AP BIOLOGY

UNIT 1

Chemistry of Life

8–11%
AP EXAM WEIGHTING

~5–7
CLASS PERIODS

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

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

Personal Progress Check 1

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

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

UNIT 1

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

Chemistry of Life

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

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

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

Developing Understanding

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

Building Science Practices

1.A 2.A 6.E.b

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

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

Preparing for the AP Exam

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

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

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

UNIT AT A GLANCE

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

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

SAMPLE INSTRUCTIONAL ACTIVITIES

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

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

Unit Planning Notes

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

SUGGESTED SKILL

Visual Representations

2.A

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

TOPIC 1.1
Structure of Water and Hydrogen Bonding

Required Course Content

ENDURING UNDERSTANDING

SYI-1

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

LEARNING OBJECTIVE

SYI-1.A

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

ESSENTIAL KNOWLEDGE

SYI-1.A.1

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

SYI-1.A.2

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

SYI-1.A.3

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

TOPIC 1.2
Elements of Life

SUGGESTED SKILL

Visual Representations

2.A

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

Required Course Content

ENDURING UNDERSTANDING

ENE-1

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

LEARNING OBJECTIVE

ENE-1.A

Describe the composition of macromolecules required by living organisms.

ESSENTIAL KNOWLEDGE

ENE-1.A.1

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

ENE-1.A.2

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

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

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

SUGGESTED SKILL

Visual Representations

2.A

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

AVAILABLE RESOURCES

- Classroom Resources > **Visualizing Information**

TOPIC 1.3
Introduction to Biological Macromolecules

Required Course Content

ENDURING UNDERSTANDING

SYI-1

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

LEARNING OBJECTIVE

SYI-1.B

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

ESSENTIAL KNOWLEDGE

SYI-1.B.1

Hydrolysis and dehydration synthesis are used to cleave and form covalent bonds between monomers.

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

TOPIC 1.4
Properties of Biological Macromolecules

Required Course Content

ENDURING UNDERSTANDING

SYI-1

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

LEARNING OBJECTIVE

SYI-1.B

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

ESSENTIAL KNOWLEDGE

SYI-1.B.2

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

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

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

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

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SUGGESTED SKILL

Concept Explanation

1.A

Describe biological concepts and/or processes.

AVAILABLE RESOURCES

- Classroom Resources > Visualizing Information

LEARNING OBJECTIVE

SYI-1.B

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

ESSENTIAL KNOWLEDGE

d. Lipids are nonpolar macromolecules—

i. Differences in saturation determine the structure and function of lipids.

ii. Phospholipids contain polar regions that interact with other polar molecules, such as water, and with nonpolar regions that are often hydrophobic.

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

TOPIC 1.5
Structure and Function of Biological Macromolecules

Required Course Content

ENDURING UNDERSTANDING

SYI-1

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

LEARNING OBJECTIVE

SYI-1.C

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

ESSENTIAL KNOWLEDGE

SYI-1.C.1

Directionality of the subcomponents influences structure and function of the polymer—

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

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

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

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SUGGESTED SKILL

Argumentation

6.E.b

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

ILLUSTRATIVE EXAMPLE

- Cellulose versus starch versus glycogen

LEARNING OBJECTIVE

SYI-1.C

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

ESSENTIAL KNOWLEDGE

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

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

TOPIC 1.6
Nucleic Acids

SUGGESTED SKILL

Visual Representations

2.A

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

Required Course Content

ENDURING UNDERSTANDING

IST-1

Heritable information provides for continuity of life.

LEARNING OBJECTIVE

IST-1.A

Describe the structural similarities and differences between DNA and RNA.

ESSENTIAL KNOWLEDGE

IST-1.A.1

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

a. Both DNA and RNA have three components—sugar, a phosphate group, and a nitrogenous base—that form nucleotide units that are connected by covalent bonds to form a linear molecule with 5′ and 3′ ends, with the nitrogenous bases perpendicular to the sugar-phosphate backbone.
b. The basic structural differences between DNA and RNA include the following:
    i. DNA contains deoxyribose and RNA contains ribose.
    ii. RNA contains uracil and DNA contains thymine.
    iii. DNA is usually double stranded; RNA is usually single stranded.
    iv. The two DNA strands in double-stranded DNA are antiparallel in directionality.

AP BIOLOGY

UNIT 2

Cell Structure and Function

10–13%
AP EXAM WEIGHTING

~11–13
CLASS PERIODS

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

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

Personal Progress Check 2

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

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

UNIT 2

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

Cell Structure and Function

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

BIG IDEA 2
Energetics ENE
- How do the mechanisms for transport across membranes support energy conservation?
- What are the advantages and disadvantages of cellular compartmentalization?

BIG IDEA 4
Systems Interactions SYI
- How are living systems affected by the presence or absence of subcellular components?

Developing Understanding

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

Building Science Practices

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

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

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

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

Preparing for the AP Exam

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

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

UNIT AT A GLANCE

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

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

SAMPLE INSTRUCTIONAL ACTIVITIES

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

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

Unit Planning Notes

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

SUGGESTED SKILL

Concept Explanation

1.A

Describe biological concepts and/or processes.

ILLUSTRATIVE EXAMPLE

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

TOPIC 2.1
Cell Structure: Subcellular Components

Required Course Content

ENDURING UNDERSTANDING

SYI-1

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

LEARNING OBJECTIVE

SYI-1.D

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

ESSENTIAL KNOWLEDGE

SYI-1.D.1

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

SYI-1.D.2

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

SYI-1.D.3

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

a. Rough ER compartmentalizes the cell.
b. Smooth ER functions include detoxification and lipid synthesis.

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

SYI-1.D.4

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

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

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LEARNING OBJECTIVE

SYI-1.D

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

ESSENTIAL KNOWLEDGE

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

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

c. Lysosomes are membrane-enclosed sacs that contain hydrolytic enzymes.

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

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

SUGGESTED SKILL

Argumentation

6.A

Make a scientific claim.

TOPIC 2.2
Cell Structure and Function

Required Course Content

ENDURING UNDERSTANDING

SYI-1

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

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

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LEARNING OBJECTIVE

SYI-1.F

Describe the structural features of a cell that allow organisms to capture, store, and use energy.

ESSENTIAL KNOWLEDGE

SYI-1.F.3

The thylakoids are organized in stacks, called grana.

SYI-1.F.4

Membranes contain chlorophyll pigments and electron transport proteins that comprise the photosystems.

SYI-1.F.5

The light-dependent reactions of photosynthesis occur in the grana.

SYI-1.F.6

The stroma is the fluid within the inner chloroplast membrane and outside of the thylakoid.

