant or homozygous recessive genotype.

8.7.A.3

Mutations are not directed by specific environmental pressures.

BIG IDEA 4

Systems Interactions: Biological systems interact, and these systems and their interactions exhibit complex properties.

LEARNING OBJECTIVE

8.7.B

Explain how invasive species affect ecosystem dynamics.

ESSENTIAL KNOWLEDGE

8.7.B.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 native species for resources.

SUGGESTED SKILL

Statistical Tests and Data Analysis

5.D

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

ILLUSTRATIVE EXAMPLES

EK 8.7.B.1

- Kudzu
- Zebra mussels

EK 8.7.C.1

- Dutch elm disease
- Potato blight

EK 8.7.D.1

- Global climate change
- Logging
- Urbanization
- Monocropping
- El Nino
- Continental drift
- Meteor impact on dinosaurs

LEARNING OBJECTIVE	ESSENTIAL KNOWLEDGE
8.7.C Describe human activities that lead to changes in ecosystem structure and dynamics.	**8.7.C.1** Human impact accelerates changes at local and global levels. These activities can drive changes in ecosystems, such as the following, that cause extinctions to occur: i. Biomagnification ii. Eutrophication
8.7.D Explain how geological and meteorological activity leads to changes in ecosystem structure and dynamics.	**8.7.D.1** Geological and meteorological events affect habitat change and ecosystem distribution. Biogeographical studies illustrate these changes.

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 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 and 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 Biology 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 to have a computer and projector to show computer-based animations and simulations for prelab activities or postlab 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 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 you 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 DonorsChoose and AdoptAClassroom.org.

Lab Time

It is critical that lab work be 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 to meet the time requirements identified in the course outline for laboratory 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 you 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 should be encouraged to proceed independently; by the end of the course you should only be providing minor guidance. Students should have many opportunities for postlab 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. Prelab 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 postlab 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 prelab and postlab work should be extensions of student learning in the classroom rather than discrete activities. Design prelab exercises and discussions that prepare students for each lab experience, and then follow up each investigation with a postlab discussion to debrief procedures, errors, and conclusions. Test 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 foster 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 you 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 labs 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 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
- The 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 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 a non-exhaustive list of approved 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 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 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 pp. 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:

- Learners selecting among questions and posing new questions
- Learners being directed to collect certain data
- Learners being given data and asked to analyze it
- Learners being given data and told how to analyze it
- Learners being guided in the process of formulating explanations from evidence
- Learners being directed toward areas and sources of scientific knowledge
- Learners being 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 your 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	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. Have 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 students 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, and 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	Students engage 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	Invite students to 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; also gives students the responsibility of supporting their opinions and responses using specific evidence	Divide students into two groups, and ask them to form two concentric circles. The inner circle can explain photosynthesis to students in the outer circle, and the outer circle can explain cellular respiration to students in the inner circle.
Graph and Switch	Students generate 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 should then switch papers and 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	Students respond to new material based on the results of a spinner marked into four quadrants, with the following labels: "Predict," "Explain," "Summarize," and "Evaluate." After new material is presented, the classroom spinner is spun and students answer a question based on where it lands. For example, if the spinner lands in the "Summarize" quadrant, students can respond to a prompt such as "Summarize 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	On index cards, students summarize their thoughts about a concept, lesson, unit topic, etc., on one side, and on the other side they identify something about the subject that they do not yet fully understand.	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	Students are presented with a common or predictable misconception about a concept, principle, or process. Students respond, stating whether they agree or disagree and 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	Present students with a question that can be answered in one minute that is focused on particular content.	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	Students write for a short, specific amount of time about a designated topic related to a text.	Allows students to generate 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 in writing 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	Students consider a topic or question and then write down what they've learned. They then join partners or small groups and share their ideas. Finally, each small group shares their ideas in a whole-class discussion.	Provides students an opportunity to construct meaning about a topic or question, tests thinking in relation to the ideas of others, and helps prepare students for a discussion with a larger group	When teaching about biological molecules ask students to reflect on their current understanding 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 share their answers. After a few minutes of sharing, 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 develop skills that are fundamental to the discipline of biology. These science practices represent the complex skills that adept biologists demonstrate, and students will benefit from multiple opportunities to develop the 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 and processes presented in written format.

The ability to use verbal and written explanations that describe biological processes is an important learning outcome of the AP Biology course that 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 predictions (see Practice 6). Additionally, they should be able to use their understanding to explain the results of their own investigations.

Science Practice 1: *Concept Explanation*

Skill	Task	Sample Activity	Instructional Strategy
1.A: *Describe biological concepts and processes.*	Describe characteristics, attributes, traits, and elements of biological concepts and processes. Describe the components of a process. Describe how a process occurs. Describe structures and functions.	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: *Concept Explanation (cont'd)*

Skill	Task	Sample Activity	Instructional Strategy
1.B: *Explain biological concepts and processes.*	Explain characteristics, attributes, traits, and elements of concepts and processes. 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 (such as iodine dissolved in water) move from areas of high concentration to areas of lower concentration but not vice versa.	Misconception Check
1.C: *Explain biological concepts and processes 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

Science Practice 2: Analyze visual representations of biological concepts and processes.

Visual representations are indispensable tools for learning and exploring scientific concepts and ideas. Throughout the year, students should create and use representations of increasing complexity to illustrate biological processes and concepts, communicate information, 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*

Skill	Task	Sample Activity	Instructional Strategy
2.A: *Describe characteristics of visual representations of biological concepts and processes.*	Describe the characteristics of a visual representation. Describe patterns or trends in the representation.	Have students use a visual representation of experimental results to describe the relationship between the independent and dependent variables.	Quickwrite
2.B: *Explain relationships between characteristics of biological models in both theoretical and applied contexts.*	Compare patterns and/or trends in a representation. Explain the concept a model is representing. Explain patterns and trends based on visual representation.	Provide a visual representation of the photosystems in a light dependent reaction to students and have them explain how the electron transport chain yields NADPH.	Ask the Expert
2.C: *Explain how biological models relate to larger principles, concepts, processes, systems, or theories.*	Consider how biological concepts or processes relate to larger concepts.	Have students explain how phylogenetic trees demonstrate evolutionary trends.	Construct an Argument
2.D: *Represent relationships within biological models, including mathematical models, diagrams, flowcharts, and systems.*	Diagram a biological process. Visually represent flow charts, concept maps, or pathways. Use a visual representation to explain a biological concept.	Represent how carbon flows through a particular ecosystem.	Misconception Check

Science Practice 3: Determine scientific questions and methods.

To gain a deeper understanding of concepts, students should pose, refine, and evaluate scientific questions about natural phenomena and investigate answers through experimentation, research, information gathering, and discussion. Consider the following 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, can be evaluated using data, and addressed through hypothesis testing. After identifying possible sources of error in an experimental procedure or data set, students can 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*

Skill	Task	Sample Activity	Instructional Strategy
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.	Have students discuss the scientific evidence that supports evolution by natural selection, and pose testable questions related to the evidence about how evolution works for students to answer in writing.	Quickwrite
3.B: *State the null hypothesis or predict the results of an experiment.*	State the null hypothesis. Predict the results of an experiment.	Give students an experimental scenario, and ask them to state the null hypothesis or predict the results of an experiment. Students with differing predictions can argue their case for why they think their prediction is accurate.	Debate
3.C: *Identify experimental procedures that align with the question, including:* *i. identifying dependent and independent variables* *ii. identifying appropriate controls* *iii. justifying appropriate controls*	Identify 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 variables and controls, and justify why the control is applicable to a particular experiment.	Misconception Check

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Science Practice 3: *Questions and Methods (cont'd)*

Skill	Task	Sample Activity	Instructional Strategy
3.D: *Propose a new investigation based on an evaluation of the experimental design or evidence.*	Evaluate and refine investigations related to natural phenomena, and investigate answers through experimentation, research, and information gathering and discussion.	After they evaluate a data set to identify possible sources of error in an experimental procedure, have students propose a new investigation that makes more sense to the experimental question being asked.	Debate

Science Practice 4: Represent and describe data.

The ability to analyze different types of graphs is a skill that will help students succeed in the course and on the AP Exam, as well as in their future scientific studies. Students should be able to appropriately label a graph and correctly plot data. During this course, students have the opportunity to 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 construct the appropriate graph for a given set of data. Frequent practice analyzing different types of data to identify patterns and connect variables is important for their success.

