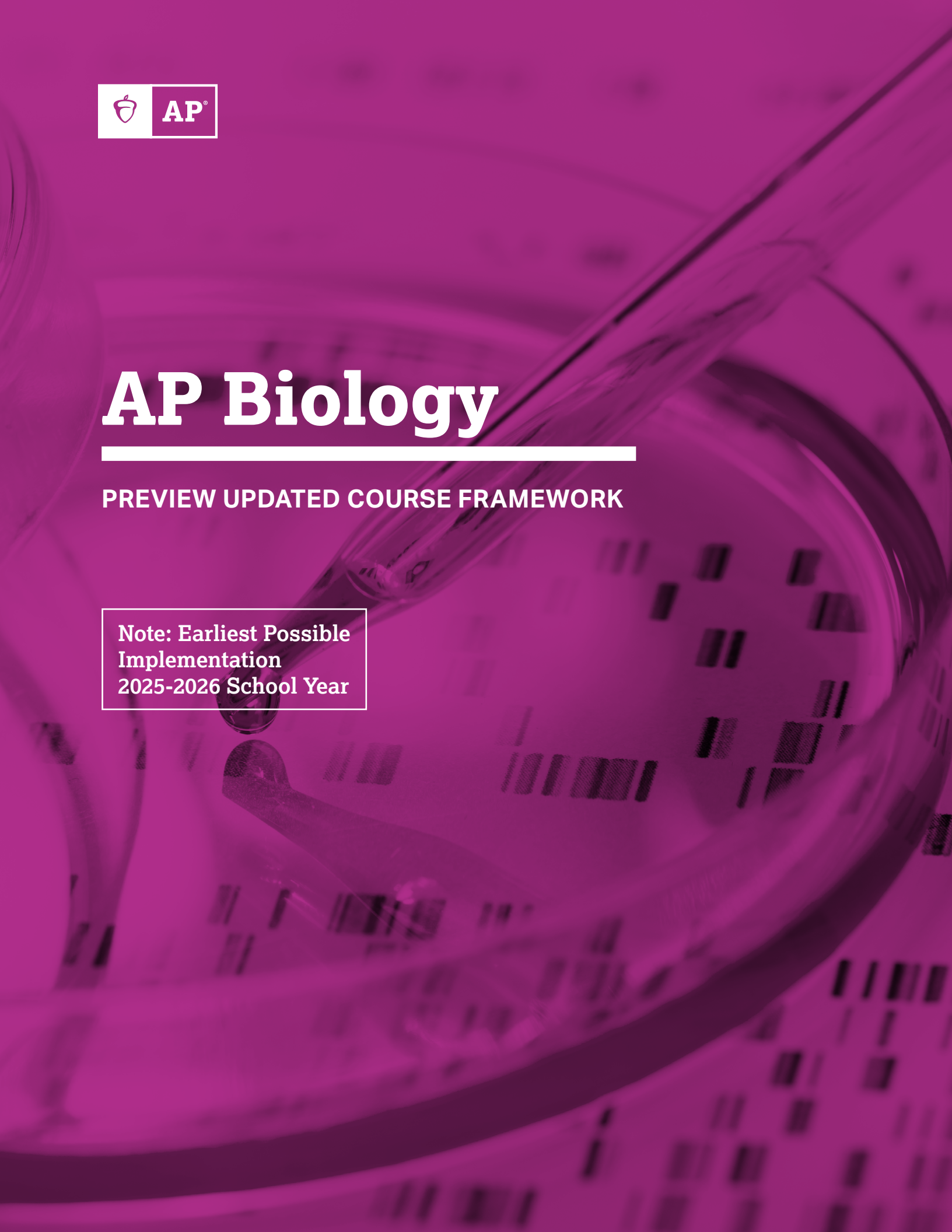

AP Biology

PREVIEW UPDATED COURSE FRAMEWORK

Note: Earliest Possible Implementation 2025-2026 School Year

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, 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 39 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: Equity and Access

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

Offering AP Courses: The AP Course Audit

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

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

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

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

How the AP Program Is Developed

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

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

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

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

How AP Exams Are Scored

The exam scoring process, like the course and exam development process, relies on the expertise of both AP teachers and college faculty. While multiple-choice questions are scored by machine, the free-response questions and through-course performance assessments, as applicable, are scored by thousands of college faculty and expert AP teachers. Most are scored at the annual AP Reading, while a small portion are 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, a search engine is available at **apstudent.collegeboard.org/creditandplacement/search-credit-policies**.

BECOMING AN AP READER

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

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

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

How to Apply

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

About the AP Biology Course

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

College Course Equivalent

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

Prerequisites

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

Laboratory Requirement

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

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

Course Framework Components

Course Units

Unit 1: Chemistry of Life

Unit 2: Cells

Unit 3: Cellular Energetics

Unit 4: Cell Communication and Cell Cycle

Unit 5: Heredity

Unit 6: Gene Expression and Regulation

Unit 7: Natural Selection

Unit 8: Ecology

Course Framework Overview

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

The course framework includes two essential components:

- **AP Biology Science Practices** (p. 8)
  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.
- **Course Content** (p. 11)
  The course content is organized into commonly taught units of study that provide a suggested sequence for the course and detail required content and conceptual understandings that colleges and universities typically expect students to master to qualify for college credit and/or placement.

