



SPRINGFIELD PUBLIC SCHOOLS

**ENGAGING STUDENTS • FOSTERING ACHIEVEMENT • CULTIVATING 21ST CENTURY
GLOBAL SKILLS**

**Springfield Public Schools
Springfield, New Jersey 07081**

**AP Biology
Grades 11 & 12**

Curriculum Manual

2026

**This curriculum may be modified through varying materials, techniques, and
strategies as per an individual student's IEP.**

*Springfield Board of Education
Approved on July 27, 2026*

Springfield Public Schools

Cultivating compassionate and extraordinary learners!

EXTRACT OF THE MINUTES OF A MEETING OF
THE BOARD OF EDUCATION OF
THE TOWNSHIP OF SPRINGFIELD
COUNTY OF UNION, NEW JERSEY
AS RECORDED IN THE OFFICIAL MINUTE BOOK

Resolution: 21

Introduced By: Mrs. Gamarekian

Seconded By: Vice President Rinaldi

Adopted: July 27, 2026

Curriculum Adoption

To approve the following new and revised curriculum and courses for the 2026-2027 school year:

1. High School Courses

- a. AP Cybersecurity (new course)
- b. AP Business with Personal Finance (new course)
- c. AP Biology
- d. AP Chemistry
- e. AP Physics 1
- f. PLTW Robotics and Automation
- g. PLTW Introduction to Engineering Design
- h. PLTW Principles of Engineering
- i. Biology
- j. Biology Honors
- k. Chemistry
- l. Chemistry Honors
- m. Conceptual Physics
- n. Physics
- o. Environmental Science
- p. Forensics
- q. Human Anatomy and Physiology
- r. Oceanography
- s. Science 8
- t. Molecular Biology Research Lab (new course)

2. Middle School Courses

- a. Science 6
- b. Science 7

3. Elementary School Courses

- a. Kindergarten Science
- b. Grade 1 Science
- c. Grade 2 Science

Michelle Calas, School Business Administrator/Board Secretary

(continued)

I, Michelle Calas, School Business Administrator/ Board Secretary of the Springfield Board of Education, hereby certify that the extract from the minutes of a meeting of the Board of Education duly called and held on July 27, 2026 has been compared by me with the original minute book of said Board of Education, and is a true, complete and exact copy thereof, as far as the same relates to the subject matter to on said extract.

In WITNESS THEREOF, I have hereunto set my hand and seal of the Springfield Board of Education, this 28th day of July 2026.

SEAL

A handwritten signature in black ink, appearing to read 'Michelle Calas', is written over a horizontal line.

Michelle Calas
School Business Administrator/ Board Secretary



**Springfield Public Schools
Springfield, New Jersey**

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Superintendent of Schools**

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Introduction

This template is the product of an initiative led by the New Jersey Department of Education, Office of Academic Standards, in partnership with the New Jersey Association for Supervision and Curriculum Development (NJASCD) and the New Jersey Principals and Supervisors Association (NJPSA). The project was undertaken with the assistance of New Jersey content area supervisors, curriculum coordinators, and teachers during spring-summer 2009. The goal of the project was to design exemplar unit plans and accompanying lesson plans aligned with the New Jersey Student Learning Standards that may be used by districts as models for the development of local curricula.

The Unit Overview Template, which follows, is a tool that can help districts define one unit plan of several that comprise a specific course in the curriculum for any content area. It is designed, once completed, to summarize the content and objectives for the unit, outline lessons and assessments that support the unit, and provide links to documents that facilitate delivery of the unit, such as student materials, background information, resources, and performance rubrics. To see how the units fit together in the design of a course, see the Curriculum Design Template included at the end of this document.

Seven content area Unit Overviews were created as part of the project to serve as exemplar unit plans that are aligned with the New Jersey Student Learning Standards and that assist in achieving the goal of engaging students, fostering achievement, and cultivating 21st century global skills. The units stress the integration of 21st century themes and skills, global perspectives, technology, and cross-curricular connections.

We encourage districts to use the exemplars in conjunction with the curriculum development tools and templates that emanated from this project as models for teaching and learning based on the New Jersey Student Learning Standards.