SYI-1.F.7

The carbon fixation (Calvin-Benson cycle) reactions of photosynthesis occur in the stroma.

SYI-1.F.8

The Krebs cycle (citric acid cycle) reactions occur in the matrix of the mitochondria.

SYI-1.F.9

Electron transport and ATP synthesis occur on the inner mitochondrial membrane.

SUGGESTED SKILLS

Statistical Tests and Data Analysis

5.A.d

Perform mathematical calculations, including ratios.

Visual Representations

2.D.a

Represent relationships within biological models, including mathematical models.

ILLUSTRATIVE EXAMPLES
SA/V Ratios and Exchange

- Root hair cells
- Guard cells
- Gut epithelial cells

ILLUSTRATIVE EXAMPLES

- Vacuoles
- Cilia
- Stomata

TOPIC 2.3
Cell Size

Required Course Content

ENDURING UNDERSTANDING

ENE-1

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

LEARNING OBJECTIVE

ENE-1.B

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

ESSENTIAL KNOWLEDGE

ENE-1.B.1

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

RELEVANT EQUATIONS

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

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

Volume of a Rectangular Solid: $V = lwh$

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

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

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

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

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

r = radius
l = length
h = height
w = width
s = length of one side of a cube

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

SUGGESTED SKILL

Visual Representations

2.A

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

TOPIC 2.4
Plasma Membranes

Required Course Content

ENDURING UNDERSTANDING

ENE-2

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

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

TOPIC 2.5
Membrane Permeability

Required Course Content

ENDURING UNDERSTANDING

ENE-2

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

LEARNING OBJECTIVE	ESSENTIAL KNOWLEDGE
ENE-2.C Explain how the structure of biological membranes influences selective permeability.	**ENE-2.C.1** The structure of cell membranes results in selective permeability.
	ENE-2.C.2 Cell membranes separate the internal environment of the cell from the external environment.
	ENE-2.C.3 Selective permeability is a direct consequence of membrane structure, as described by the fluid mosaic model.
	ENE-2.C.4 Small nonpolar molecules, including N_2, O_2, and CO_2, freely pass across the membrane. Hydrophilic substances, such as large polar molecules and ions, move across the membrane through embedded channel and transport proteins.
	ENE-2.C.5 Polar uncharged molecules, including H_2O, pass through the membrane in small amounts.
ENE-2.D Describe the role of the cell wall in maintaining cell structure and function.	**ENE-2.D.1** Cell walls provide a structural boundary, as well as a permeability barrier for some substances to the internal environments.
	ENE-2.D.2 Cell walls of plants, prokaryotes, and fungi are composed of complex carbohydrates.

SUGGESTED SKILL

Questions and Methods

3.D

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

Statistical Tests and Data Analysis

5.D.b

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

SUGGESTED SKILL

Questions and Methods

3.E.b

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

TOPIC 2.6
Membrane Transport

Required Course Content

ENDURING UNDERSTANDING

ENE-2

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

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

TOPIC 2.7
Facilitated Diffusion

SUGGESTED SKILL

Argumentation

6.E.b

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

Required Course Content

ENDURING UNDERSTANDING

ENE-2

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

LEARNING OBJECTIVE

ENE-2.G

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

ESSENTIAL KNOWLEDGE

ENE-2.G.1

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

a. Large quantities of water pass through aquaporins.
b. Charged ions, including Na^+ and K^+, require channel proteins to move through the membrane.
c. Membranes may become polarized by movement of ions across the membrane.

ENE-2.G.2

Membrane proteins are necessary for active transport.

ENE-2.G.3

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

ENE-2.G.4

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

SUGGESTED SKILL

Representing and Describing Data

4.A

Construct a graph, plot, or chart.

TOPIC 2.8
Tonicity and Osmoregulation

AVAILABLE RESOURCES

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

ILLUSTRATIVE EXAMPLES

- Contractile vacuole in protists
- Central vacuoles in plant cells

Required Course Content

ENDURING UNDERSTANDING

ENE-2

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

LEARNING OBJECTIVE

ENE-2.H

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

ESSENTIAL KNOWLEDGE

ENE-2.H.1

External environments can be hypotonic, hypertonic or isotonic to internal environments of cells—

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

RELEVANT EQUATION

Water Potential:

$\Psi = \Psi_p + \Psi_s$

$\Psi_p =$ pressure potential

$\Psi_s =$ solute potential

ENE-2.I

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

ENE-2.I.1

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

continued on next page

LEARNING OBJECTIVE

ENE-2.I

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

ESSENTIAL KNOWLEDGE

ENE-2.I.2

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

SOLUTE POTENTIAL OF A SOLUTION

$$\Psi_s = -iCRT$$

where:

i = ionization constant

C = molar concentration

R = pressure constant

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

T = temperature in Kelvin (°C + 273)

SUGGESTED SKILL

Concept Explanation

1.B

Explain biological concepts and/or processes.

TOPIC 2.9
Mechanisms of Transport

Required Course Content

ENDURING UNDERSTANDING

ENE-2

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

LEARNING OBJECTIVE

ENE-2.J

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

ESSENTIAL KNOWLEDGE

ENE-2.J.1

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

TOPIC 2.10
Compartmentalization

SUGGESTED SKILL

Argumentation

6.E.a

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

Required Course Content

ENDURING UNDERSTANDING

ENE-2

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

LEARNING OBJECTIVE

ENE-2.K

Describe the membrane-bound structures of the eukaryotic cell.

ENE-2.L

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

ESSENTIAL KNOWLEDGE

ENE-2.K.1

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

ENE-2.L.1

Internal membranes facilitate cellular processes by minimizing competing interactions and by increasing surface areas where reactions can occur.

SUGGESTED SKILL

Argumentation

6.B

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

TOPIC 2.11
Origins of Cell Compartmentalization

Required Course Content

ENDURING UNDERSTANDING

EVO-1

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

LEARNING OBJECTIVE

EVO-1.A

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

ESSENTIAL KNOWLEDGE

EVO-1.A.1

Membrane-bound organelles evolved from once free-living prokaryotic cells via endosymbiosis.

EVO-1.A.2

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

EVO-1.A.3

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

EVO-1.B

Describe the relationship between the functions of endosymbiotic organelles and their free-living ancestral counterparts.

EVO-1.B.1

Membrane-bound organelles evolved from previously free-living prokaryotic cells via endosymbiosis.