Science Practice 4: *Representing and Describing Data*

Skill	Task	Sample Activity	Instructional Strategy
4.A: *Construct a graph to represent the data, including: x-y graphs (bar, histogram, line, log scale, dual y), scatter plot, box and whisker plot, and pie chart. The graph should include the following components:* *i. type of graph appropriate for the data* *ii. axis labeling, including appropriate units and legend* *iii. scaling* *iv. accurately plotted data (including error bars when appropriate)* *v. trend line (when appropriate)*	Construct the appropriate graph for a given set of data, taking care to add all of the graphing components required.	Give students a real or hypothetical data set, as gathered from an in-class lab investigation. Ask students to identify the type of graph that should be constructed for the data set, and then graph the data.	Graph and Switch
4.B: *Describe data from a table or graph, including:* *i. identifying specific data points* *ii. describing trends and patterns in the data* *iii. 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

Graphing

Students will be expected to construct graphs to represent data. The following information will provide guidance in what will be expected of students to earn points for constructing the different types of graphs required for the course.

Bar Graphs

Bar graphs are used to visually compare two samples of categorical or discrete data. Bar graphs are also used to visually compare the calculated means with error bars of normal data (Figure 1). Many questions and investigations in biology call for a comparison of populations. If a variable is being measured across multiple groups, the most appropriate way to represent the data is likely a bar graph showing the means of the two samples with standard error indicated. In Figure 1, the sample standard error (also known as the sample error of the sample mean) is indicated by an error bar at the top of each shaded bar.

Comparison of Ivy Leaf Width Under Shady and Sunny Conditions

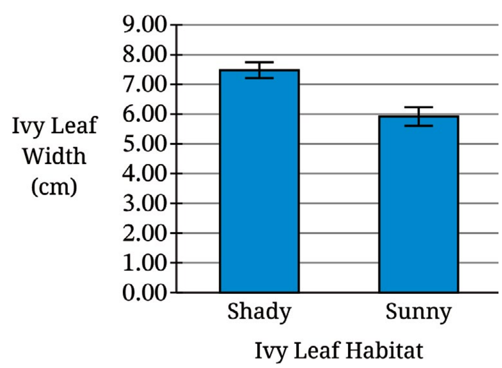

Figure 1. Bar Graph, error bars represent $\pm 2SE_{\bar{x}}$

Histograms

Histograms are used to display the distribution of data, showing the central tendencies and the spread of the data. They are different from bar graphs in that they illustrate ranges or frequencies of data within the bar, whereas bar graphs only show comparisons of categorical data. Additionally, bar graphs compare two variables while histograms show only one variable. Figure 2 is an example of a histogram that consists of uniform range intervals (e.g., 160–199, 200–239) that span the entire range of the data. If enough measurements are made, the data on a histogram can show an approximate normal distribution, or bell-shaped distribution. The normal distribution is very common in biology and is a basis for the predictive power of statistical analysis.

Diameter of Oak Tree Trunks in a Particular Forest

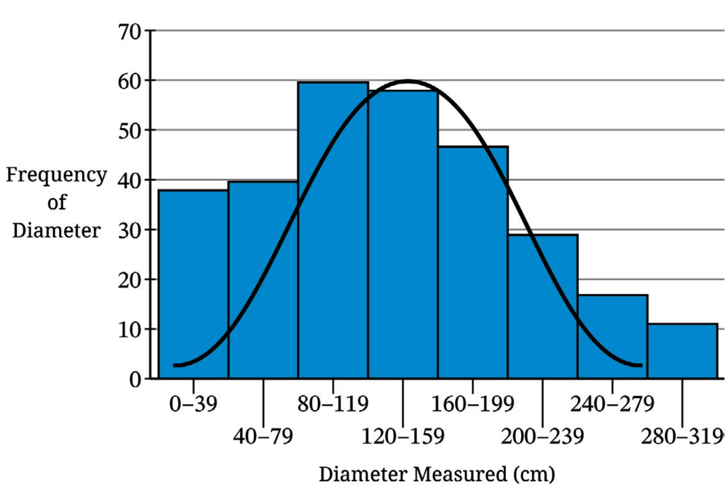

Figure 2. Histogram

Line Graphs

Line graphs (Figure 3) are used to track changes over time using a series of continuous data points as opposed to discrete data. Line graphs help to visualize relationships between variables when changes in the dependent variable are tracked over time. Data points should be clearly marked and connected by a line.

Spots on Adult Male Guppies

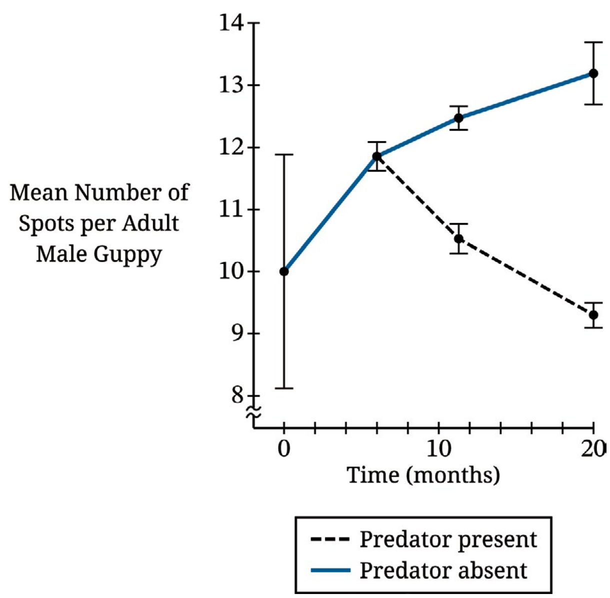

Figure 3. Line Graph (error bars represent $\pm 2SE_{\bar{x}}$)

Log Scale Graphs

Log scale graphs use a nonlinear scale to plot data that span very large quantities (Figure 4); this helps prevent the axes from being too long for the graph. This type of graph is useful for illustrating the differences between the lowest and highest points in the data.

Plant Percent Chance of Survival in Compound X

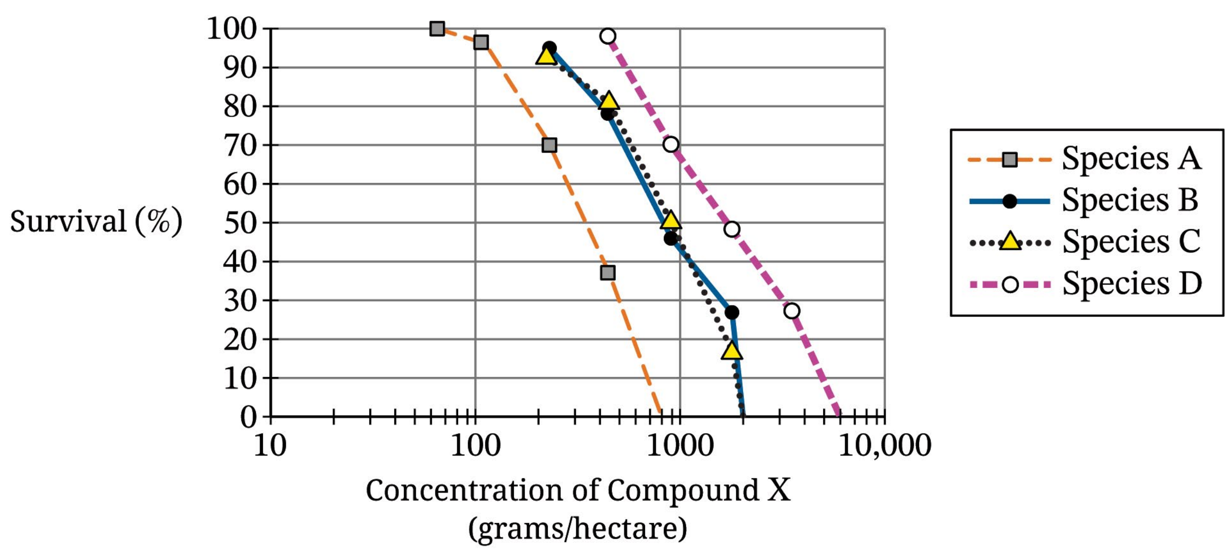

Figure 4. Log Scale Graph

Dual y-Axes Graphs

Dual y-axes graphs are used when comparing two datasets that have different units of measurement. Figure 5 is an example of a dual y-axes line graph (note that bar graphs can also have dual y-axes), which shows the proportion of a frog population infected by a parasite and the relative frog population size.