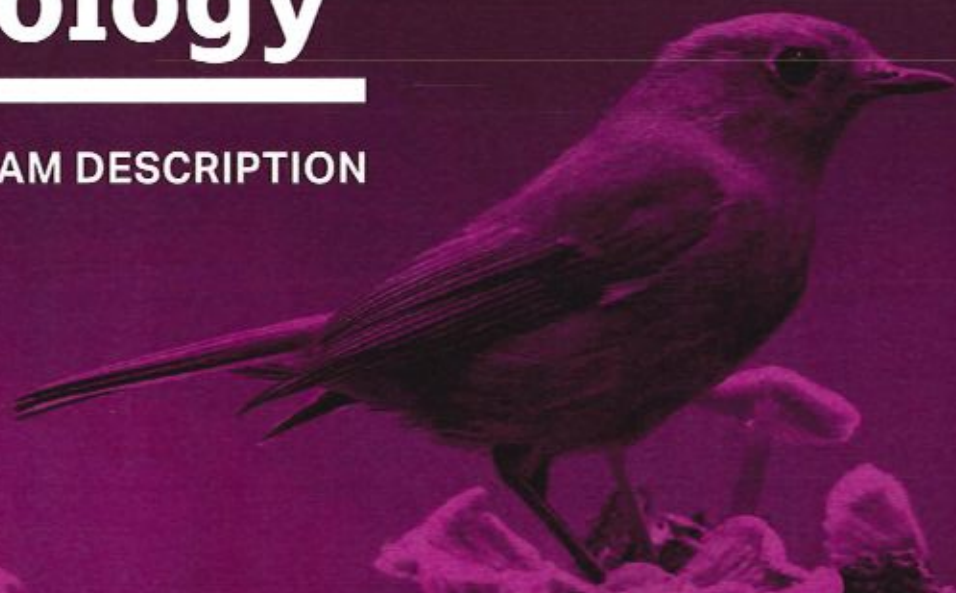
INCLUDES

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

AP[®] Biology

COURSE AND EXAM DESCRIPTION

Effective
Fall 2025





AP[®] Biology

COURSE AND EXAM DESCRIPTION

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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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 multiple-choice questions are scored by machine, the free-response questions and through-course performance

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

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

- The number of points successful college students earn when their professors administer AP Exam questions to them.
- 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.

AP BIOLOGY

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.

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.



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:

- identifying dependent and independent variables
- identifying appropriate controls
- justifying appropriate controls

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

**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:

- type of graph appropriate for the data
- axis labeling, including appropriate units and legend
- scaling
- accurately plotted data (including error bars when appropriate)
- trend line (when appropriate)

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

- identifying specific data points
- describing trends and patterns in the data
- describing relationships between variables

5.A Perform mathematical calculations, including:

- mathematical equations in the curriculum
- means
- rates
- ratios
- 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	Unit 2	Unit 3	Unit 4	Unit 5	Unit 6	Unit 7	Unit 8
	Chemistry of Life	Cells	Cellular Energetics	Cell Communication and Cell Cycle	Heredity	Gene Expression and Regulation	Natural Selection	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 | 4 Representing and Describing Data |
| 2 Visual Representations | 5 Statistical Tests and Data Analysis |
| 3 Questions and Methods | 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

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

UNIT 2

Cells

~14-16

Class Periods

10-13%

AP Exam Weighting

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 1

Multiple-Choice: ~24 questions

Free-Response: 2 questions

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

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** 3.1 Enzymes
- 3**
- 6** 3.2 Environmental Impacts on Enzyme Function
- 6**
- 6** 3.3 Cellular Energy
- 6**
- 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**
- 1** 4.2 Introduction to Signal Transduction
- 6**
- 6** 4.3 Signal Transduction Pathways
- 6**
- 6** 4.4 Feedback
- 4** 4.5 Cell Cycle
- 5**
- 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**
- 3** 5.2 Meiosis and Genetic Diversity
- 5** 5.3 Mendelian Genetics
- 6**
- 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

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^h LESSON PERIODS ~9–11 CLASS PERIODS

Chemistry of Life

Developing Understanding

This first unit sets the foundation for students to understand the chemical basis of life, which is needed for mastery of future areas of focus and provides students with a survey of the elements necessary for carbon-based systems to function. Students learn that water and the properties of water play a vital role in the survival of all cells and biological systems. They also learn that living systems exist in a dynamic, complex organization that requires input of energy and the exchange of materials. This unit also addresses in detail how and in what concentrations molecules and ions are transported across membranes. The structure of macromolecules and polymers, together with function, is the unit that follows, which is a detailed understanding of the structure and function of biological molecules.