AP Biology Science Practices

Science Practice 1

Concept Explanation 1

Explain biological concepts and processes presented in written format.

Science Practice 2

Visual Representations 2

Analyze visual representations of biological concepts and processes.

Science Practice 3

Questions and Methods 3

Determine scientific questions and methods.

SKILLS

1.A Describe biological concepts and processes.

1.B Explain biological concepts and processes.

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

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

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

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

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

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

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

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

i. Identifying dependent and independent variables

ii. Identifying appropriate controls

iii. Justifying appropriate controls

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

AP Biology
Science Practices *(cont'd)*

Science Practice 4

Representing and Describing Data 4

Represent and describe data.

Science Practice 5

Statistical Tests and Data Analysis 5

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

Science Practice 6

Argumentation 6

Develop and justify scientific arguments using evidence.

SKILLS

4.A Construct a graph, scatter plot, or chart (e.g., x, y; log y; bar; histogram; line, dual y; box and whisker; pie), including:

i. the type of graph appropriate for the data
ii. axis labeling, including appropriate units and legend
iii. scaling
iv. the plotting of data including error bars
v. the trend line

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

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

5.A Perform mathematical calculations, including:

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

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

5.C Perform chi-square hypothesis testing.

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

6.A Make a scientific claim.

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

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

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

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

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AP BIOLOGY

UNIT 1

Chemistry of Life

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TOPIC 1.1
Structure of Water and Hydrogen Bonding

LEARNING OBJECTIVE

1.1.A

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

ESSENTIAL KNOWLEDGE

1.1.A.1

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

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

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

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

1.1.A.2

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

TOPIC 1.2
Elements of Life

LEARNING OBJECTIVE

1.2.A

Describe the composition of macromolecules required by living organisms.

ESSENTIAL KNOWLEDGE

1.2.A.1

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

i. Sulfur is used in the building of proteins.
ii. Phosphorus is used in the building of phospholipids (a type of lipid) and nucleic acids.
iii. Nitrogen is used in the building of nucleic acids.

TOPIC 1.3
Introduction to Macromolecules

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

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.*

TOPIC 1.5
Lipids

LEARNING OBJECTIVE

1.5.A

Describe the structure and function of lipids.

ESSENTIAL KNOWLEDGE

1.5.A.1

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

i. Saturated fatty acids contain only single bonds between carbon atoms.
ii. Unsaturated fatty acids contain at least one double bond between carbon atoms, which causes the carbon chain to kink.
iii. The more double bonds in a fatty acid tail, the more unsaturated the lipid becomes.
iv. The more unsaturated a lipid is, the more liquid it is at room temperature.

1.5.A.2

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

i. Fats provide energy storage and support cell function. In some cases, they can also provide insulation to help keep mammals warm.
ii. Steroids are hormones that support physiological functions including growth and development, energy metabolism, and homeostasis.
iii. Cholesterol provides essential structural stability to animal cell membranes.
iv. Phospholipids group together to form the lipid bilayers found in plasma and cell membranes.

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

TOPIC 1.6
Nucleic Acids

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.*

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.

TOPIC 1.7
Proteins

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 ($-COOH$) of one amino acid and an amine group ($-NH_2$) of the next amino acid, resulting in a growing peptide chain.

1.7.A.2

Amino acids are composed of a central carbon atom with a hydrogen atom, a carboxyl group, an amine group, and a variable R group covalently bound to it. The R group of an amino acid can be categorized by three possible chemical properties: hydrophobic/nonpolar, hydrophilic/polar, or ionic. The interactions of these R groups determine the structure and function of that region of the protein.

1.7.A.3

The specific sequence of amino acids in proteins determines the primary structure of a polypeptide as well as the overall shape of the protein.

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

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

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TOPIC 2.1
Cell Structure and Function

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.

2.1.A.3

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

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

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

2.1.A.4

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

i. Correctly folding and chemically modifying newly synthesized cellular products
ii. Packaging proteins for trafficking

X 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).

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.

TOPIC 2.2
Cell Size

LEARNING OBJECTIVE

2.2.A

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

ESSENTIAL KNOWLEDGE

2.2.A.1

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

RELEVANT EQUATIONS

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

Volume of a Cube: $V = s^3$

Volume of a Rectangular Solid: $V = lwh$

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

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

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

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

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

r = radius

l = length

h = height

w = width

s = length of one side of a cube

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.

