AP BIOLOGY

# UNIT 1

# Chemistry of Life

**8–11%**
AP EXAM WEIGHTING

**~9–11**
CLASS PERIODS

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

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

## Progress Check 1

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

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

UNIT 1

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

# Chemistry of Life

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

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

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

## Developing Understanding

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

## Building Science Practices

1.A 2.A 6.E

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

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

## Preparing for the AP Exam

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

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

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

# UNIT AT A GLANCE

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

# SAMPLE INSTRUCTIONAL ACTIVITIES

The sample activities on this page are optional ways to incorporate varied instructional approaches in the teaching of this course. You do not need to use these activities or instructional approaches and are encouraged to adapt the activities to best support students in your classroom. The following examples were developed in partnership with teachers from the AP community to share ways that they approach teaching some of the topics in this unit. Please refer to the Instructional Approaches section beginning on p. 171 for more examples of activities and strategies.

| Activity | Topic | Sample Activity |
|---|---|---|
| 1 | 1.1 | **Graph and Switch**<br>Have students determine how many drops of water can fit onto a penny. They can add various substances (e.g., salt, sugar, vinegar, dish detergent) to the water to investigate how the surface tension of the water is affected. Ask students to graph their data and calculate descriptive statistics. Finally, students should switch graphs with a peer to compare and discuss findings. |
| 2 | 1.1<br>1.3 | **Index Card Summaries/Questions**<br>Have students use diagrams of water, glucose, amino acids, nucleotides, glycerol, and fatty acids to learn how dehydration synthesis builds molecules. Find the diagrams online and print the templates on colored paper so that students can easily differentiate water from the various monomers in order to visualize the formation of the covalent bonds. Then, ask students to respond to each diagram, using index cards to summarize their understanding or ask any outstanding questions. |
| 3 | 1.4<br>1.5<br>1.6<br>1.7 | **Think-Pair-Share**<br>Distribute cards containing pictures of biological molecules to students and ask them to find patterns in the molecules. They should identify the building blocks, functional groups, and monomers and mark them on each card, and then organize the cards based on similarities in their structures. After students mark up the molecules on their set of cards, have them pair up with another student and identify each of the molecules on the cards with their classmate. |

**SUGGESTED SKILL**

*Visual Representations*

**2.A**

Describe characteristics of visual representations of biological concepts and processes.

# TOPIC 1.1
# Structure of Water and Hydrogen Bonding

## Required Course Content

### BIG IDEA 4

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

### LEARNING OBJECTIVE

**1.1.A**

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

### ESSENTIAL KNOWLEDGE

**1.1.A.1**

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

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

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

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

**1.1.A.2**

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

# TOPIC 1.2
# Elements of Life

**SUGGESTED SKILL**

*Visual Representations*

**2.A**

Describe characteristics of visual representations of biological concepts and processes.

## Required Course Content

### BIG IDEA 2

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

### LEARNING OBJECTIVE

**1.2.A**

Describe the composition of macromolecules required by living organisms.

### ESSENTIAL KNOWLEDGE

**1.2.A.1**

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

i. Sulfur is used in the building of proteins.

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

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

**SUGGESTED SKILL**

*Visual Representations*

**2.A**

Describe characteristics of visual representations of biological concepts and processes.

**AVAILABLE RESOURCE**

- AP Central > Classroom Resources > Visualizing Information

# TOPIC 1.3
# Introduction to Macromolecules

## Required Course Content

### BIG IDEA 4

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

### LEARNING OBJECTIVE

**1.3.A**

Describe the chemical reactions that build and break biological macromolecules.

### ESSENTIAL KNOWLEDGE

**1.3.A.1**

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

**1.3.A.2**

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

# TOPIC 1.4
# Carbohydrates

SUGGESTED SKILL

*Concept Explanation*

1.A

Describe biological concepts and processes.

## Required Course Content

### BIG IDEA 4

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

#### LEARNING OBJECTIVE

1.4.A

Describe the structure and function of carbohydrates.

#### ESSENTIAL KNOWLEDGE

1.4.A.1

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

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

ILLUSTRATIVE EXAMPLES

EK 1.4.A.1

- Cellulose
- Starch
- Glycogen

**SUGGESTED SKILL**

*Argumentation*

6.E

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

# TOPIC 1.5
# Lipids

## Required Course Content

### BIG IDEA 4

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

### LEARNING OBJECTIVE

1.5.A

Describe the structure and function of lipids.

### ESSENTIAL KNOWLEDGE

1.5.A.1

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

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

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

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

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

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## LEARNING OBJECTIVE

1.5.A

Describe the structure and function of lipids.

## ESSENTIAL KNOWLEDGE

**1.5.A.2**

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

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

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

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

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

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

**SUGGESTED SKILL**

*Visual Representations*

**2.A**

Describe characteristics of visual representations of biological concepts and processes.