Chytridiomycosis Infection in a Frog Population

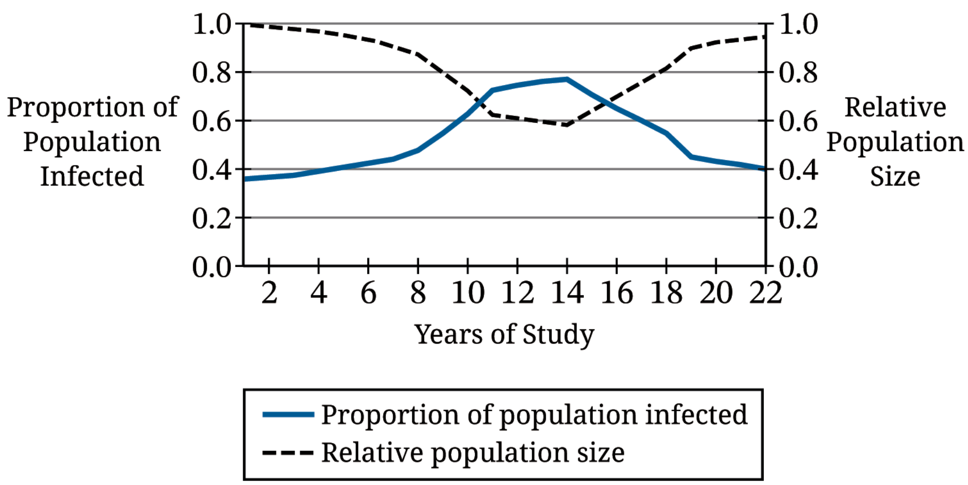

Figure 5. Line Graph with Dual y-Axes

Scatterplots

Scatterplots (Figure 6) are graphs used to visually explore associations between two variables. When comparing one measured variable to another and looking for trends, it is appropriate to plot the individual data points on an *x-y* plot, creating a scatterplot. Trend lines show the general direction (increase or decrease) in the overall data trends and can be estimated or calculated. Scatterplots can also be used to plot a manipulated independent *x*-variable against the dependent *y*-variable.

Body Temperature and Heart Rate

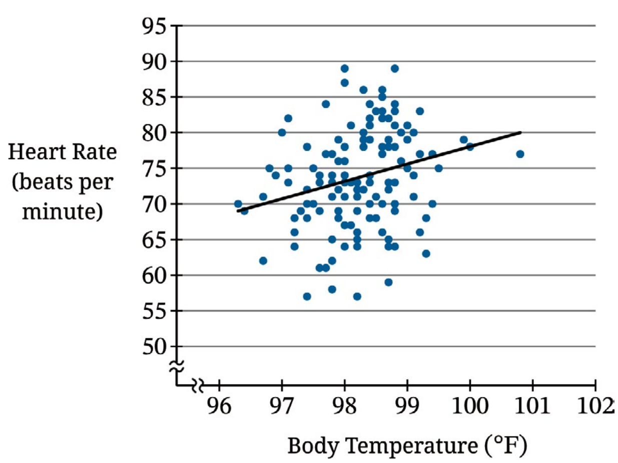

Figure 6. Scatterplot with a Trend Line

Box and Whisker Plots

Box and whisker plots allow graphical comparison of two samples of data. Figure 7 shows plotted data from Table 1. Box and whisker plots illustrate the medians and quartiles as well as the minimum and maximum data points. In the graph, the tops and bottoms of the vertical lines show the maximum and minimum values in the dataset, respectively (these are known as the whiskers). The whiskers are commonly mistaken for error bars. The top of each box shows the upper quartile, the bottom of each box shows the lower quartile, and the horizontal line within each box represents the median. The graph allows the investigator to determine at a glance, in this case, that the ash leaves appear to decay the fastest and the beech leaves take the longest to decay.

Table 1. Leaf Decay in Different Tree Species

Bag	Percent Decay per Bag		
Number	Ash	Sycamore	Beech
1	51	40	34
2	63	33	15
3	44		26
4		52	21
5	48	48	
6	32	35	11
7	70	44	19
8	48	63	32
9	57	40	

Comparison of Leaf Decay in Different Tree Species

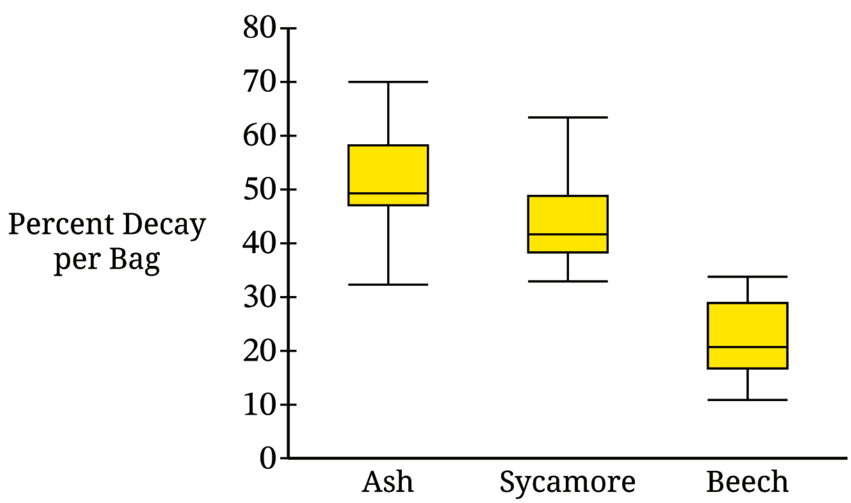

Figure 7. Box and Whisker Plot

Pie Charts

Pie charts are used for comparing different parts of a whole or percentages (Figure 8 and Figure 9). The segments in a pie chart should be representative of that part's proportion in relation to the full dataset being displayed.

Average Amount of Time Spent by a Particular Type of Eukaryotic Cell in Each Phase of the Cell Cycle

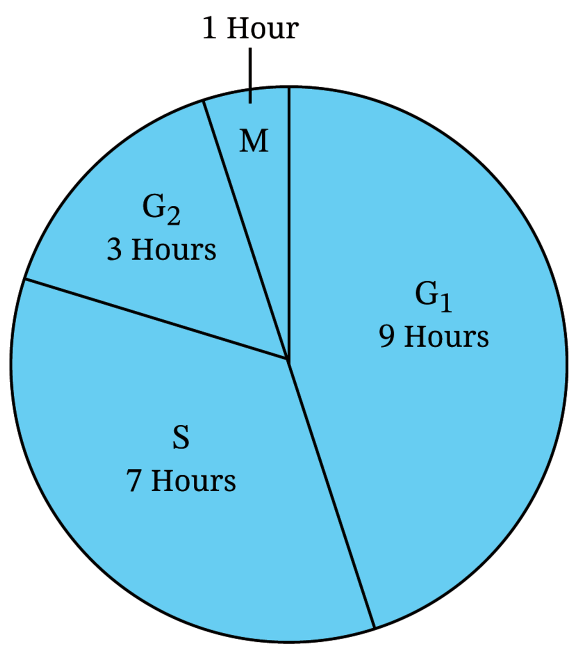

Figure 8. Cell Cycle Pie Chart

Effect of Water-Soluble Pollutants on Membrane Permeability

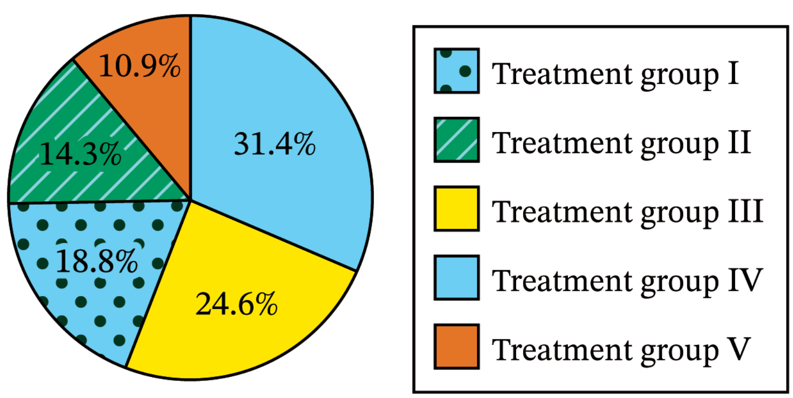

Figure 9. Water Soluble Pollutants Pie Chart

How Graphs are Scored

The second free-response question (FRQ2) on the AP Biology Exam will have a data table with which students will construct a graph. Students can earn up to three points for a correctly constructed graph. Students should be using all graphing elements listed in Skill 4.A to prepare for the AP Exam, as any element from the skill may be included in FRQ2. The question task will specify which element of Skill 4.A will be required for a given data set. While having a graph title does not earn a point, be sure students know that a graph should have a title that informs the reader about the experiment and exactly what is being measured.