AP BIOLOGY

UNIT 3

Cellular Energetics

12–16%
AP EXAM WEIGHTING

~14–17
CLASS PERIODS

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

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

Personal Progress Check 3

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

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

UNIT 3

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

Cellular Energetics

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

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

Developing Understanding

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

Building Science Practices

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

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

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

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

Preparing for the AP Exam

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

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

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

UNIT AT A GLANCE

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

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

SAMPLE INSTRUCTIONAL ACTIVITIES

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

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

Unit Planning Notes

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

SUGGESTED SKILL

Concept Explanation

1.B

Explain biological concepts and/or processes.

TOPIC 3.1
Enzyme Structure

Required Course Content

ENDURING UNDERSTANDING

ENE-1

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

LEARNING OBJECTIVE

ENE-1.D

Describe the properties of enzymes.

ESSENTIAL KNOWLEDGE

ENE-1.D.1

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

ENE-1.D.2

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

TOPIC 3.2
Enzyme Catalysis

Required Course Content

ENDURING UNDERSTANDING

ENE-1

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

LEARNING OBJECTIVE

ENE-1.E

Explain how enzymes affect the rate of biological reactions.

ESSENTIAL KNOWLEDGE

ENE-1.E.1

The structure and function of enzymes contribute to the regulation of biological processes—

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

SUGGESTED SKILLS

Questions and Methods

3.C.b

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

3.C.c

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

SUGGESTED SKILL

Argumentation

6.E.c

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

AVAILABLE RESOURCES

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

TOPIC 3.3
Environmental Impacts on Enzyme Function

Required Course Content

ENDURING UNDERSTANDING

ENE-1

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

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

continued on next page

LEARNING OBJECTIVE

ENE-1.G

Explain how the cellular environment affects enzyme activity.

ESSENTIAL KNOWLEDGE

RELEVANT EQUATION

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

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

ENE-1.G.2

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

ENE-1.G.3

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

ENE-1G.4

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

SUGGESTED SKILL

Argumentation

6.C

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

TOPIC 3.4
Cellular Energy

Required Course Content

ENDURING UNDERSTANDING

ENE-1

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

LEARNING OBJECTIVE

ENE-1.H

Describe the role of energy in living organisms.

ESSENTIAL KNOWLEDGE

ENE-1.H.1

All living systems require constant input of energy.

ENE-1.H.2

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

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

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

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

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

ENE-1.H.3

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

TOPIC 3.5
Photosynthesis

SUGGESTED SKILL

Argumentation

6.B

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

AVAILABLE RESOURCES

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

Required Course Content

ENDURING UNDERSTANDING

ENE-1

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

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

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LEARNING OBJECTIVE

ENE-1.J

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

ESSENTIAL KNOWLEDGE

ENE-1.J.2

Photosystems I and II are embedded in the internal membranes of chloroplasts and are connected by the transfer of higher energy electrons through an electron transport chain (ETC).

ENE-1.J.3

When electrons are transferred between molecules in a sequence of reactions as they pass through the ETC, an electrochemical gradient of protons (hydrogen ions) is established across the internal membrane.

ENE-1.J.4

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

ENE-1.J.5

The energy captured in the light reactions and transferred to ATP and NADPH powers the production of carbohydrates from carbon dioxide in the Calvin cycle, which occurs in the stroma of the chloroplast.

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

TOPIC 3.6
Cellular Respiration

Required Course Content

ENDURING UNDERSTANDING

ENE-1

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

LEARNING OBJECTIVE

ENE-1.K

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

ESSENTIAL KNOWLEDGE

ENE-1.K.1

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

ENE-1.K.2

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

ENE-1.K.3

The electron transport chain transfers energy from electrons in a series of coupled reactions that establish an electrochemical gradient across membranes—

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

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

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SUGGESTED SKILL

Representing and Describing Data

4.A

Construct a graph, plot, or chart.

AVAILABLE RESOURCES

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

LEARNING OBJECTIVE

ENE-1.K

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

ESSENTIAL KNOWLEDGE

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

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

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

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

ENE-1.L

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

ENE-1.L.1

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

ENE-1.L.2

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

ENE-1.L.3

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

ENE-1.L.4

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

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LEARNING OBJECTIVE

ENE-1.L

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

ESSENTIAL KNOWLEDGE

ENE-1.L.5

When electrons are transferred between molecules in a sequence of reactions as they pass through the ETC, an electrochemical gradient of protons (hydrogen ions) across the inner mitochondrial membrane is established.

ENE-1.L.6

Fermentation allows glycolysis to proceed in the absence of oxygen and produces organic molecules, including alcohol and lactic acid, as waste products.

ENE-1.L.7

The conversion of ATP to ADP releases energy, which is used to power many metabolic processes.

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

EXCLUSION STATEMENT—*Memorization of the steps in glycolysis and the Krebs cycle, and of the structures of the molecules and the names of the enzymes involved, are beyond the scope of the course and the AP Exam.*

SUGGESTED SKILL

Argumentation

6.C

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

AVAILABLE RESOURCES

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

ILLUSTRATIVE EXAMPLES

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

TOPIC 3.7
Fitness

Required Course Content

ENDURING UNDERSTANDING

SYI-3

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

LEARNING OBJECTIVE

SYI-3.A

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

ESSENTIAL KNOWLEDGE

SYI-3.A.1

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

SYI-3.A.2

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

AP BIOLOGY

UNIT 4

Cell Communication and Cell Cycle

10–15%
AP EXAM WEIGHTING

~9–11
CLASS PERIODS

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

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

Personal Progress Check 4

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

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

UNIT 4

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

Cell Communication and Cell Cycle

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

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

Developing Understanding

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

Building Science Practices

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

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

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

Preparing for the AP Exam

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

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

UNIT 4

Cell Communication and Cell Cycle

UNIT AT A GLANCE

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

SAMPLE INSTRUCTIONAL ACTIVITIES

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

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

Unit Planning Notes

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

SUGGESTED SKILL

Concept Explanation

1.B

Explain biological concepts and/or processes.

AVAILABLE RESOURCES

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

ILLUSTRATIVE EXAMPLES

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

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

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

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

IST-3.B.1.a

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

TOPIC 4.1
Cell Communication

Required Course Content

ENDURING UNDERSTANDING

IST-3

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

LEARNING OBJECTIVE

IST-3.A

Describe the ways that cells can communicate with one another.

IST-3.B

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

ESSENTIAL KNOWLEDGE

IST-3.A.1

Cells communicate with one another through direct contact with other cells or from a distance via chemical signaling—

a. Cells communicate by cell-to-cell contact.

IST-3.B.1

Cells communicate over short distances by using local regulators that target cells in the vicinity of the signal-emitting cell—

a. Signals released by one cell type can travel long distances to target cells of another cell type.

TOPIC 4.2
Introduction to Signal Transduction

SUGGESTED SKILL

Concept Application

1.A

Describe biological concepts and/or processes.