TOPIC 2.3
Plasma Membrane

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

TOPIC 2.4
Membrane Permeability

LEARNING OBJECTIVE	ESSENTIAL KNOWLEDGE
2.4.A Explain how the structure of biological membranes influences selective permeability.	**2.4.A.1** Plasma membranes separate the internal environment of the cell from the external environment. Selective permeability is the result of the plasma membrane having a hydrophobic interior.
	2.4.A.2 Small nonpolar molecules, including N_2, O_2, and CO_2, freely pass across the membrane. Hydrophilic substances, such as large polar molecules and ions, move across the membrane through embedded channels and transport proteins.
	2.4.A.3 The nonpolar hydrocarbon tails of phospholipids prevent the movement of ions and polar molecules across the membrane. Small polar, uncharged molecules, like H_2O or NH_3 (ammonia), pass through the membrane in small amounts.
2.4.B Describe the role of the cell wall in maintaining cell structure and function.	**2.4.B.1** Cell walls of Bacteria, Archaea, fungi, and plants provide a structural boundary as well as a permeability barrier for some substances to the internal or external cellular environments and protection from osmotic lysis.

TOPIC 2.5
Membrane Transport

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

TOPIC 2.6
Facilitated Diffusion

LEARNING OBJECTIVE

2.6.A

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

ESSENTIAL KNOWLEDGE

2.6.A.1

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

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

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

2.6.A.2

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

2.6.A.3

Aquaporins transport large quantities of water across membranes.

TOPIC 2.7
Tonicity and Osmoregulation

LEARNING OBJECTIVE

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

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

2.7.B.1
Growth and homeostasis are maintained by the constant movement of molecules across membranes.

2.7.B.2
Osmoregulation maintains water balance and allows organisms to control their internal solute composition and water potential. Water moves from regions of low osmolarity or solute concentration to regions of high osmolarity or solute concentration.

RELEVANT EQUATION

Solute Potential of a Solution:

$\Psi_s = -iCRT$ where:

i = ionization constant

C = molar concentration

R = pressure constant

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

T = temperature in Kelvin (°C + 273)

TOPIC 2.8
Mechanisms of Transport

LEARNING OBJECTIVE

2.8.A

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

ESSENTIAL KNOWLEDGE

2.8.A.1

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

i. Membrane proteins are necessary for active transport.

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

TOPIC 2.9
Compartmentalization

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

TOPIC 2.10
Origins of Cell Compartmentalization

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.

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AP BIOLOGY

UNIT 3
Cellular Energetics

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TOPIC 3.1
Enzymes

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

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

LEARNING OBJECTIVE	ESSENTIAL KNOWLEDGE
3.3.A Describe the role of energy in living organisms.	**3.3.A.1** All living systems require an input of energy. **3.3.A.2** Life requires a highly ordered system and does not violate the first and second laws of thermodynamics. i. Energy input must exceed energy loss to maintain order and to power cellular processes. ii. Cellular processes that release energy may be coupled with cellular processes that require energy. iii. Significant loss of order or energy flow results in death. **EXCLUSION STATEMENT**—*Students will need to understand the concept of energy, but the equation for Gibbs free energy is beyond the scope of the AP Exam.* **3.3.A.3** Energy-related pathways in biological systems are sequential to allow for a more controlled transfer of energy. A product of a reaction in a metabolic pathway is typically the reactant for the subsequent step in the pathway.
3.3.B Explain how shared, conserved, and fundamental processes and features support the concept of common ancestry for all organisms.	**3.3.B.1** Core metabolic pathways (e.g., glycolysis, oxidative phosphorylation) are conserved across all currently recognized domains (Archaea, Bacteria, and Eukarya).

TOPIC 3.4
Photosynthesis

LEARNING OBJECTIVE

3.4.A

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

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

ESSENTIAL KNOWLEDGE

3.4.A.1

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

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

3.4.A.2

Stroma and thylakoids are found within the chloroplast.

i. The stroma is the fluid within the inner chloroplast membrane and outside the thylakoid. The carbon fixation (Calvin cycle) reactions of photosynthesis occur in the stroma.
ii. The thylakoid membranes contain chlorophyll pigments organized into two photosystems, as well as electron transport proteins.
iii. Thylakoids are organized in stacks called grana. The light reactions of photosynthesis occur in the grana.

3.4.A.3

The light reactions of photosynthesis in eukaryotes involve a series of coordinated reaction pathways that capture energy present in light to yield ATP and NADPH, which power the production of organic molecules in the Calvin cycle. This provides energy for metabolic processes.

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.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.

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

X 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.

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.

TOPIC 3.5
Cellular Respiration

LEARNING OBJECTIVE

3.5.A

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

ESSENTIAL KNOWLEDGE

3.5.A.1

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

3.5.A.2

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

3.5.A.3

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

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

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.*

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.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.

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 inner membrane 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.

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AP BIOLOGY

UNIT 4

Cell Communication and Cell Cycle

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TOPIC 4.1
Cell Communication

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

TOPIC 4.2

Introduction to Signal Transduction

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

LEARNING OBJECTIVE	ESSENTIAL KNOWLEDGE
4.3.A Describe the different types of cellular responses elicited by a signal transduction pathway.	**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 Explain how a change in the structure of any signaling molecule affects the activity of the signaling pathway.	**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.