The following is a list of elements AP Readers look for to determine if a graph is well-constructed:

- Skill 4.A.i: The type of graph is appropriate for the type of data plotted.
- Skill 4.A.ii: Axes must be clearly labeled as follows:
  - The x-axis shows the independent variable(s) including units.
  - The y-axis denotes the dependent variable(s) including units.
  - In some data sets, more than one condition of an experiment may be shown on a graph by the use of different styles of lines, colors, and textures. A legend must be included telling the graph reader which line or bar represents which data plotted in the graph.
- Skill 4.A.iii: Scaled intervals must be uniform. For example, if one square on the x-axis equals five units, each interval must be five units. If there is a break in the graph, it should be noted with a break in the axis and a corresponding break in the data line. It is not necessary to label each interval. Labels can identify every five or 10 intervals, or whatever is appropriate. The graph should clarify whether the data start at the origin (0,0) or not. The line should not be extended to the origin if the data do not start there. In addition, the line should not be extended beyond the last data point (extrapolation) unless a dashed line (or some other demarcation) clearly indicates that this is a prediction about what may happen.
- Skill 4.A.iv: The data plotted in a graph should be easily identifiable. Error bars must be plotted when the data table indicates data for the standard error of the mean (SEM).
- Skill 4.A.v: Trend lines are appropriate when presenting scatter plots or multiple sets of data in one graph.

Science Practice 5: Perform statistical tests and mathematical calculations to analyze and interpret data.

It is important for students to be able to routinely use mathematics to solve problems, analyze experimental data, describe natural phenomena, make predictions, and describe processes symbolically. Students should be fluent in descriptive statistics and the use of chi-square. They should also be able to justify the selection of a particular mathematical routine or statistical test and apply the routine to describe natural phenomena.

In AP Biology, students will hone their ability to analyze data collected from a scientific investigation 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, they 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, students should be able to estimate the concentration of sucrose within the potato core. Additionally, students should have practice assessing the validity of experimental evidence. Using the previous 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*

Skill	Task	Sample Activity	Instructional Strategy
5.A: *Perform mathematical calculations, including:* *i. mathematical equations in the curriculum* *ii. means* *iii. rates* *iv. ratios* *v. percentages and percent changes*	Calculate one or more components of an equation such as the Hardy–Weinberg equation. Calculate the mean of a data set. Calculate the rate of a reaction. Calculate a ratio. Calculate a percent change.	Provide students a scenario related to the Hardy–Weinberg equilibrium, and ask them to calculate allele frequencies.	Misconception Check
5.B: *Use confidence intervals and error bars to estimate whether sample means are statistically different.*	Determine if there is overlap between the bars of two or more sample means.	Provide students with varying types of data sets, both graphical and tabular. Ask students to pair up and work to determine the statistically different experimental groups within the data sets.	Think-Pair-Share

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Science Practice 5: *Statistical Tests and Data Analysis (cont'd)*

Skill	Task	Sample Activity	Instructional Strategy
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 an animal behavior lab of your choice. They should formulate the null hypothesis and then calculate the chi-square test. Once the chi-square has been calculated, students can 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 rejecting or failing to reject the null 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.	Provide students with data from an experiment that can be found on a website such as Data Nuggets. Have 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. Students will predict, explain, summarize, or evaluate other students' predictions based on the Idea Spinner.	Idea Spinner

Science Practice 6: Develop and justify scientific arguments using evidence.

By the end of this course, students should be able to write and evaluate scientific descriptions, explanations, and theories that describe biological phenomena and processes. Students should also be able to call upon current knowledge and historical experiments and draw inferences from their explorations to justify claims with evidence. To practice this, 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. Reinforce student understanding and their ability to analyze, interpret, and make predictions from a model or the data obtained in an experiment and 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*

Skill	Task	Sample Activity	Instructional Strategies
6.A: *Make a scientific claim.*	Make a scientific claim related a research scenario.	Provide half the class with a graph of a real or hypothetical data set, and the other half with a description of the experiment that produced the results. Ask the group with the graph to make a claim related to the experiment using a biological concept, then evaluate their claim as a class. Switch groups and repeat the activity.	Fishbowl
6.B: *Support a claim with evidence from biological principles, concepts, processes, and data.*	Use data, evidence, or concepts to support a claim.	Provide students with a scientific paper to read that is appropriate for their reading level and content knowledge. Have students identify the claims of the research and then support the claims with evidence in the paper. As the year progresses, you may also ask students to refute the claims using evidence from the data or from biological concepts.	Construct an Argument

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Science Practice 6: *Argumentation (cont'd)*

Skill	Task	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 a brief article related to updated thinking surrounding peppered moth evolution. Ask them to use data and biological concepts from the article to provide reasoning to justify the updated claims about peppered moth evolution.	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, 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 can then learn about the work of Schwartz and Dayhoff, who obtained experimental results to support Sagan's claim, and then explain how the results support the theory of endosymbiosis.	Construct an Argument
6.E: *Predict the causes or effects of a change in, or disruption to, one or more components in a biological system.*	Predict what happens when an organism is removed from a food web. Predict how temperature affects the rate of photosynthesis. Use a visual representation to predict how cells respond to changing salinity levels in the external environment.	Give students a sequence of DNA containing a designated mutational change, and ask them to 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 (9 pts)			
	Question 2: Interpreting and Evaluating Experimental Results with Graphing (9 pts)			
	Question 3: Scientific Investigation (4 pts)			
	Question 4: Conceptual Analysis (4 pts)			
	Question 5: Analyze Model or Visual Representation of a Biological Concept or Process (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: Cells	**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 Biology Exam in both the multiple-choice and free-response sections as detailed below.

Science Practice	Multiple-Choice Section	Free-Response Section
1: Concept Explanation	Individual and set-based multiple-choice questions will 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 point per question that assess Science Practice 1.
2: Visual Representations	Individual and 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 set-based multiple-choice questions will assess students' ability to determine scientific questions and methods. Students will need to identify a testable question, state the null hypothesis or predict the results of an experiment, identify experimental procedures, and propose new investigations.	Free-response questions 1 and 3 focus on Science Practice 3.

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Science Practice	Multiple-Choice Section	Free-Response Section
4: Representing and Describing Data	Individual and 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. Free-response question 1 also assesses this practice.
5: Statistical Tests and Data Analysis	Individual and 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 questions 1 and 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 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 points 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 4–5 questions each. 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 a 9-point question that provides students with an authentic scenario and accompanying data, presented in a table, graph, or both. This question assesses student ability to do the following in four question parts:

- Part A (1 point): Describe biological concepts, processes, or models.
- Part B (3 points): Identify experimental methods or describe data.
- Part C (3 points): Identify experimental methods, analyze data, or perform calculations.
- Part D (2 points): Make and justify predictions.

Free-response question 2: Interpreting and Evaluating Experimental Results with Graphing is a 9-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 point): Describe biological concepts, processes, or models.
- Part B (4 points): Construct the appropriate graph from the data provided.
- Part C (2 points): Analyze data, perform calculations, state a null hypothesis, or predict results of an experiment.
- Part D (2 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): State the null hypothesis or predict the results of an experiment.
- 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 of a Biological Concept or Process 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 characteristic(s) 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 qualify a claim.

> **Explain "how"** typically requires analyzing the relationship, process, pattern, position, situation, or outcome.
>
> **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.

Justify: Provide evidence to support, qualify, or defend a claim, and 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 tables of numerical values to describe biological concepts, characteristics, and/or relationships.

State (the null hypothesis): Indicate or provide a hypothesis to support or defend a claim about a scientifically testable question related to the experimental variables.

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 the 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 explains 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 23 pairs of chromosomes. Which of the following statements best predicts the consequence if correct chromosome separation did not occur during meiosis II?

   (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 information.

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 (Figure 1). 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 2.