AVAILABLE RESOURCES

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

Required Course Content

ENDURING UNDERSTANDING

IST-3

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

LEARNING OBJECTIVE	ESSENTIAL KNOWLEDGE
IST-3.C Describe the components of a signal transduction pathway.	**IST-3.C.1** Signal transduction pathways link signal reception with cellular responses. **IST-3.C.2** Many signal transduction pathways include protein modification and phosphorylation cascades.
IST-3.D Describe the role of components of a signal transduction pathway in producing a cellular response.	**IST-3.D.1** Signaling begins with the recognition of a chemical messenger—a ligand—by a receptor protein in a target cell— a. The ligand-binding domain of a receptor recognizes a specific chemical messenger, which can be a peptide, a small chemical, or protein, in a specific one-to-one relationship. b. G protein-coupled receptors are an example of a receptor protein in eukaryotes. **IST-3.D.2** Signaling cascades relay signals from receptors to cell targets, often amplifying the incoming signals, resulting in the appropriate responses by the cell, which could include cell growth, secretion of molecules, or gene expression—

continued on next page

LEARNING OBJECTIVE

IST-3.D

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

ESSENTIAL KNOWLEDGE

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

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

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

TOPIC 4.3
Signal Transduction

Required Course Content

ENDURING UNDERSTANDING

IST-3

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

LEARNING OBJECTIVE

IST-3.E

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

IST-3.F

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

ESSENTIAL KNOWLEDGE

IST-3.E.1

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

IST-3.F.1

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

SUGGESTED SKILL

Argumentation

6.C

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

AVAILABLE RESOURCES

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

ILLUSTRATIVE EXAMPLES

Using Signal Transduction to Respond to the Environment

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

IST-3.F.1

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

SUGGESTED SKILL

Argumentation

6.E.b

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

AVAILABLE RESOURCES

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

TOPIC 4.4
Changes in Signal Transduction Pathways

Required Course Content

ENDURING UNDERSTANDING

IST-3

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

LEARNING OBJECTIVE

IST-3.G

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

ESSENTIAL KNOWLEDGE

IST-3.G.1

Changes in signal transduction pathways can alter cellular response—

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

IST-3.G.2

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

TOPIC 4.5
Feedback

Required Course Content

ENDURING UNDERSTANDING

ENE-3

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

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

SUGGESTED SKILL

Argumentation

6.E.b

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

AVAILABLE RESOURCES

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

ILLUSTRATIVE EXAMPLE

ENE-3.B.1

- Blood sugar regulation by insulin/glucagon

ENE-3.C.1

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

SUGGESTED SKILLS

Representing and Describing Data

4.B.b

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

Statistical Tests and Data Analysis

5.A.e

Perform mathematical calculations, including percentages.

AVAILABLE RESOURCES

- AP Biology Lab Manual > Mitosis Lab

TOPIC 4.6
Cell Cycle

Required Course Content

ENDURING UNDERSTANDING

IST-1

Heritable information provides for continuity of life.

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

TOPIC 4.7 Regulation of Cell Cycle

SUGGESTED SKILL

Argumentation

6.E.a

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

Required Course Content

ENDURING UNDERSTANDING

IST-1

Heritable information provides for continuity of life.

LEARNING OBJECTIVE

IST-1.D

Describe the role of checkpoints in regulating the cell cycle.

ESSENTIAL KNOWLEDGE

IST-1.D.1

A number of internal controls or checkpoints regulate progression through the cycle.

IST-1.D.2

Interactions between cyclins and cyclin-dependent kinases control the cell cycle.

EXCLUSION STATEMENT—*Knowledge of specific cyclin-CdK pairs or growth factors is beyond the scope of the course and the AP Exam.*

IST-1.E

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

IST-1.E.1

Disruptions to the cell cycle may result in cancer and/or programmed cell death (apoptosis).

AP BIOLOGY

UNIT 5

Heredity

8–11%
AP EXAM WEIGHTING

~9–11
CLASS PERIODS

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

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

Personal Progress Check 5

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

- Interpreting and Evaluating Experimental Results with Graphing
- Conceptual Analysis

UNIT 5

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

Heredity

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

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

BIG IDEA 4
Systems Interactions SYI
- How does the diversity of a species affect inheritance?

Developing Understanding

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

Building Science Practices

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

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

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

Preparing for the AP Exam

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

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

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

UNIT 5

Heredity

UNIT AT A GLANCE

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

SAMPLE INSTRUCTIONAL ACTIVITIES

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

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

Unit Planning Notes

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

SUGGESTED SKILL

Concept Explanation

1.B

Explain biological concepts and/or processes.

AVAILABLE RESOURCES

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

TOPIC 5.1
Meiosis

Required Course Content

ENDURING UNDERSTANDING

IST-1

Heritable information provides for continuity of life.

LEARNING OBJECTIVE

IST-1.F

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

ESSENTIAL KNOWLEDGE

IST-1.F.1

Meiosis is a process that ensures the formation of haploid gamete cells in sexually reproducing diploid organisms—

a. Meiosis results in daughter cells with half the number of chromosomes of the parent cell.
b. Meiosis involves two rounds of a sequential series of steps (meiosis I and meiosis II).

IST-1.G

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

IST-1.G.1

Mitosis and meiosis are similar in the way chromosomes segregate but differ in the number of cells produced and the genetic content of the daughter cells.

TOPIC 5.2
Meiosis and Genetic Diversity

Required Course Content

ENDURING UNDERSTANDING

IST-1

Heritable information provides for continuity of life.

LEARNING OBJECTIVE

IST-1.H

Explain how the process of meiosis generates genetic diversity.

ESSENTIAL KNOWLEDGE

IST-1.H.1

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

IST-1.H.2

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

IST-1.H.3

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

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

SUGGESTED SKILL

Questions and Methods

3.A

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

AVAILABLE RESOURCES

- AP Biology Lab Manual> Meiosis Lab

SUGGESTED SKILLS

Argumentation

6.E.c

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

Statistical Tests and Data Analysis

5.C

Perform chi-square hypothesis testing.

TOPIC 5.3
Mendelian Genetics

Required Course Content

ENDURING UNDERSTANDING

EVO-2

Organisms are linked by lines of descent from common ancestry.

IST-1

Heritable information provides for continuity of life.

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

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LEARNING OBJECTIVE

IST-1.I

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

ESSENTIAL KNOWLEDGE

IST-1.I.2

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

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

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

RELEVANT EQUATION

Laws of Probability—

If A and B are mutually exclusive, then:

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

If A and B are independent, then:

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

SUGGESTED SKILLS

Statistical Tests and Data Analysis

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

5.C
Select and perform appropriate statistical hypothesis testing.