TOPIC 4.4
Feedback

LEARNING OBJECTIVE

4.4.A

Explain how positive and negative feedback helps maintain homeostasis.

ESSENTIAL KNOWLEDGE

4.4.A.1

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

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

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

TOPIC 4.5
Cell Cycle

LEARNING OBJECTIVE	ESSENTIAL KNOWLEDGE
4.5.A Describe the events that occur in the cell cycle.	**4.5.A.1** The cell cycle is a highly regulated series of events that controls the growth and reproduction of eukaryotic cells. i. The cell cycle consists of sequential stages of interphase (G1, S, G2), mitosis, and cytokinesis. ii. G1 phase: The cell is metabolically active, duplicating organelles and cytosolic components. iii. S phase: DNA is in the form of chromatin and replicates to form two sister chromatids connected at a centromere. iv. G2 phase: Protein synthesis occurs, ATP is produced in large quantities, and centrosomes replicate. v. A cell can enter a stage (G0) in which it no longer divides, but it can reenter the cell cycle in response to appropriate cues. vi. Nondividing cells may exit the cell cycle or be held at a particular stage in the cell cycle.
4.5.B Explain how mitosis results in the transmission of chromosomes from one generation of cells to the next.	**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

LEARNING OBJECTIVE	ESSENTIAL KNOWLEDGE
4.6.A Describe the role of checkpoints in regulating the cell cycle.	**4.6.A.1** A number of internal controls or checkpoints regulate progression through the cell cycle. **4.6.A.2** Interactions between cyclins and cyclin-dependent kinases control the cell cycle. **EXCLUSION STATEMENT**—*Knowledge of specific cyclin-CdK pairs or growth factors is beyond the scope of the AP Exam.*
4.6.B Describe the effects of disruptions to the cell cycle on the cell or organism.	**4.6.B.1** Disruptions to the cell cycle may result in cancer or apoptosis (programmed cell death).

AP BIOLOGY

UNIT 5
Heredity

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TOPIC 5.1
Meiosis

LEARNING OBJECTIVE	ESSENTIAL KNOWLEDGE
5.1.A Explain how meiosis results in the transmission of chromosomes from one generation to the next.	**5.1.A.1** Meiosis is a process that ensures the formation of haploid gamete cells, sometimes referred to as daughter cells, in sexually reproducing diploid organisms. **5.1.A.2** Meiosis I involves the following steps: i. Prophase I: Homologous chromosomes pair up and condense, synapsis occurs and then chiasmata may form, meiotic spindle begins to form, centrosomes move to opposite poles of the cell, and the nuclear envelope breaks down. ii. Metaphase I: Meiotic spindle fibers align homologous pairs of chromosomes along the equator of the cell at the metaphase plate. iii. Anaphase I: Homologous chromosomes separate, while sister chromatids remain attached, as meiotic spindle fibers pull chromosomes toward poles. iv. Telophase I: Meiotic spindle breaks down, a new nuclear envelope develops, a cleavage furrow (animal cell) or cell plate (plant cell) forms, and cytokinesis occurs. Two haploid daughter cells are formed (at the end of meiosis I). **5.1.A.3** Meiosis II involves the following steps: i. Prophase II: Meiotic spindle forms; sister chromatids connected at the centromere attach to meiotic spindle. ii. Metaphase II: Chromosomes align along the metaphase plate; the kinetochore of each chromatid is attached to a microtubule extending from the poles. iii. Anaphase II: Proteins at the centromeres break down, and sister chromatids are pulled apart and toward opposite poles in the cell. iv. Telophase II: Meiotic spindle breaks down, a new nuclear envelope develops, a cleavage furrow (animal cell) or a cell plate (plant cell) forms, chromatids begin to decondense, and cytokinesis occurs. Four haploid daughter cells are formed, each with an unduplicated chromatid.
5.1.B Describe similarities and differences between the phases and outcomes of mitosis and meiosis.	**5.1.B.1** Mitosis and meiosis are similar in the use of a spindle apparatus to move chromosomes but differ in the number of cells produced and the genetic content of the daughter cells.

TOPIC 5.2
Meiosis and Genetic Diversity

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

LEARNING OBJECTIVE

5.3.A

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

ESSENTIAL KNOWLEDGE

5.3.A.1

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

5.3.A.2

In most cases, fertilization involves the fusion of two haploid gametes, restoring the diploid number of chromosomes and increasing genetic variation in populations by creating new combinations of alleles in the zygote.