Building Science Practices

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.

Preparing for the AP Exam

The AP Biology Exam requires students to make predictions and justify their reasoning with solid evidence. Students are expected to interpret and evaluate experimental results, analyze biological concepts, and use the investigation and pattern data analysis and statistical testing.

Attention to detail is critical for students to understand that all biological systems depend on relationships that, when compromised, can have far-reaching consequences within the system. These consequences can sometimes be addressed 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 protease. This confusion often results in a failure to earn points on free-response questions. Help students become familiar with the proper use of appropriate terminology throughout the course.

BIG IDEA 2
Evolution
• What is the role of energy in the mixing and breaking of polymers?

BIG IDEA 3
Information Storage and Processing
• How do living systems transmit information in order to process their environment?

BIG IDEA 4
Systems Interactions
• How do living systems function without the polarity of the water molecule?

AP Biology Course and Exam Description Course Framework V.1 | 28

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 Skills	Class Periods ~9–11 (4–6 lessons)
1.1 Structure of Water and Hydrogen Bonding	1.1 Describe characteristics of visual representations of biological concepts and processes.	
1.2 Elements of Life	1.2 Describe characteristics of visual representations of biological concepts and processes.	
1.3 Introduction to Macromolecules	1.3 Describe characteristics of visual representations of biological concepts and processes.	
1.4 Carbohydrates	1.4 Describe biological concepts and processes.	
1.5 Lipids	1.5 Predict the causes or effects of a change in, or duration to, one or more components in a biological system.	
1.6 Nucleic Acids	1.6 Describe characteristics of visual representations of biological concepts and processes.	
1.7 Proteins	1.7 Predict the causes or effects of a change in, or duration to, one or more components in a biological system.	

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

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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

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.

UNIT
1

Activity	Topic	Sample Activity
1	1.1	Graph and Switch Have students determine how many drops of water can fit on a penny. They can add various substances to a 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 groups with a partner to compare and discuss findings.
2	1.2	Index Card Summaries/Questions Have students use diagrams of water places, amino acids, nucleotides, glycerol, and fatty acids to learn how different molecules build molecules. Read the diagrams out loud and give the summaries on colored paper so that students can easily differentiate water from the various monomers in order to understand the formation of the macromolecules. Then, ask students to respond to each diagram using index cards to summarize their understanding of each with any additional questions.
3	1.4	Think-Pair-Share Distribute cards containing pictures of biological molecules to students and ask them to find partners in the room. They should identify the building blocks, functional groups, and monomers and name them on each card and then organize the cards based on similarities in their structures. After class, have the students exchange cards and have them pair up with another student and identify each of the molecules on the cards with their classmates.

AP Biology Course and Exam Description

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

UNIT 8

Ecology

TOPIC 8.1

Responses to the Environment

Required Course Content

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

LEARNING OBJECTIVE
2.B.1 Explain how the behavioral and physiological responses of an organism are related to changes in internal or external environments.

ESSENTIAL KNOWLEDGE
2.B.1.A Organisms respond to changes in their environment through behavioral and physiological mechanisms.
2.B.1.B Feedback statements—Knowledge of specific behavioral or physiological mechanisms is beyond the scope of the AP Exam.
2.B.1.C Organisms exchange information with one another in response to internal changes and external cues, which can change behavior.

ILLUSTRATIVE EXAMPLES
BEHAVIOR
• Migration and phototaxis in plants
• Taxa and species in animals
• Nocturnal and diurnal activity
PHYSIOLOGY
• Temperature response
• Predator avoidance
• Plant responses to herbivory
CELLULAR
• Seasonal marking in mammals
• Cooperation in flowering plants and animals
• Bird song
• Fly behavior in animals
• Predator avoidance

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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)

Chemistry of Life



Developing Understanding

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?

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.

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.		

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.

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.

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

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



ILLUSTRATIVE EXAMPLES

EK 1.4.A.1

- Cellulose
- Starch
- Glycogen

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.*

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.

- Saturated fatty acids contain only single bonds between carbon atoms.
- Unsaturated fatty acids contain at least one double bond between carbon atoms, which causes the carbon chain to kink.
- The more double bonds in a fatty acid tail, the more unsaturated the lipid becomes.
- 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.