Figure 1. Lake with an Impermeable Curtain

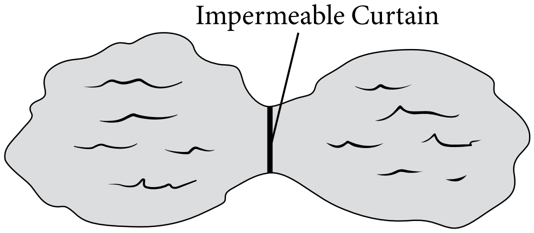
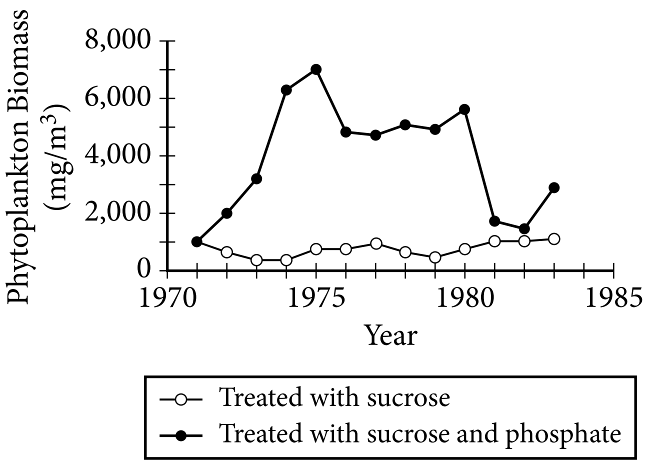


Figure 2. Phytoplankton Biomass in Two Sides of a Small Lake that is Divided by an Impermeable Curtain



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.

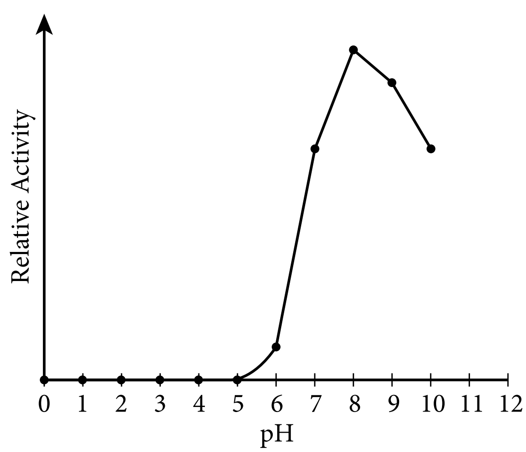
5. The average growth rate of the phytoplankton population from 1971 to 1975 in the side of the lake treated with sucrose and phosphate is closest to which of the following?
   (A) 125 (mg/m^3)/year
   (B) 1,000 (mg/m^3)/year
   (C) 1,500 (mg/m^3)/year
   (D) 6,000 (mg/m^3)/year

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 the figure.

Effect of pH on the Activity of Trypsin



Which of the following statements best explains the activity levels of trypsin shown in the figure?
   (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 increases 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.

9. Different photosynthetic organisms have different types of chlorophyll molecules. The distribution of chlorophylls in several different groups of organisms is shown in the table. A plus sign (+) in the table indicates the presence of a chlorophyll, while a minus sign (–) indicates its absence.

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	+	–	–	–

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.

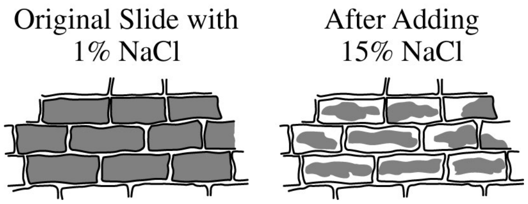
(B) Because green algae and flowering plants contain chloroplasts, they evolved more recently than brown algae, red algae, and cyanobacteria did.

(C) Because increasingly complex forms of chlorophyll are found in red algae, brown algae, green algae, and flowering plants, the evolutionary relationship among these organisms can be seen over time.

(D) Because all of the organisms contain chlorophyll *a*, the organisms share a common ancestor.

10. A student used a microscope to observe a slide of red onion 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 the figure.

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 several 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.

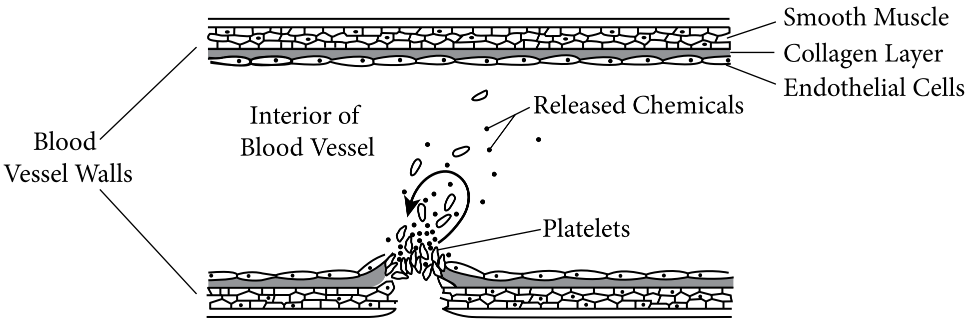
(B) The single fly species will evolve into two distinct species because of the lack of gene flow between the two populations.

(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.

14. 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 as seen in the figure.

Formation of a Platelet Plug in a Damaged Blood Vessel Wall



Which of the following best explains the feedback mechanism illustrated in the figure?

(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)

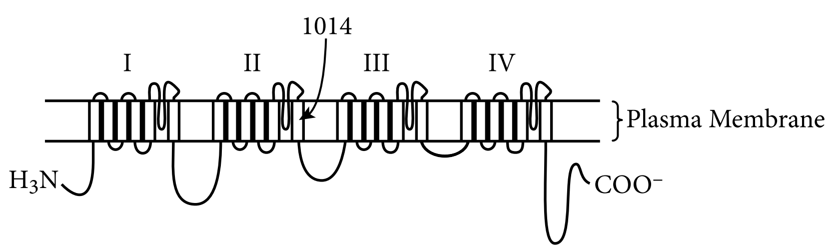
In many countries, *Anopheles gambiae* mosquitoes are responsible for transmitting the parasite that causes malaria to people through their bites. A primary tool for mosquito control is the use of insecticidal nets sprayed with chemicals known as pyrethroids, which are relatively safe for people but 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.

Part A

Describe the most likely cause of the amino acid substitution in the sodium channel protein.

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.

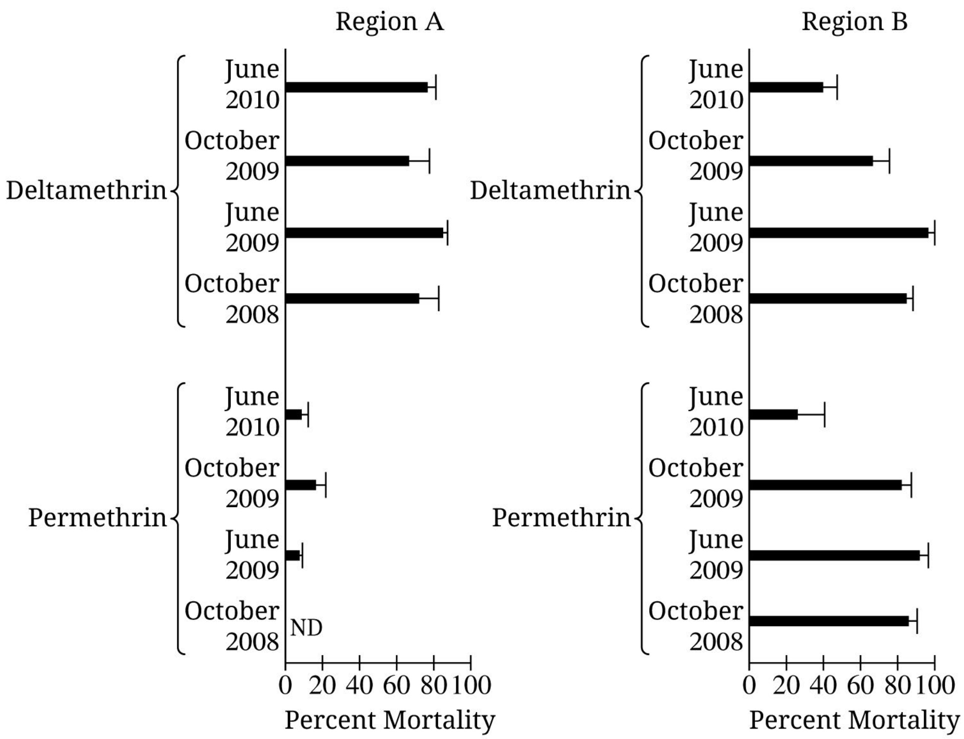


To investigate pyrethroid resistance, mosquitoes were collected four times over a two-year period from the following two regions.