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

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

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

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

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

LEARNING OBJECTIVE

5.4.A

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

ESSENTIAL KNOWLEDGE

5.4.A.1

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

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

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

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

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

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

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TOPIC 6.1
DNA and RNA Structure

LEARNING OBJECTIVE	ESSENTIAL KNOWLEDGE
6.1.A Describe the structures involved in passing hereditary information from one generation to the next.	**6.1.A.1** Genetic information is stored in and passed to subsequent generations through DNA molecules and, in some cases, RNA molecules. i. Prokaryotic organisms typically have circular chromosomes. ii. Eukaryotic organisms typically have multiple linear chromosomes that are comprised of DNA. These chromosomes are condensed using histones and associated proteins. **6.1.A.2** Prokaryotes and eukaryotes can contain plasmids, which are extra-chromosomal circular molecules of DNA.
6.1.B Describe the characteristics of DNA that allow it to be used as hereditary material.	**6.1.B.1** Nucleic acids exhibit specific nucleotide base pairing that is conserved through evolution. i. Purines (guanine and adenine) have a double ring structure. ii. Pyrimidines (cytosine, thymine, and uracil) have a single ring structure. iii. Purines pair with pyrimidines: adenine with thymine (or uracil in RNA) and guanine with cytosine.

TOPIC 6.2
DNA Replication

LEARNING OBJECTIVE

6.2.A

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

ESSENTIAL KNOWLEDGE

6.2.A.1

DNA replication ensures continuity of hereditary information.

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

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.*

TOPIC 6.3
Transcription and RNA Processing

LEARNING OBJECTIVE

6.3.A

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

ESSENTIAL KNOWLEDGE

6.3.A.1

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

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

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

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

6.3.A.2

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

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.

TOPIC 6.4
Translation

LEARNING OBJECTIVE

6.4.A

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

ESSENTIAL KNOWLEDGE

6.4.A.1

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

6.4.A.2

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

6.4.A.3

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

i. Translation is initiated when the rRNA in the ribosome interacts with the mRNA at the start codon (AUG, coding for the amino acid methionine).
ii. The sequence of nucleotides on the mRNA is read in triplets, called codons.
iii. Each codon encodes a specific amino acid, which can be deduced by using a genetic code chart. Many amino acids are encoded by more than one codon.
iv. Nearly all living organisms use the same genetic code, which is evidence for the common ancestry of all living organisms.
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.

TOPIC 6.5
Regulation of Gene Expression

LEARNING OBJECTIVE	ESSENTIAL KNOWLEDGE
6.5.A Describe the types of interactions that regulate gene expression.	**6.5.A.1** Regulatory sequences are stretches of DNA that interact with regulatory proteins to control transcription. Some genes are constitutively expressed, and others are inducible.
	6.5.A.2 Epigenetic changes can affect gene expression through reversible modifications of DNA or histones.
	6.5.A.3 The phenotype of a cell or an organism is determined by the combination of genes that are expressed and the levels at which they are expressed. i. Observable cell differentiation results from the expression of genes for tissue-specific proteins. ii. Induction of transcription factors during development results in sequential gene expression. iii. The function and amount of gene products determine the phenotype of organisms.
6.5.B Explain how the location of regulatory sequences relates to their function.	**6.5.B.1** Both prokaryotes and eukaryotes have groups of genes that are coordinately regulated. i. Prokaryotes regulate operons in an inducible or repressible system. ii. In eukaryotes, groups of genes may be influenced by the same transcription factors to coordinately regulate expression.

TOPIC 6.6

Gene Expression and Cell Specialization

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

TOPIC 6.7
Mutations

LEARNING OBJECTIVE	ESSENTIAL KNOWLEDGE
6.7.A Describe the various types of mutation.	**6.7.A.1** Alterations in a DNA sequence are mutations that can cause changes in the type or amount of the protein produced and the consequent phenotype. DNA mutations can be beneficial, detrimental, or neutral based on the effect or the lack of effect they have on the resulting nucleic acid or protein and the phenotypes that are conferred by the protein. i. Point mutations occur when one nucleotide has been substituted for a different nucleotide. ii. Frameshift mutations occur when one or more nucleotides are inserted or deleted, causing the reading frame to be shifted. iii. Nonsense mutations occur when there is a point mutation that causes a premature stop. iv. Silent mutations occur when the change in the nucleotide sequence has no effect on the amino acid sequence. **EXCLUSION STATEMENT**—*Knowledge of specific mutations and their effects is beyond the scope of the AP Exam.*
6.7.B Explain how changes in genotype may result in changes in phenotype.	**6.7.B.1** Errors in DNA replication or DNA repair mechanisms as well as external factors, including radiation and reactive chemicals, can cause random mutations in the DNA. i. Whether a mutation is beneficial, detrimental, or neutral depends on the environmental context. ii. Mutations are a source of genetic variation. **6.7.B.2** Errors in mitosis or meiosis can result in changes in phenotype. i. Changes in chromosome number resulting from nondisjunction often result in new phenotypes caused by triploidy (aneuploidy). ii. Changes in chromosome number often result in disorders with developmental limitations. iii. Alterations in chromosome structure lead to genetic disorders. **EXCLUSION STATEMENT**—*Knowledge of specific disorders related to changes in chromosome number is beyond the scope of the AP Exam.*

Gene Expression and Regulation

LEARNING OBJECTIVE

6.7.C

Explain how alterations in DNA sequences contribute to variation that can be subject to natural selection.