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**1.6.A**

Describe the structure and function of DNA and RNA.

ESSENTIAL KNOWLEDGE**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

1.7.A

Describe the structure and function of proteins.

ESSENTIAL KNOWLEDGE

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 ($-\text{COOH}$) of one amino acid and an amine group ($-\text{NH}_2$) 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.

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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)

Cells



Developing Understanding

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?

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 5.A 5.B 5.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
2.1 Cell Structure and Function	1.A Describe biological concepts and processes. 6.A Make a scientific claim.	~14–16 CLASS PERIODS
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)*

		Class Periods
Topic	Suggested Skills	~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

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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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

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.

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

- Correctly folding and chemically modifying newly synthesized cellular products
- 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:

- mathematical equations in the curriculum
- means
- rates
- ratios
- 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

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

$$\text{Volume of a Cube: } V = s^3$$

$$\text{Volume of a Rectangular Solid: } V = lwh$$

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

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

$$\text{Surface Area of a Cube: } SA = 6s^2$$

$$\text{Surface Area of a Rectangular Solid:}$$

$$SA = 2lh + 2lw + 2wh$$

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

r = radius

l = length

h = height

w = width

s = length of one side of a cube

continued on next page

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

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.B

Describe the fluid mosaic model of cell membranes.

ESSENTIAL KNOWLEDGE

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.

- Hydrophilic regions of the proteins are either inside the interior of the protein or exposed to the cytosol (cytoplasm).
- Hydrophobic regions of proteins make up the protein surface that interacts with the fatty acids in the interior membrane.

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

2.4.A

Explain how the structure of biological membranes influences selective permeability.

2.4.B

Describe the role of the cell wall in maintaining cell structure and function.

ESSENTIAL KNOWLEDGE

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.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

2.5.A

Describe the mechanisms that organisms use to maintain solute and water balance.

2.5.B

Describe the mechanisms that organisms use to transport large molecules across the plasma membrane.

ESSENTIAL KNOWLEDGE

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.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.

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

- type of graph appropriate for the data
- axis labeling, including appropriate units and legend
- scaling
- accurately plotted data (including error bars when appropriate)
- 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

2.7.A

Explain how concentration gradients affect the movement of molecules across membranes.

2.7.B

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

ESSENTIAL KNOWLEDGE

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.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:

$$\psi_s = -iCRT \text{ where:}$$

i = ionization constant

C = molar concentration

R = pressure constant

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

T = temperature in Kelvin ($^{\circ}\text{C} + 273$)

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.

- Membrane proteins are necessary for active transport.
- 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**2.9.A**

Describe the membrane-bound structures of the eukaryotic cell.

2.9.B

Explain how internal membranes and membrane-bound organelles contribute to compartmentalization of eukaryotic cell functions.

ESSENTIAL KNOWLEDGE**2.9.A.1**

Membranes and membrane-bound organelles in eukaryotic cells compartmentalize intracellular metabolic processes and specific enzymatic reactions.

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)

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
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	~12–14 CLASS PERIODS
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:

- identifying dependent and independent variables
- identifying appropriate controls
- 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**3.1.A**

Explain how enzymes affect the rate of biological reactions.

ESSENTIAL KNOWLEDGE**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

3.2.A

Explain how changes to the structure of an enzyme may affect its function.

ESSENTIAL KNOWLEDGE

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.

- 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.
- 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

3.2.B

Explain how the cellular environment affects enzyme activity.

ESSENTIAL KNOWLEDGE

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.

- Energy input must exceed energy loss to maintain order and to power cellular processes.
- Cellular processes that release energy may be coupled with cellular processes that require energy.
- 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**3.3.B**

Explain how shared, conserved, and fundamental processes and features support the concept of common ancestry for all organisms.

ESSENTIAL KNOWLEDGE**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).

- Photosynthetic organisms capture energy from the sun and produce sugars that can be used in biological processes or stored.
- Photosynthesis first evolved in prokaryotic organisms.
- Scientific evidence supports the claim that prokaryotic (cyanobacterial) photosynthesis was responsible for the production of an oxygenated atmosphere.
- Prokaryotic photosynthetic pathways were the foundation of eukaryotic photosynthesis.

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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.

3.4.B

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

ESSENTIAL KNOWLEDGE

3.4.A.2

Stroma and thylakoids are found within the chloroplast.