- 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 as shown in the table.

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.



Part B

i. **Identify** the dependent variable in the experiment whose data are graphed in Figure 2.

ii. **Identify** the positive control in the experiment.

iii. **Justify** exposing some mosquitoes to untreated filter paper each time the experiment was performed.

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

Part C

i. 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.

ii. 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.

iii Use the data in the table 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.

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.

Part D

i. **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.

ii. Based on the data in the table and the information provided, provide evidence to **support** the scientists’ claim.

Interpreting and Evaluating Experimental Results with Graphing (Question 2 on the AP Exam)

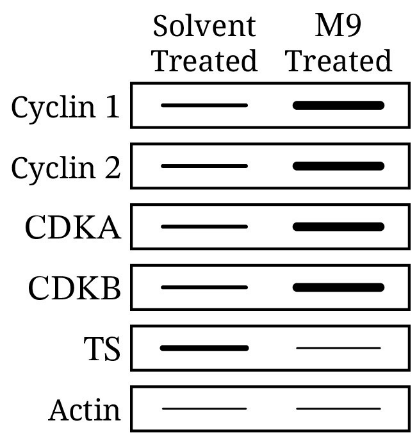
RH is a hormone that binds to the RH receptor in the plasma membrane and affects cell division. Researchers studying cancer have identified a chemical, M9, that performs the same role as RH, and they were interested in the effect of M9 on the growth of cancer cells.

Part A

Describe one property of M9 that allows it to perform the same role as RH.

In the first experiment, the researchers treated cancer cells growing in a petri dish with either solvent alone or solvent and M9. They used gel electrophoresis to determine the effect of M9 on the production of six proteins. The six proteins include two cyclin proteins (cyclin 1 and cyclin 2), two cyclin-dependent kinases (CDKA and CDKB), the tumor suppressor protein TS, and actin, a protein typically expressed equally in all cells. The thickness of the line in the figure indicates a higher concentration of protein.

Relative Amounts of Six Proteins in Cancer Cells Treated with Solvent Alone or Solvent and M9



In the second experiment, the researchers investigated the effect of M9 on apoptosis. They incubated cancer cells with either solvent alone or with increasing concentrations of M9 and then determined the percentage of cells undergoing apoptosis in each treatment group relative to the control as shown in the table.

Cells Undergoing Apoptosis After Treatment with M9

Concentration of M9	Percentage of Cells Undergoing Apoptosis, Relative to the Control ($\pm 2SE_{\bar{x}}$)
0 nM (Control)	100
50 nM	110 ± 5
200 nM	95 ± 6
1,000 nM	92 ± 3
5,000 nM	85 ± 4

Part B

i. Using the template in the space provided for your response, **construct** a bar graph that represents the data in the table. Your graph should be appropriately plotted and labeled.

ii. Based on the data in the table, **determine** which two M9 concentrations are statistically similar to one another.

Part C

i. Using the data from the figure, **describe** the effect of M9 on the production of CDK proteins.

ii. Researchers also investigated the effect of M9 on apoptosis shown in the table. Assuming there were 115,000 cells undergoing apoptosis in the control dish, use the data in the table to **calculate** the average number of cells undergoing apoptosis in the dish treated with 5,000 nM M9.

Part D

In addition to M9, researchers tested another chemical, MA6, which is known to block RH from binding to its receptor.

i. **Predict** the amount of cyclin 1 in cells treated with MA6 relative to the amount of cyclin 1 in cells treated with M9.

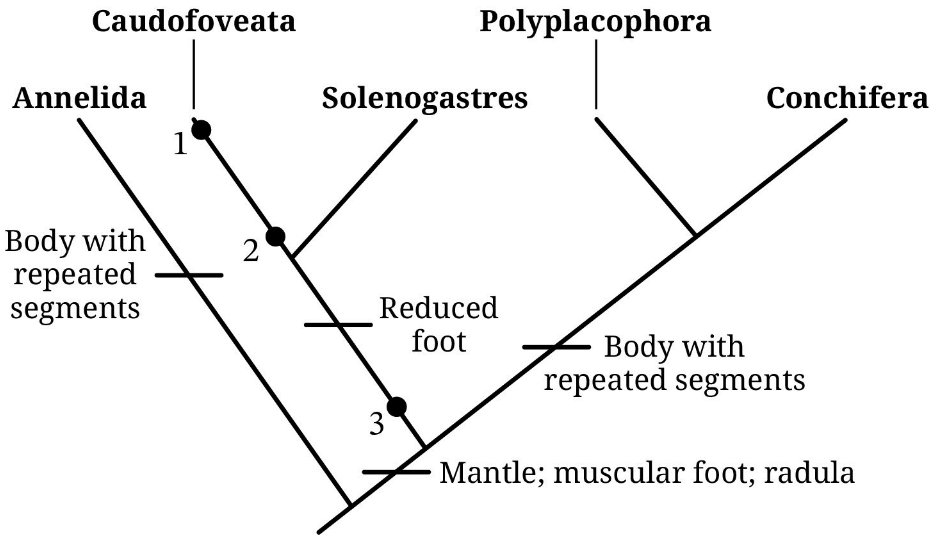
ii. **Justify** your prediction.

Analyze Model or Visual Representation of a Biological Concept or Process (Question 5 on the AP Exam)

Mollusks are a group of invertebrates that include animals such as clams, snails, and octopuses. Although their external phenotypes vary, all mollusks have three shared derived characters: the mantle, the muscular foot, and the radula.

A possible evolutionary relationship among four groups of mollusks—Caudofoveata, Solenogastres, Polyplacophora, and Conchifera—is shown in the cladogram in the figure. The cladogram also shows the relationship with Annelida as a group of invertebrates that has a lineage and is an out-group. Horizontal lines indicate the evolution of certain characters.

A Cladogram Representing a Possible Evolutionary Relationship Among Four Groups of Mollusks and One Group of Invertebrates



Part A

Describe a difference between Annelida and mollusks that defines Annelida as an out-group.

Part B

Explain how two separate lineages represented in the figure have a body with repeated segments.

Part C

Identify the number from the figure that represents a point at which the genomes of Caudofoveata and Solenogastres were most similar.

Part D

Explain how genome changes contributed to the formation of the four groups of mollusks and one group of invertebrates.

Answer Key and Question Alignment to Course Framework

Multiple-Choice Question	Answer	Skill	Learning Objective	Unit
1	A	1.C	LO 4.1.B	4
2	B	6.E	LO 5.1.A	5
3	D	3.A	LO 6.6.A	6
4	B	6.B	LO 8.3.A	8
5	C	5.A	LO 8.3.A	8
6	A	3.C	LO 8.3.A	8
7	D	6.E	LO 8.2.C	8
8	D	2.B	LO 3.2.A	3
9	D	4.B	LO 7.6.B	7
10	C	2.B	LO 2.7.A	2
11	B	1.C	LO 6.3.A	6
12	C	1.C	LO 1.3.A	1
13	B	1.C	LO 7.10.C	7
14	A	2.C	LO 4.4.A	4
15	B	6.B	LO 3.4.A	3

Free-Response Question	Question Type	Skill	Learning Objective	Unit
1	Interpreting and Evaluating Experimental Results	1.A, 3.C, 4.B, 5.A, 6.E, 6.B	LO 7.2.A, LO 7.4.A, LO 7.4.C, LO 6.7.A, LO 1.7.A	1, 6, 7
2	Interpreting and Evaluating Experimental Results with Graphing	1.A, 4.A, 5.B, 4.B, 5.A, 6.E, 6.C	LO 4.2.B, LO 4.3.A, LO 4.3.B, LO 4.6.A, LO 4.6.B	4
5	Analyze Model or Visual Representation of a Biological Concept or Process	1.A, 2.B, 2.D, 2.C	LO 7.9.A, LO 7.10.B, LO 7.9.B, LO 7.10.A, LO 7.4.A	7

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

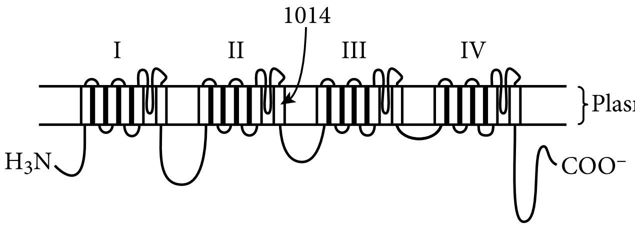
Scoring Guidelines

Question 1: Interpreting and Evaluating Experimental Results

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.