ESSENTIAL KNOWLEDGE

6.7.C.1

Changes in genotype may affect phenotypes that are subject to natural selection. Genetic changes that enhance survival and reproduction can be selected for by environmental conditions.

i. The horizontal acquisitions of genetic information in prokaryotes via transformation (uptake of DNA), transduction (viral transmission of genetic information), conjugation (cell-to-cell transfer of DNA), and transposition (movement of DNA segments within and between DNA molecules) increase genetic variation.

ii. Related viruses can recombine genetic information if they infect the same host cell.

iii. Reproductive processes that increase genetic variation are evolutionarily conserved and are shared by various organisms.

TOPIC 6.8
Biotechnology

LEARNING OBJECTIVE

6.8.A

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

ESSENTIAL KNOWLEDGE

6.8.A.1

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

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

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

iii. Bacterial transformation introduces foreign DNA into bacterial cells.

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

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

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AP BIOLOGY

UNIT 7

Natural Selection

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TOPIC 7.1
Introduction to Natural Selection

LEARNING OBJECTIVE	ESSENTIAL KNOWLEDGE
7.1.A Describe the causes of natural selection.	**7.1.A.1** Natural selection is a major mechanism of evolution. **7.1.A.2** According to Darwin's theory of natural selection, competition for limited resources results in differential survival. Individuals with more favorable phenotypes are more likely to survive and produce more offspring, thus passing on those favorable traits to subsequent generations.
7.1.B Explain how natural selection affects populations.	**7.1.B.1** Evolutionary fitness is measured by reproductive success. **7.1.B.2** Biotic and abiotic environments can fluctuate, affecting the rate and direction of evolution. Different genetic variations can be selected in each generation.

TOPIC 7.2
Natural Selection

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

TOPIC 7.3
Artificial Selection

LEARNING OBJECTIVE

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

ESSENTIAL KNOWLEDGE

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

TOPIC 7.4
Population Genetics

LEARNING OBJECTIVE	ESSENTIAL KNOWLEDGE
7.4.A Explain how random occurrences affect the genetic makeup of a population.	**7.4.A.1** Evolution is also driven by random occurrences. i. Mutation is a random process that adds new genetic variation to a population. ii. Genetic drift is a change in allele frequencies attributable to a nonselective process occurring in small populations. iii. The bottleneck effect is a type of genetic drift that occurs when a population size is reduced to a small number of individuals for at least one generation. iv. The founder effect is a type of genetic drift that occurs when a population is separated from other members of the population. The frequency of genes and traits will shift based on the genes in this new founder population. v. Migration can result in gene flow (the addition or removal of alleles from a population).
7.4.B Describe the role of random processes in the evolution of specific populations.	**7.4.B.1** Random processes can lead to changes in allele frequencies in a population. i. Mutations result in genetic variation, which provides phenotypes on which natural selection acts. ii. Genetic drift can allow a small population to diverge from other populations of the same species. iii. Gene flow between two populations prevents them from diverging into separate species.
7.4.C Describe the change in the genetic makeup of a population over time.	**7.4.C.1** Changes in allele frequencies provide evidence for the occurrence of evolution in a population.

TOPIC 7.5
Hardy-Weinberg Equilibrium

LEARNING OBJECTIVE

7.5.A

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

ESSENTIAL KNOWLEDGE

7.5.A.1

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

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

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

7.5.A.2

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

RELEVANT EQUATIONS

Hardy-Weinberg Equation—

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

$$p + q = 1,$$

where

p = frequency of allele 1 in the population

q = frequency of allele 2 in the population

TOPIC 7.6
Evidence of Evolution

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

TOPIC 7.7
Common Ancestry

LEARNING OBJECTIVE

7.7.A

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

ESSENTIAL KNOWLEDGE

7.7.A.1

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

i. Membrane-bound organelles
ii. Linear chromosomes
iii. Genes that contain introns

TOPIC 7.8
Continuing Evolution

LEARNING OBJECTIVE

7.8.A

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

ESSENTIAL KNOWLEDGE

7.8.A.1

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

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

TOPIC 7.9
Phylogeny

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

TOPIC 7.10
Speciation

LEARNING OBJECTIVE	ESSENTIAL KNOWLEDGE
7.10.A Describe the conditions under which new species may arise.	**7.10.A.1** Speciation occurs when two populations become reproductively isolated from each other. **7.10.A.2** The biological species concept provides a commonly used definition of a species for sexually reproducing organisms. It states that species can be defined as a group capable of interbreeding and exchanging genetic information to produce viable, fertile offspring.
7.10.B Describe the rate of evolution and speciation under different ecological conditions.	**7.10.B.1** Punctuated equilibrium is when evolution occurs rapidly after a long period of stasis. Gradualism is when evolution occurs slowly over hundreds of thousands or millions of years. **7.10.B.2** Divergent evolution occurs when adaptation to new habitats results in phenotypic diversification. Speciation rates can be especially rapid during times of adaptive radiation as new habitats become available. **7.10.B.3** Convergent evolution occurs when similar selective pressures result in similar phenotypic adaptations in different populations or species.
7.10.C Explain the processes and mechanisms that drive speciation.	**7.10.C.1** Sympatric speciation occurs in populations with geographic overlap. Allopatric speciation occurs in populations that are geographically isolated. **7.10.C.2** Various pre-zygotic and post-zygotic mechanisms can maintain reproductive isolation and prevent gene flow between populations.