ILLUSTRATIVE EXAMPLES

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

TOPIC 5.4
Non-Mendelian Genetics

Required Course Content

ENDURING UNDERSTANDING

IST-1
Heritable information provides for continuity of life.

LEARNING OBJECTIVE

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

ESSENTIAL KNOWLEDGE

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

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

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

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

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LEARNING OBJECTIVE

IST-1.J

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

ESSENTIAL KNOWLEDGE

IST-1.J.4

Some traits result from non-nuclear inheritance—

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

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

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

SUGGESTED SKILL

Concept Explanation

1.C

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

ILLUSTRATIVE EXAMPLES

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

TOPIC 5.5
Environmental Effects on Phenotype

Required Course Content

ENDURING UNDERSTANDING

SYI-3

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

LEARNING OBJECTIVE

SYI-3.B

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

ESSENTIAL KNOWLEDGE

SYI-3.B.1

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

TOPIC 5.6 Chromosomal Inheritance

Required Course Content

ENDURING UNDERSTANDING

SYI-3

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

LEARNING OBJECTIVE

SYI-3.C

Explain how chromosomal inheritance generates genetic variation in sexual reproduction.

ESSENTIAL KNOWLEDGE

SYI-3.C.1

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

SYI-3.C.2

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

SYI-3.C.3

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

SUGGESTED SKILL

Argumentation

6.E.b

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

ILLUSTRATIVE EXAMPLES

SYI-3.C.3

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

AP BIOLOGY

UNIT 6

Gene Expression and Regulation

12–16%
AP EXAM WEIGHTING

~18–21
CLASS PERIODS

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

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

Personal Progress Check 6

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

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

UNIT 6

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

Gene Expression and Regulation

BIG IDEA 3
Information Storage and Transmission IST

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

Developing Understanding

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

Building Science Practices

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

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

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

Preparing for the AP Exam

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

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

UNIT AT A GLANCE

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

SAMPLE INSTRUCTIONAL ACTIVITIES

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

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

Unit Planning Notes

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

SUGGESTED SKILL

Concept Explanation

1.C

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

AVAILABLE RESOURCES

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

TOPIC 6.1
DNA and RNA Structure

Required Course Content

ENDURING UNDERSTANDING

IST-1

Heritable information provides for continuity of life.

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

TOPIC 6.2
Replication

Required Course Content

ENDURING UNDERSTANDING

IST-1

Heritable information provides for continuity of life.

LEARNING OBJECTIVE

IST-1.M

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

ESSENTIAL KNOWLEDGE

IST-1.M.1

DNA replication ensures continuity of hereditary information—

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

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

SUGGESTED SKILL

Visual Representations

2.B.b

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

AVAILABLE RESOURCES

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

SUGGESTED SKILL

Visual Representations

2.B.b

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

AVAILABLE RESOURCES

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

TOPIC 6.3
Transcription and RNA Processing

Required Course Content

ENDURING UNDERSTANDING

IST-1

Heritable information provides for continuity of life.

LEARNING OBJECTIVE

IST-1.N

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

ESSENTIAL KNOWLEDGE

IST-1.N.1

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

a. mRNA molecules carry information from DNA to the ribosome.
b. Distinct tRNA molecules bind specific amino acids and have anti-codon sequences that base pair with the mRNA. tRNA is recruited to the ribosome during translation to generate the primary peptide sequence based on the mRNA sequence.
c. rRNA molecules are functional building blocks of ribosomes.

IST-1.N.2

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

IST-1.N.3

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

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LEARNING OBJECTIVE

IST-1.N

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

ESSENTIAL KNOWLEDGE

IST-1.N.4

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

IST-1.N.5

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

IST-1.N.6

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

a. Addition of a poly-A tail.
b. Addition of a GTP cap.
c. Excision of introns and splicing and retention of exons.
d. Excision of introns and splicing and retention of exons can generate different versions of the resulting mRNA molecule; this is known as alternative splicing.

SUGGESTED SKILLS

Argumentation

6.E.a

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

Visual Representations

2.D.b

Represent relationships within biological models, including diagrams.

AVAILABLE RESOURCES

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

TOPIC 6.4
Translation

Required Course Content

ENDURING UNDERSTANDING

IST-1

Heritable information provides for continuity of life.

LEARNING OBJECTIVE

IST-1.O

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

ESSENTIAL KNOWLEDGE

IST-1.O.1

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

IST-1.O.2

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

IST-1.O.3

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

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

IST-1.O.4

The salient features of translation include—

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

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

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LEARNING OBJECTIVE

IST-1.0

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

ESSENTIAL KNOWLEDGE

c. Each codon encodes a specific amino acid, which can be deduced by using a genetic code chart. Many amino acids are encoded by more than one codon.

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

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

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

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

h. The process terminates by release of the newly synthesized polypeptide/protein.

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

IST-1.0.5

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

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

SUGGESTED SKILL

Argumentation

6.A

Make a scientific claim.

AVAILABLE RESOURCES

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

TOPIC 6.5
Regulation of Gene Expression

Required Course Content

ENDURING UNDERSTANDING

IST-2

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

LEARNING OBJECTIVE	ESSENTIAL KNOWLEDGE
IST-2.A Describe the types of interactions that regulate gene expression.	**IST-2.A.1** Regulatory sequences are stretches of DNA that interact with regulatory proteins to control transcription. **IST-2.A.2** Epigenetic changes can affect gene expression through reversible modifications of DNA or histones. **IST-2.A.3** The phenotype of a cell or organism is determined by the combination of genes that are expressed and the levels at which they are expressed— a. Observable cell differentiation results from the expression of genes for tissue-specific proteins. b. Induction of transcription factors during development results in sequential gene expression.
IST-2.B Explain how the location of regulatory sequences relates to their function.	**IST-2.B.1** Both prokaryotes and eukaryotes have groups of genes that are coordinately regulated— a. In prokaryotes, groups of genes called operons are transcribed in a single mRNA molecule. The *lac* operon is an example of an inducible system. b. In eukaryotes, groups of genes may be influenced by the same transcription factors to coordinately regulate expression.

TOPIC 6.6
Gene Expression and Cell Specialization

Required Course Content

ENDURING UNDERSTANDING

IST-2

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

LEARNING OBJECTIVE

IST-2.C

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

ESSENTIAL KNOWLEDGE

IST-2.C.1

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

IST-2.C.2

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

IST-2.D

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

IST-2.D.1

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

IST-2.D.2

Certain small RNA molecules have roles in regulating gene expression.