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- Region B: a northern rice-growing region where very little insecticide is applied for rice protection

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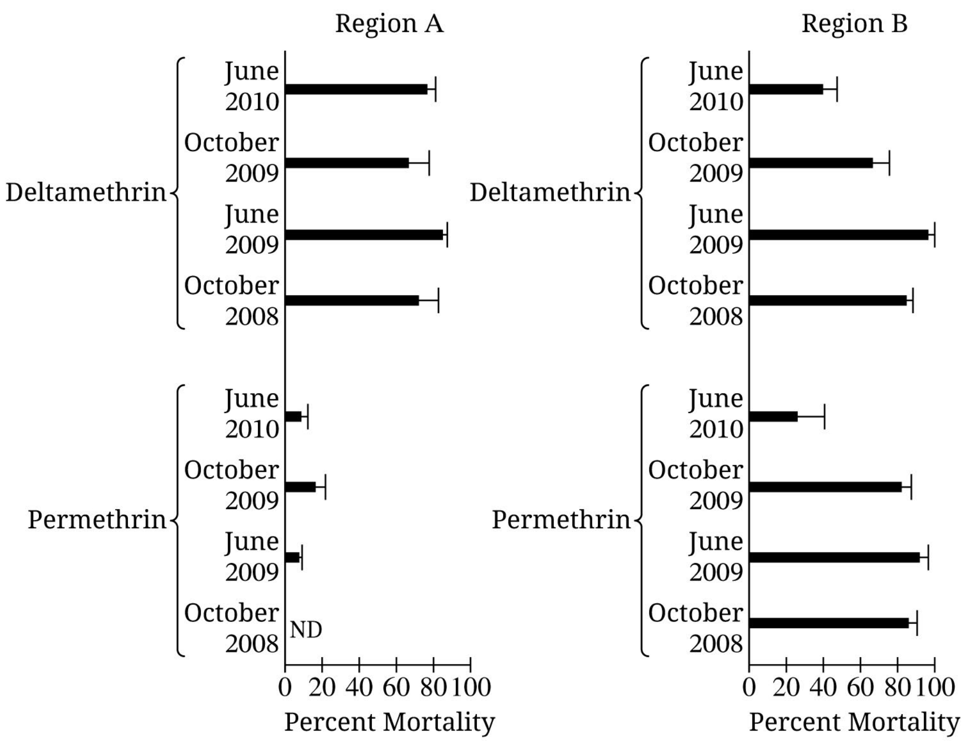

Frequencies of leucine and phenylalanine at position 1014 of the sodium channel

Region	Date	Total Mosquitoes Tested	Homozygous for Leucine	Heterozygous for Leucine and Phenylalanine	Homozygous for Phenylalanine
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Scoring Guidelines for Question 1: Interpreting and Evaluating Experimental Results — 9 points

Learning Objectives: LO 7.2.A | LO 7.4.A | LO 7.4.C | LO 6.7.A | LO 1.7.A

Part A. **Describe** the most likely cause of amino acid substitution in the sodium channel protein. — **1 point** (1.A)

- A change occurred in the DNA sequence encoding the sodium channel polypeptide.

Total for part A. — 1 point

Part B.

i. **Identify** the dependent variable in the experiment. — **1 point** (3.C)

Accept one of the following:

- Percent mortality
- Susceptibility to insecticide

ii. **Identify** the positive control in the experiment. — **1 point** (3.C)

- Testing the strain that is susceptible to the insecticides

iii. **Justification** of exposing some mosquitoes to untreated filter paper each time the experiment was performed. — **1 point** (3.C)

- Exposing mosquitoes to untreated filter paper confirms that any observed mortality is from the insecticides rather than from the filter paper itself or any other experimental conditions.

Total for part B. — 3 points

Part C.

i. **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. — **1 point** (4.B)

- Mosquitoes from region A are much more likely to survive to reproduce, so the region A mosquitoes will have greater evolutionary fitness.

ii. **Describe** any significant change in the susceptibility of mosquitoes from region B to each of the two insecticides over the two-year period. — **1 point** (4.B)

- For permethrin, there was little significant change in susceptibility until the June 2010 test, when the mosquitoes were significantly less susceptible than they had been for the previous three tests. For deltamethrin, there was a significant decrease in susceptibility from June 2009 to October 2009 and then a further significant decrease from October 2009 to June 2010.

iii. **Calculate** the frequency of the allele coding for phenylalanine in each population of mosquitoes in October 2008. Answers must be rounded to two decimal places No points are awarded for working, just answers in the acceptable range. — **1 point** (5.A)

- Mosquitoes from region A: $5 + 2(31) = 67$ and $\frac{67}{78} = 86$.

  Acceptable range is .85 – .86

- Mosquitoes from region B: $5 + 2(2) = 9$ and $\frac{9}{54} = .17$.

  Acceptable range is .16 – .17

Total for part C. — 3 points

Part D. i. 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.

1 point

3.B

Accept one of the following:

- The mosquitoes will all die.
- The mosquitoes will be 100% susceptible

---

ii. 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. Provide evidence to **support** the scientists' claim.

1 point

6.B

- The frequency of the phenylalanine allele increased from very low to much higher (OR: from 0.17 to 0.5) for population B mosquitoes that come from an area with low insecticide use. Thus insecticide use is not selecting for those mosquitoes with the phenylalanine allele; it is more likely that pyrethroid-resistant mosquitoes with the phenylalanine allele are immigrating to the area, thus increasing the frequency of the allele in the population.

Total for part D. **2 points**

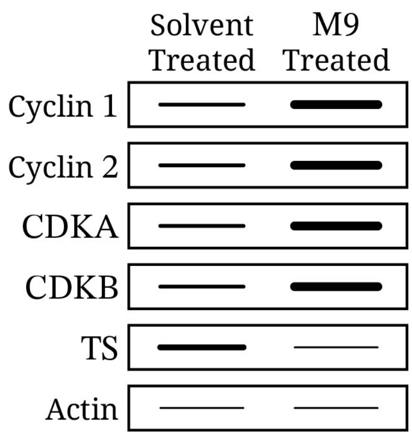
Total for question 1 **9 points**

Question 2: Interpreting and Evaluating Experimental Results with Graphing

RH is a hormone that binds to the RH receptor in the plasma membrane and affects cell division. Researchers studying cancer have identified a chemical, M9, that performs the same role as RH, and they were interested in the effect of M9 on the growth of cancer cells.

In the first experiment, the researchers treated cancer cells growing in a petri dish with either solvent alone or solvent and M9. They used gel electrophoresis to determine the effect of M9 on the production of six proteins. The six proteins include two cyclin proteins (cyclin 1 and cyclin 2), two cyclin-dependent kinases (CDKA and CDKB), the tumor suppressor protein TS, and actin, a protein typically expressed equally in all cells. The thickness of the line in the figure indicates a higher concentration of protein.

Relative Amounts of Six Proteins in Cancer Cells Treated with Solvent Alone or Solvent and M9



In the second experiment, the researchers investigated the effect of M9 on apoptosis. They incubated cancer cells with solvent alone or with increasing concentrations of M9 and then determined the percentage of cells undergoing apoptosis in each treatment group relative to the control as shown in the table.