- 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.
- The thylakoid membranes contain chlorophyll pigments organized into two photosystems, as well as electron transport proteins.
- 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.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.

continued on next page

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:

- the type of graph appropriate for the data
- axis labeling, including appropriate units and legend
- scaling
- accurately plotted data (including error bars when appropriate)
- 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.

- In cellular respiration, electrons delivered by NADH and FADH₂ 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

Cell Communication and Cell Cycle



Developing Understanding

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?

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

4.1.A

Describe the ways that cells can communicate with one another.

4.1.B

Explain how cells communicate with one another over short and long distances.

ESSENTIAL KNOWLEDGE

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.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

4.2.A

Describe the components of a signal transduction pathway.

4.2.B

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

ESSENTIAL KNOWLEDGE

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.1

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

- The ligand-binding domain of a receptor recognizes a specific chemical messenger, which can be a peptide (protein) or a small molecule.
- G protein-coupled receptors are an example of a receptor protein in eukaryotes.
- 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.

- 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.
- 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.

- The cell cycle consists of sequential stages of interphase (G₁, S, G₂), mitosis, and cytokinesis.
- G₁ phase: The cell is metabolically active, duplicating organelles and cytosolic components.
- S phase: DNA is in the form of chromatin and replicates to form two sister chromatids connected at a centromere.
- G₂ phase: Protein synthesis occurs, ATP is produced in large quantities, and centrosomes replicate.
- 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.
- 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:

- identifying specific data points
- describing trends and patterns in the data
- describing relationships between variables

 *Statistical Tests and Data Analysis*

5.A

Perform mathematical calculations, including:

- mathematical equations in the curriculum
- means
- rates
- ratios
- 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

4.6.A

Describe the role of checkpoints in regulating the cell cycle.

4.6.B

Describe the effects of disruptions to the cell cycle on the cell or organism.

ESSENTIAL KNOWLEDGE

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.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

The icon consists of a white circle containing a blue square with the letters 'AP' in white. Below the square is a small blue icon of a computer monitor.

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

Heredity



Developing Understanding

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?

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 3.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:

- 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.
- Metaphase I:** Meiotic spindle fibers align homologous pairs of chromosomes along the equator of the cell at the metaphase plate.
- Anaphase I:** Homologous chromosomes separate, while sister chromatids remain attached, as meiotic spindle fibers pull chromosomes toward poles.
- 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

5.1.A

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

5.1.B

Describe similarities and differences between the phases and outcomes of mitosis and meiosis.

ESSENTIAL KNOWLEDGE

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.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.

- Rules of probability can be applied to analyze the passing of single-gene traits from parent to offspring.
- Monohybrid, dihybrid, and test crosses can be used to determine whether alleles are dominant or recessive.
- 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.
- 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.

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

- mathematical equations in the curriculum
- means
- rates
- ratios
- 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.



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

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).

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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

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 5.A 5.B 5.D 5.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
6.1 DNA and RNA Structure	1.C Explain biological concepts and processes in applied contexts.	~18–20 CLASS PERIODS
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.

6.1.B

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

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.

- Prokaryotic organisms typically have circular chromosomes.
- 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.

6.1.B.1

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

- Purines (guanine and adenine) have a double ring structure.
- Pyrimidines (cytosine, thymine, and uracil) have a single ring structure.
- 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.

- DNA is synthesized in the 5' to 3' direction.
- Replication is a semiconservative process, meaning one strand of DNA serves as the template for a new strand of complementary DNA.
- Helicase unwinds the DNA strands.
- Topoisomerase relaxes supercoiling in front of the replication fork.
- DNA polymerase requires RNA primers to initiate DNA synthesis.
- DNA polymerase synthesizes new strands of DNA continuously on the leading strand and discontinuously on the lagging strand.
- Ligase joins the fragments on the lagging strand.

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.

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

- Translation is initiated when the rRNA in the ribosome interacts with the mRNA at the start codon (AUG, coding for the amino acid methionine).
- The sequence of nucleotides on the mRNA is read in triplets, called codons.
- 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.
- 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.

- Observable cell differentiation results from the expression of genes for tissue-specific proteins.
- Induction of transcription factors during development results in sequential gene expression.
- The function and amount of gene products determine the phenotype of organisms.

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