SUGGESTED SKILL

Argumentation

6.B

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

AVAILABLE RESOURCES

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

SUGGESTED SKILLS

Visual Representations

2.C

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

Questions and Methods

3.D

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

AVAILABLE RESOURCES

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

ILLUSTRATIVE EXAMPLES

IST-2.E.1

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

IST-4.B.1

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

TOPIC 6.7
Mutations

Required Course Content

ENDURING UNDERSTANDING

IST-2

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

LEARNING OBJECTIVE

IST-2.E

Describe the various types of mutation.

ESSENTIAL KNOWLEDGE

IST-2.E.1

Changes in genotype can result in changes in phenotype—

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

IST-2.E.2

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

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ENDURING UNDERSTANDING

IST-4

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

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

SUGGESTED SKILL

Argumentation

6.D

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

AVAILABLE RESOURCES

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

ILLUSTRATIVE EXAMPLES

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

TOPIC 6.8
Biotechnology

Required Course Content

ENDURING UNDERSTANDING

IST-1

Heritable information provides for continuity of life.

LEARNING OBJECTIVE

IST-1.P

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

ESSENTIAL KNOWLEDGE

IST-1.P.1

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

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

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

AP BIOLOGY

UNIT 7

Natural Selection

13–20%
AP EXAM WEIGHTING

~20–23
CLASS PERIODS

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

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

Personal Progress Check 7

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

- Interpreting and Evaluating Experimental Results with Graphing
- Analyze Data

UNIT 7

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

Natural Selection

BIG IDEA 1
Evolution EVO

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

BIG IDEA 4
Systems Interactions SYI

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

Developing Understanding

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

Building Science Practices

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

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

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

Preparing for the AP Exam

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

UNIT AT A GLANCE

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

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UNIT AT A GLANCE *(cont'd)*

Enduring Understanding	Topic	Suggested Skill	Class Periods ~20–23 CLASS PERIODS
EVO-3	**7.8 Continuing Evolution**	3.E.a Propose a new/next investigation based on an evaluation of the evidence from an experiment.	
	7.9 Phylogeny	2.D.c Represent relationships within biological models, including flowcharts.	
	7.10 Speciation	6.E.a Predict the causes or effects of a change in, or disruption to, one or more components in a biological system based on biological concepts or processes. 2.B.a Explain relationships between different characteristics of biological concepts, processes, or models represented visually in theoretical contexts.	
	7.11 Extinction	3.B State the null and alternative hypotheses, or predict the results of an experiment.	
SYI-3	**7.12 Variations in Populations**	6.C Provide reasoning to justify a claim by connecting evidence to biological theories.	
	7.13 Origin of Life on Earth	3.B State the null and alternative hypotheses, or predict the results of an experiment.	
	Go to **AP Classroom** to assign the **Personal Progress Check** for Unit 7. Review the results in class to identify and address any student misunderstandings.		

SAMPLE INSTRUCTIONAL ACTIVITIES

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

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

Unit Planning Notes

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

TOPIC 7.1
Introduction to Natural Selection

Required Course Content

ENDURING UNDERSTANDING

EVO-1

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

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

SUGGESTED SKILL

Visual Representations

2.A

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

AVAILABLE RESOURCES

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

SUGGESTED SKILL

Concept Explanation

1.B

Explain biological concepts and/or processes.

AVAILABLE RESOURCES

- Classroom Resources > **Evolution and Change**

ILLUSTRATIVE EXAMPLES

EVO-1.E.2

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

EVO-1.E.3 B

- Sickle cell anemia
- DDT resistance in insects

TOPIC 7.2
Natural Selection

Required Course Content

ENDURING UNDERSTANDING

EVO-1

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

LEARNING OBJECTIVE

EVO-1.E

Describe the importance of phenotypic variation in a population.

ESSENTIAL KNOWLEDGE

EVO-1.E.1

Natural selection acts on phenotypic variations in populations.

EVO-1.E.2

Environments change and apply selective pressures to populations.

EVO-1.E.3

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

TOPIC 7.3
Artificial Selection

Required Course Content

ENDURING UNDERSTANDING

EVO-1

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

LEARNING OBJECTIVE

EVO-1.F

Explain how humans can affect diversity within a population.

EVO-1.G

Explain the relationship between changes in the environment and evolutionary changes in the population.

ESSENTIAL KNOWLEDGE

EVO-1.F.1

Through artificial selection, humans affect variation in other species.

EVO-1.G.1

Convergent evolution occurs when similar selective pressures result in similar phenotypic adaptations in different populations or species.

SUGGESTED SKILL

Representing and Describing Data

4.B.c

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

AVAILABLE RESOURCES

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

SUGGESTED SKILL

Questions and Methods

3.B

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

AVAILABLE RESOURCES

- Classroom Resources > **Evolution and Change**

TOPIC 7.4
Population Genetics

Required Course Content

ENDURING UNDERSTANDING

EVO-1

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

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

TOPIC 7.5
Hardy-Weinberg Equilibrium

Required Course Content

ENDURING UNDERSTANDING

EVO-1

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

LEARNING OBJECTIVE

EVO-1.K

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

ESSENTIAL KNOWLEDGE

EVO-1.K.1

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

EVO-1.K.2

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

RELEVANT EQUATION

Hardy-Weinberg Equation—

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

$$p + q = 1$$

where:

p = frequency of allele 1 in the population

q = frequency of allele 2 in the population

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SUGGESTED SKILLS

Statistical Tests

5.A.a

Perform mathematical calculations, including mathematical equations in the curriculum.

Data Analysis and Concept Explanation

1.C

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

AVAILABLE RESOURCES

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

ILLUSTRATIVE EXAMPLE

EVE-1.K.2

- Graphical analysis of allele frequencies in a population

UNIT 7

Natural Selection

LEARNING OBJECTIVE

EVO-1.L

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

ESSENTIAL KNOWLEDGE

EVO-1.L.1

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

EVO-1.L.2

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

TOPIC 7.6
Evidence of Evolution

Required Course Content

ENDURING UNDERSTANDING

EVO-1

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

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

SUGGESTED SKILL

Representing and Describing Data

4.B.a

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

AVAILABLE RESOURCES

- Classroom Resources > **Evolution and Change**

UNIT 7

Natural Selection

ENDURING UNDERSTANDING

EVO-2

Organisms are linked by lines of descent from common ancestry.

LEARNING OBJECTIVE

EVO-2.B

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

ESSENTIAL KNOWLEDGE

EVO-2.B.1

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

EVO-2.B.2

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

TOPIC 7.7
Common Ancestry

Required Course Content

ENDURING UNDERSTANDING

EVO-2

Organisms are linked by lines of descent from common ancestry.