Cells Undergoing Apoptosis After Treatment with M9

Concentration of M9	Percentage of Cells Undergoing Apoptosis, Relative to the Control ($\pm 2SE_{\bar{x}}$)
0 nM (Control)	100
50 nM	110 ± 5
200 nM	95 ± 6
1,000 nM	92 ± 3
5,000 nM	85 ± 4

Scoring Guidelines for Question 2: Interpreting and Evaluating Experimental Results with Graphing — 9 points

Learning Objectives: LO 4.2.B LO 4.3.A LO 4.3.B LO 4.6.A LO 4.6.B

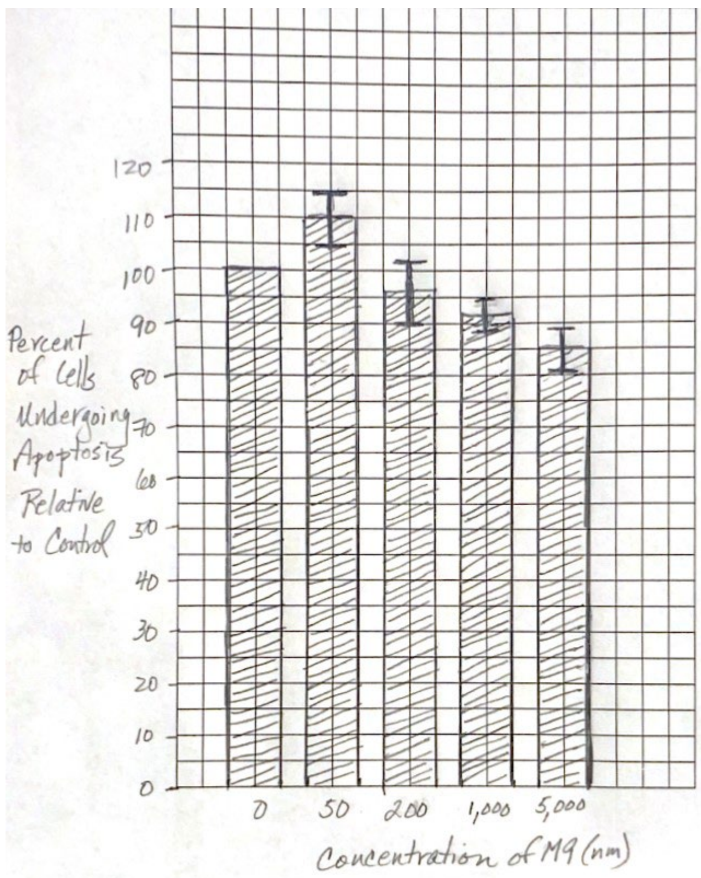
Part A. **Describe** one property of M9 that allows it to perform the same role as RH. — **1 point** (1.A)

- M9 has a structure that can bind to and activate the RH receptor.

Total for part A. **1 point**

Part B. i. Using the template in the space provided for your response, **construct** a bar graph that represents the data in the table. Your graph should be appropriately plotted and labeled. — **1 point** (4.A)

Sample response:



- Data are represented in a bar graph.

i. Using the template in the space provided for your response, **construct** a bar graph that represents the data in the table. Your graph should be appropriately plotted and labeled. — **1 point** (4.A)

- Data and error bars are accurately plotted.

i. Using the template in the space provided for your response, **construct** a bar graph that represents the data in the table. Your graph should be appropriately plotted and labeled. — **1 point** (4.A)

- Graph includes labeled axes and legend.

ii. Based on the data in the table, **determine** which two M9 concentrations are statistically similar to one another. — **1 point** (5.B)

- 200 nM and 1,000 nM

Total for part B. **4 points**

Part C. i. Using the data from the figure, **describe** the effect that M9 has on the production of CDK proteins. **1 point** 4.B

- M9 causes the production of CDK proteins to increase.

ii. Researchers also investigated the effect of M9 on apoptosis in the table. Assuming there were 115,000 cells undergoing apoptosis in the control dish, use the data in the table to **calculate** the average number of cells undergoing apoptosis in the dish treated with 5,000 nM M9. **1 point** 5.A

- 97,750 (Acceptable range is 93,150 - 102,350)

Total for part C. 2 points

Part D. i. In addition to M9, researchers tested another chemical, MA6, which is known to block RH from binding to its receptor. **Predict** the amount of cyclin 1 in cells treated with MA6 relative to the amount of cyclin 1 in cells treated with M9. **1 point** 6.E

- The amount of cyclin 1 will be lower in cells treated with MA6 (than in cells treated with M9).

ii. **Justify** your prediction. **1 point** 6.C

- If the signal cannot bind to the receptor, the pathway that leads to an increase in cyclin 1 expression cannot be activated.

Total for part D. 2 points

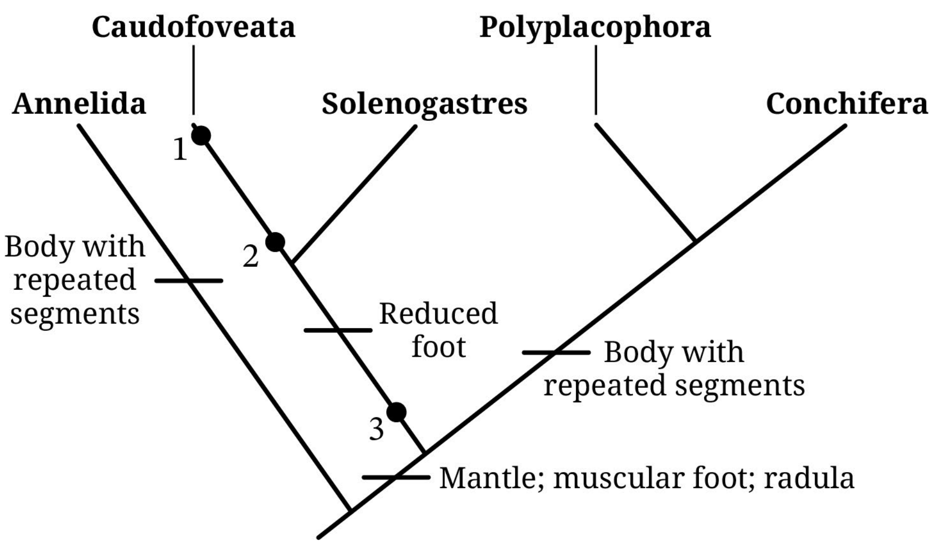
Total for question 2 9 points

Question 5: Analyze Model or Visual Representation of a Biological Concept or Process

Mollusks are a group of invertebrates that include animals such as clams, snails, and octopuses. Although their external phenotypes vary, all mollusks have three shared derived characters: the mantle, the muscular foot, and the radula.

A possible evolutionary relationship among four groups of mollusks—Caudofoveata, Solenogastres, Polyplacophora, and Conchifera—is shown in the cladogram in the figure. The cladogram also shows the relationship with Annelida as a group of invertebrates that has a lineage and is an out-group. Horizontal lines indicate the evolution of certain characters.

A Cladogram Representing a Possible Evolutionary Relationship Among Four Groups of Mollusks and One Group of Invertebrates



Scoring Guidelines for Question 5: Analyze Model or Visual Representation of a Biological Concept or Process — 4 points

Learning Objectives: LO 7.9.A LO 7.10.B LO 7.9.B LO 7.10.A LO 7.4.A

Part A.	**Describe** a difference between Annelida and mollusks that defines Annelida as an out-group. Accept one of the following: ▪ Annelida lacks a mantle (while mollusks have a mantle). ▪ Annelida lacks a muscular foot (while mollusks have a muscular foot). ▪ Annelida lacks a radula (while mollusks have a radula).	**1 point** 1.A
Part B.	**Explain** how two separate lineages represented in the figure have a body with repeated segments. Accept one of the following: ▪ This character arose independently (in each lineage) because of similar environmental selective pressures/convergent evolution. ▪ Individuals in each of the two lineages developed this character due to (one or more) mutations, then the character was favored by selective pressures/because of convergent evolution.	**1 point** 2.B
Part C.	**Identify** the number from the figure that represents a point at which the genomes of Caudofoveata and Solenogastres were most similar. ▪ 2	**1 point** 2.D
Part D.	**Explain** how genome changes contributed to the formation of the four groups of mollusks and one group of invertebrates. Accept one of the following: ▪ Changes in the genome lead to reproductive isolation between the populations. ▪ Random mutations occurred in organisms that were exposed to different selective pressures, and the mutations that provided advantageous traits in different environments became fixed.	**1 point** 2.C
	Total for question 5	**4 points**

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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

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 = frequency of allele 1 in a population

$p + q = 1$ q = frequency of allele 2 in a population

$\bar{x}$ = 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

$\sum$ = sum of all

Degrees of freedom are equal to the number of distinct possible outcomes minus one.

Metric Prefixes

Factor	Prefix	Symbol
10^9	giga	G
10^6	mega	M
10^3	kilo	k
10^{-1}	deci	d
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

dN = change in population size

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 $(°C + 273)$

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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