TOPIC 7.11
Variations in Populations

LEARNING OBJECTIVE

7.11.A

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

ESSENTIAL KNOWLEDGE

7.11.A.1

The level of variation in a population affects population dynamics.

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

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

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

TOPIC 7.12
Origins of Life on Earth

LEARNING OBJECTIVE

7.12.A

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

ESSENTIAL KNOWLEDGE

7.12.A.1

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

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

ii. Earth formed approximately 4.6 billion years ago (bya). The environment was too hostile for life until about 3.9 bya, and the earliest fossil evidence for life dates to 3.5 bya. Taken together, this evidence provides a plausible range of dates for the origin of life.

7.12.A.2

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

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

ii. Base-pairing is necessary for replication.

iii. Genetically encoded proteins were not involved as catalysts.

AP BIOLOGY

UNIT 8

Ecology

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TOPIC 8.1
Responses to the Environment

LEARNING OBJECTIVE	ESSENTIAL KNOWLEDGE
8.1.A Explain how the behavioral and physiological response of an organism is related to changes in internal or external environment.	**8.1.A.1** Organisms respond to changes in their environment through behavioral and physiological mechanisms. **EXCLUSION STATEMENT**—*Knowledge of specific behavioral or physiological mechanisms is beyond the scope of the AP Exam.* **8.1.A.2** Organisms exchange information with one another in response to internal changes and external cues, which can change behavior.
8.1.B Explain how the behavioral responses of organisms affect their overall fitness and may contribute to the success of a population.	**8.1.B.1** Organisms communicate through various mechanisms (visual, audible, tactile, electrical, and/or chemical signals). i. Organisms have a variety of signaling behaviors that produce changes in the behavior of other organisms and can result in differential reproductive success. ii. Animals use signals to indicate dominance, find food, establish territory, and ensure reproductive success. **EXCLUSION STATEMENT**—*Knowledge of specific mechanisms of communication is beyond the scope of the AP Exam.* **8.1.B.2** Responses to information and communication of information are vital to natural selection and evolution. i. Fitness favors innate and learned behaviors that increase survival and reproductive success. ii. Cooperative behavior tends to increase the fitness of the individual and the survival of the population. **EXCLUSION STATEMENT**—*The details of the various communications and community behavioral systems are beyond the scope of the AP Exam.*

TOPIC 8.2
Energy Flow Through Ecosystems

LEARNING OBJECTIVE	ESSENTIAL KNOWLEDGE
8.2.A Describe the strategies organisms use to acquire and use energy.	**8.2.A.1** Organisms use energy to organize, grow, reproduce, and maintain homeostasis. i. Organisms use different strategies to regulate body temperature and metabolism. Endotherms use thermal energy generated by metabolism to maintain homeostatic body temperatures. Ectotherms lack efficient internal mechanisms for maintaining body temperature, although they may regulate their temperature behaviorally by moving into the sun or shade or by aggregating with other individuals. ii. A net gain in energy results in energy storage, the growth of an organism, and increased reproductive output. iii. A net loss of energy results in loss of mass, a decrease in reproductive output, and, eventually, the death of an organism. **8.2.A.2** Different organisms use various reproductive strategies in response to energy availability. Some organisms alternate between asexual and sexual reproduction in response to energy availability.
8.2.B Explain how energy flows and matter cycles through trophic levels.	**8.2.B.1** Ecological levels of organization include populations, communities, ecosystems, and biomes. **8.2.B.2** Energy flows through ecosystems, while matter and nutrients cycle between the environment and organisms via biogeochemical cycles. The cycles are essential for life, and each cycle demonstrates the conservation of matter. The cycles are interdependent. **8.2.B.3** Biogeochemical cycles include abiotic and biotic reservoirs, as well as processes that cycle matter between reservoirs. **8.2.B.4** The hydrologic (water) cycle involves water movement and storage within the hydrosphere. Reservoirs include oceans, surface water, the atmosphere, and living organisms. Processes include evaporation, condensation, precipitation, and transpiration. **8.2.B.5** The carbon cycle involves recycling carbon atoms through Earth's biosphere into organisms as carbohydrates and back into the atmosphere as carbon dioxide (CO_2). At the highest levels of organization, the carbon cycle can be simplified into four parts: photosynthesis, cellular respiration, decomposition, and combustion.