LEARNING OBJECTIVE

EVO-2.C

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

ESSENTIAL KNOWLEDGE

EVO-2.C.1

Structural evidence indicates common ancestry of all eukaryotes—

a. Membrane-bound organelles

b. Linear chromosomes

c. Genes that contain introns

SUGGESTED SKILL

Argumentation

6.E.b

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

AVAILABLE RESOURCES

- Classroom Resources > **Evolution and Change**

SUGGESTED SKILL

Questions and Methods

3.E.a

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

AVAILABLE RESOURCES

- Classroom Resources > **Evolution and Change**

TOPIC 7.8
Continuing Evolution

Required Course Content

ENDURING UNDERSTANDING

EVO-3

Life continues to evolve within a changing environment.

LEARNING OBJECTIVE

EVO-3.A

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

ESSENTIAL KNOWLEDGE

EVO-3.A.1

Populations of organisms continue to evolve.

EVO-3.A.2

All species have evolved and continue to evolve—

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

TOPIC 7.9 Phylogeny

SUGGESTED SKILL

Visual Representations

2.D.c

Represent relationships within biological models, including flowcharts.

AVAILABLE RESOURCES

- Classroom Resources > **Evolution and Change**

Required Course Content

ENDURING UNDERSTANDING

EVO-3

Life continues to evolve within a changing environment.

LEARNING OBJECTIVE

EVO-3.B

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

ESSENTIAL KNOWLEDGE

EVO-3.B.1

Phylogenetic trees and cladograms show evolutionary relationships among lineages—

a. Phylogenetic trees and cladograms both show relationships between lineages, but phylogenetic trees show the amount of change over time calibrated by fossils or a molecular clock.
b. Traits that are either gained or lost during evolution can be used to construct phylogenetic trees and cladograms—
    i. Shared characters are present in more than one lineage.
    ii. Shared, derived characters indicate common ancestry and are informative for the construction of phylogenetic trees and cladograms.
    iii. The out-group represents the lineage that is least closely related to the remainder of the organisms in the phylogenetic tree or cladogram.
c. Molecular data typically provide more accurate and reliable evidence than morphological traits in the construction of phylogenetic trees or cladograms.

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UNIT 7

Natural Selection

LEARNING OBJECTIVE

EVO-3.C

Explain how a phylogenetic tree and/or cladogram can be used to infer evolutionary relatedness.

ESSENTIAL KNOWLEDGE

EVO-3.C.1

Phylogenetic trees and cladograms can be used to illustrate speciation that has occurred. The nodes on a tree represent the most recent common ancestor of any two groups or lineages.

EVO-3.C.2

Phylogenetic trees and cladograms can be constructed from morphological similarities of living or fossil species and from DNA and protein sequence similarities.

EVO-3.C.3

Phylogenetic trees and cladograms represent hypotheses and are constantly being revised, based on evidence.

TOPIC 7.10
Speciation

Required Course Content

ENDURING UNDERSTANDING

EVO-3

Life continues to evolve within a changing environment.

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

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SUGGESTED SKILLS

Argumentation

6.E.a

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

Visual Representations

2.B.a

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

AVAILABLE RESOURCES

- Classroom Resources > **Evolution and Change**

ILLUSTRATIVE EXAMPLES

EVO-3.F.1

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

Natural Selection

LEARNING OBJECTIVE

EVO-3.F

Explain the processes and mechanisms that drive speciation.

ESSENTIAL KNOWLEDGE

EVO-3.F.1

Speciation results in diversity of life forms.

EVO-3.F.2

Speciation may be sympatric or allopatric.

EVO-3.F.3

Various prezygotic and postzygotic mechanisms can maintain reproductive isolation and prevent gene flow between populations.

TOPIC 7.11 Extinction

Required Course Content

ENDURING UNDERSTANDING

EVO-3

Life continues to evolve within a changing environment.

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

SUGGESTED SKILL

Questions and Methods

3.B

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

AVAILABLE RESOURCES

- Classroom Resources > **Evolution and Change**

SUGGESTED SKILL

Argumentation

6.C

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

AVAILABLE RESOURCES

- Classroom Resources > **Evolution and Change**

ILLUSTRATIVE EXAMPLES

SYI-3.D.1.a

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

TOPIC 7.12
Variations in Populations

Required Course Content

ENDURING UNDERSTANDING

SYI-3

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

LEARNING OBJECTIVE

SYI-3.D

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

ESSENTIAL KNOWLEDGE

SYI-3.D.1

The level of variation in a population affects population dynamics—

a. Population ability to respond to changes in the environment is influenced by genetic diversity. Species and populations with little genetic diversity are at risk of decline or extinction.
b. Genetically diverse populations are more resilient to environmental perturbation because they are more likely to contain individuals who can withstand the environmental pressure.
c. Alleles that are adaptive in one environmental condition may be deleterious in another because of different selective pressures.

TOPIC 7.13 Origins of Life on Earth

Required Course Content

ENDURING UNDERSTANDING

SYI-3

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

LEARNING OBJECTIVE

SYI-3.E

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

ESSENTIAL KNOWLEDGE

SYI-3.E.1

Several hypotheses about the origin of life on Earth are supported with scientific evidence—

a. Geological evidence provides support for models of the origin of life on Earth.
   i. Earth formed approximately 4.6 billion years ago (bya). The environment was too hostile for life until 3.9 bya, and the earliest fossil evidence for life dates to 3.5 bya. Taken together, this evidence provides a plausible range of dates when the origin of life could have occurred.

b. There are several models about the origin of life on Earth—
   i. Primitive Earth provided inorganic precursors from which organic molecules could have been synthesized because of the presence of available free energy and the absence of a significant quantity of atmospheric oxygen (O_2).
   ii. Organic molecules could have been transported to Earth by a meteorite or other celestial event.

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SUGGESTED SKILL

Questions and Methods

3.B

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

AVAILABLE RESOURCES

- Classroom Resources > **Evolution and Change**

Natural Selection

LEARNING OBJECTIVE

SYI-3.E

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

ESSENTIAL KNOWLEDGE

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

SYI-3.E.2

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

AP BIOLOGY

UNIT 8

Ecology

10–15%
AP EXAM WEIGHTING

~18–21
CLASS PERIODS

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

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

Personal Progress Check 8

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

- Interpreting and Evaluating Experimental Results with Graphing
- Scientific Investigation

UNIT 8

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

Ecology

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

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

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

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

Developing Understanding

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

Building Science Practices

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

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

Preparing for the AP Exam

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

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

UNIT AT A GLANCE

Enduring Understanding	Topic	Suggested Skill	Class Periods ~18–21 CLASS PERIODS
ENE-3, IST-5	**8.1 Responses to the Environment**	3.C.a Identify experimental procedures that are aligned to the question, including identifying dependent and independent variables.	
ENE-1	**8.2 Energy Flow Through Ecosystems**	6.D Explain the relationship between experimental results and larger biological concepts, processes, or theories.	
SYI-1	**8.3 Population Ecology**	4.A Construct a graph, plot, or chart.	
	8.4 Effect of Density of Populations	5.A.c Perform mathematical calculations, including rates.	
ENE-4	**8.5 Community Ecology**	5.B Use confidence intervals and/or error bars (both determined using standard errors) to determine whether sample means are statistically different.	
SYI-3	**8.6 Biodiversity**	6.E.c Predict the causes or effects of a change in, or disruption to, one or more components in a biological system based on data.	
EVO-1, SYI-2	**8.7 Disruptions to Ecosystems**	5.D.a Use data to evaluate a hypothesis (or prediction), including rejecting or failing to reject the null hypothesis. 5.D.b Use data to evaluate a hypothesis (or prediction), including supporting or refuting the alternative hypothesis.	
	Go to **AP Classroom** to assign the **Personal Progress Check** for Unit 8. Review the results in class to identify and address any student misunderstandings.		

SAMPLE INSTRUCTIONAL ACTIVITIES

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

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

Unit Planning Notes

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

SUGGESTED SKILL

Questions and Methods

3.C.a

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

AVAILABLE RESOURCES

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

ILLUSTRATIVE EXAMPLES

ENE-3.D.1

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

ENE-3.D.2

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

IST-5.A.2.a

- Territorial marking in mammals
- Coloration in flowers

IST-5.A.2.b

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

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TOPIC 8.1
Responses to the Environment

Required Course Content

ENDURING UNDERSTANDING

ENE-3

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

LEARNING OBJECTIVE

ENE-3.D

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

ESSENTIAL KNOWLEDGE

ENE-3.D.1

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

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

ENE-3.D.2

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

ENDURING UNDERSTANDING

IST-5

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

LEARNING OBJECTIVE

IST-5.A

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

ESSENTIAL KNOWLEDGE

IST-5.A.1

Individuals can act on information and communicate it to others.

IST-5.A.2

Communication occurs through various mechanisms—

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

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

IST-5.A.3

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

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

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

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

ILLUSTRATIVE EXAMPLES

IST-5.A.3.a

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

IST-5.A.3.b

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

SUGGESTED SKILL

Argumentation

6.D

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

AVAILABLE RESOURCES

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

ILLUSTRATIVE EXAMPLES

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

ENE-1.N.1

- Food chains/webs
- Trophic pyramids/ diagrams

TOPIC 8.2
Energy Flow Through Ecosystems

Required Course Content

ENDURING UNDERSTANDING

ENE-1

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

LEARNING OBJECTIVE

ENE-1.M

Describe the strategies organisms use to acquire and use energy.

ESSENTIAL KNOWLEDGE

ENE-1.M.1

Organisms use energy to maintain organization, grow, and reproduce—

a. Organisms use different strategies to regulate body temperature and metabolism.
   i. Endotherms use thermal energy generated by metabolism to maintain homeostatic body temperatures.
   ii. Ectotherms lack efficient internal mechanisms for maintaining body temperature, though they may regulate their temperature behaviorally by moving into the sun or shade or by aggregating with other individuals.
b. Different organisms use various reproductive strategies in response to energy availability.
c. There is a relationship between metabolic rate per unit body mass and the size of multicellular organisms—generally, the smaller the organism, the higher the metabolic rate.
d. A net gain in energy results in energy storage or the growth of an organism.
e. A net loss of energy results in loss of mass and, ultimately, the death of an organism.

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

SUGGESTED SKILL

Representing and Describing Data

4.A

Construct a graph, plot, or chart.

AVAILABLE RESOURCES

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

TOPIC 8.3
Population Ecology

Required Course Content

ENDURING UNDERSTANDING

SYI-1

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

LEARNING OBJECTIVE

SYI-1.G

Describe factors that influence growth dynamics of populations.

ESSENTIAL KNOWLEDGE

SYI-1.G.1

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

SYI-1.G.2

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

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

RELEVANT EQUATION

Population Growth—

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

where:

dt = chage in time

B = birth rate

D = death rate

N = population size

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

continued on next page

LEARNING OBJECTIVE

SYI-1.G

Describe factors that influence growth dynamics of populations.

ESSENTIAL KNOWLEDGE

RELEVANT EQUATION

Exponential Growth—

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

where:

dt = change in time

N = population size

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

SUGGESTED SKILL

Statistical Tests and Data Analysis

5.A.c

Perform mathematical calculations, including rates.

TOPIC 8.4
Effect of Density of Populations

Required Course Content

ENDURING UNDERSTANDING

SYI-1

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

LEARNING OBJECTIVE

SYI-1.H

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

ESSENTIAL KNOWLEDGE

SYI-1.H.1

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

SYI-1.H.2

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

RELEVANT EQUATION

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

where:

dt = change in time

N = population size

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

K = carrying capacity

TOPIC 8.5
Community Ecology

SUGGESTED SKILL

Statistical Tests and Data Analysis

5.B

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

Required Course Content

ENDURING UNDERSTANDING

ENE-4

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

LEARNING OBJECTIVE

ENE-4.A

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

ESSENTIAL KNOWLEDGE

ENE-4.A.1

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

RELEVANT EQUATION

Simpson's Diversity Index—

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

n = the total number of organisms of a particular species

N = total number of organisms of all species

ENE-4.B

Explain how interactions within and among populations influence community structure.

ENE-4.B.1

Communities change over time depending on interactions between populations.

ENE-4.B.2

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

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

TOPIC 8.6
Biodiversity

SUGGESTED SKILL

Argumentation

6.E.c

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

Required Course Content

ENDURING UNDERSTANDING

SYI-3

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

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

SUGGESTED SKILLS

Statistical Tests and Data Analysis

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

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

ILLUSTRATIVE EXAMPLES

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

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

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

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

TOPIC 8.7
Disruptions to Ecosystems

Required Course Content

ENDURING UNDERSTANDING

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

LEARNING OBJECTIVE

EVO-1.O
Explain the interaction between the environment and random or preexisting variations in populations.

ESSENTIAL KNOWLEDGE

EVO-1.O.1
An adaptation is a genetic variation that is favored by selection and is manifested as a trait that provides an advantage to an organism in a particular environment.

EVO-1.O.2
Mutations are random and are not directed by specific environmental pressures.

ENDURING UNDERSTANDING

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

LEARNING OBJECTIVE

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

ESSENTIAL KNOWLEDGE

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

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