LEARNING OBJECTIVE	ESSENTIAL KNOWLEDGE
8.2.B Explain how energy flows and matter cycles through trophic levels.	**8.2.B.6** The nitrogen cycle involves several steps, including nitrogen fixation, assimilation, ammonification, nitrification, and denitrification. These steps are performed by microorganisms in the soil. The largest reservoir of nitrogen is the atmosphere. In nitrogen fixation, nitrogen gas (N_2) is fixed into ammonia (NH_3), which ionizes to ammonium (NH_4^+) by acquiring hydrogen ions from the soil solution. **8.2.B.7** The phosphorus cycle involves weathering rocks releasing phosphate (PO_4^{3-}) into soil and groundwater. Producers take in phosphate, which is incorporated into biological molecules; consumers eat producers, transferring phosphate to animals. Phosphorus returns to the soil via decomposition of biomass, or excretion. Phosphate can also be incorporated back into the environment via decomposition of decaying organic matter.
8.2.C Explain how changes in energy availability affect populations, communities, and ecosystems.	**8.2.C.1** Changes in energy availability can result in changes in population size. **8.2.C.2** Changes in energy availability can result in disruptions to an ecosystem. i. A change in energy resources such as sunlight can affect the number and size of the trophic levels. Trophic levels include producers; primary, secondary, tertiary, and quaternary consumers; and decomposers. ii. A change in the biomass or number of producers in a given geographic area can affect the number and size of other trophic levels.
8.2.D Explain how the activities of autotrophs and heterotrophs enable the flow of energy within an ecosystem.	**8.2.D.1** Autotrophs capture energy from physical or chemical sources in the environment. i. Photosynthetic organisms capture energy present in sunlight contributing to primary productivity. ii. Chemosynthetic organisms capture energy from small inorganic molecules present in their environment, which can occur in the absence of oxygen. **8.2.D.2** Heterotrophs, which include carnivores, herbivores, omnivores, decomposers, and scavengers, metabolize carbohydrates, lipids, and proteins as sources of energy. Heterotrophs capture the energy present in carbon compounds by consuming organic matter derived from autotrophs incorporating matter into their tissues.

TOPIC 8.3
Population Ecology

LEARNING OBJECTIVE

8.3.A

Describe factors that influence growth dynamics of populations.

ESSENTIAL KNOWLEDGE

8.3.A.1

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

8.3.A.2

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

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

RELEVANT EQUATION

Population Growth—

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

where

dt = change in time

B = birth rate

D = death rate

N = population size

dN = change in population size

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

RELEVANT EQUATION

Exponential Growth—

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

where

dt = change in time

N = population size

dN = change in population size

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

TOPIC 8.4
Effect of Density on Populations

LEARNING OBJECTIVE

8.4.A

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

ESSENTIAL KNOWLEDGE

8.4.A.1

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

8.4.A.2

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

RELEVANT EQUATION

Logistical Growth—

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

where

dt = change in time

N = population size

dN = change in population size

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

K = carrying capacity

TOPIC 8.5
Community Ecology

LEARNING OBJECTIVE	ESSENTIAL KNOWLEDGE
8.5.A Describe the structure of a community according to its species composition and diversity.	**8.5.A.1** The structure of a community is measured and described in terms of species composition and species diversity. **RELEVANT EQUATION** Simpson's Diversity Index— Diversity Index $= 1 - \Sigma\left(\frac{n}{N}\right)^2$ where n = total number of organisms of a particular species N = total number of organisms of all species
8.5.B Explain how interactions within and among populations influence community structure.	**8.5.B.1** Communities are groups of interacting populations of different species that change over time based on the interactions between those populations. **8.5.B.2** Interactions among populations determine how they access energy and matter within a community. **8.5.B.3** Relationships among interacting populations can be characterized by positive and negative effects and can be modeled. Examples include predator/prey interactions, cooperation, trophic cascades, and niche partitioning. **8.5.B.4** Competition, predation, and symbioses, including parasitism, mutualism, and commensalism, can drive population dynamics.

TOPIC 8.6
Biodiversity

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

TOPIC 8.7
Disruptions in Ecosystems

LEARNING OBJECTIVE	ESSENTIAL KNOWLEDGE
8.7.A Explain the interaction between the environment and random or preexisting variations in populations.	**8.7.A.1** An adaptation is a genetic variation that is favored by selection and manifests as a trait that provides an advantage to an organism in a particular environment. **8.7.A.2** Heterozygote advantage is when the heterozygous genotype has a higher relative fitness than either the homozygous dominant or homozygous recessive genotype. **8.7.A.3** Mutations are not directed by specific environmental pressures.
8.7.B Explain how invasive species affect ecosystem dynamics.	**8.7.B.1** The intentional or unintentional introduction of an invasive species can allow the species to exploit a new niche free of predators or competitors or to outcompete native species for resources.
8.7.C Describe human activities that lead to changes in ecosystem structure and dynamics.	**8.7.C.1** Human impact accelerates changes at local and global levels. These activities can drive changes in ecosystems, such as the following, that cause extinctions to occur: i. Biomagnification ii. Eutrophication
8.7.D Explain how geological and meteorological activity leads to changes in ecosystem structure and dynamics.	**8.7.D.1** Geological and meteorological events affect habitat change and ecosystem distribution. Biogeographical studies illustrate these changes.