# TOPIC 1.6
# Nucleic Acids

## Required Course Content

### BIG IDEA 3

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

### LEARNING OBJECTIVE

**1.6.A**

Describe the structure and function of DNA and RNA.

### ESSENTIAL KNOWLEDGE

**1.6.A.1**

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

**1.6.A.2**

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

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

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## LEARNING OBJECTIVE

**1.6.A**

Describe the structure and function of DNA and RNA.

## ESSENTIAL KNOWLEDGE

**1.6.A.3**

DNA is structured as an antiparallel double helix, with two strands of nucleotides running in opposite 5′ to 3′ orientation. In DNA, adenine nucleotides pair with thymine nucleotides via hydrogen bonds (A-T), and cytosine nucleotides pair with guanine nucleotides via hydrogen bonds (C-G). In RNA, adenine pairs with uracil (A-U).

**1.6.A.4**

Structural differences between DNA and RNA include:

i. DNA contains the sugar deoxyribose, and RNA contains the sugar ribose.

ii. DNA contains the nitrogenous base thymine, and RNA contains the nitrogenous base uracil.

iii. DNA is typically double stranded, while RNA is typically single stranded.

**SUGGESTED SKILL**

*Argumentation*

6.E

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

# TOPIC 1.7
# Proteins

## Required Course Content

### BIG IDEA 3

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

### LEARNING OBJECTIVE

**1.7.A**

Describe the structure and function of proteins.

### ESSENTIAL KNOWLEDGE

**1.7.A.1**

Proteins comprise linear chains of amino acids connected by the formation of covalent (peptide) bonds that form between a carboxyl group (–COOH) of one amino acid and an amine group ($-NH_2$) of the next amino acid, resulting in a growing peptide chain.

**1.7.A.2**

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

**1.7.A.3**

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

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

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## LEARNING OBJECTIVE

**1.7.A**

Describe the structure and function of proteins.

## ESSENTIAL KNOWLEDGE

**1.7.A.4**

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

**1.7.A.5**

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

**1.7.A.6**

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

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AP BIOLOGY

# UNIT 2

# Cells

**10–13%**
AP EXAM WEIGHTING

**~14–16**
CLASS PERIODS

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

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

## Progress Check 2

**Multiple-choice: ~33 questions (2 parts)**

**Free-response: 2 questions**

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

UNIT 2

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

# Cells

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

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

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

## Developing Understanding

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

## Building Science Practices

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

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

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

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

## Preparing for the AP Exam

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

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

# UNIT AT A GLANCE

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

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# UNIT AT A GLANCE *(cont'd)*

| Topic | Suggested Skills | Class Periods<br>~14–16 CLASS PERIODS |
|---|---|---|
| **2.9 Cell Compartmentalization** | 6.E Predict the causes or effects of a change in, or disruption to, one or more components in a biological system. | |
| **2.10 Origins of Cell Compartmentalization** | 6.B Support a claim with evidence from biological principles, concepts, processes, and data. | |
| Go to **AP Classroom** to assign the **Progress Check** for Unit 2. Review the results in class to identify and address any student misunderstandings. | | |

# SAMPLE INSTRUCTIONAL ACTIVITIES

The sample activities on this page are optional ways to incorporate varied instructional approaches in the teaching of this course. You do not need to use these activities or instructional approaches and are encouraged to adapt the activities to best support students in your classroom. The following examples were developed in partnership with teachers from the AP community to share ways that they approach teaching some of the topics in this unit. Please refer to the Instructional Approaches section beginning on p. 171 for more examples of activities and strategies

| Activity | Topic | Sample Activity |
|---|---|---|
| 1 | 2.1 | **Ask the Expert**<br>Place students in groups and assign each group a cellular or subcellular component to study. Through their study, students should become "experts" on their topic. Ask students to then rotate through the expert stations to learn about the other cellular and subcellular components from their peers. |
| 2 | 2.2 | **Misconception Check**<br>Provide students with agar cubes of different sizes that are soaked in phenolphthalein, and ask them to soak the cubes in vinegar. Have students make assumptions about which cubes will become clear first, then have them time how long it takes for the cubes to become clear as the vinegar diffuses into the cubes. Students will find that the smaller cubes become clear before the larger cubes. They can use their observations to determine how cell size affects cell function. Use this transport model to discuss any misconceptions students may still have about surface area-to-volume ratio and how it affects rates of cellular transport. |
| 3 | 2.3<br>2.4<br>2.5 | **One-Minute Essay**<br>Before learning about the topic, have students read a case study about osmosis and answer questions (either those given with the case study or those you create) about the scenario. Ask students to draw what they think is occurring on the cellular level. Then teach the topic in the way that best fits your classroom. Once students have demonstrated an understanding of the topic, have them revisit their answers to the questions in the case study as well as their drawings by writing a one-minute essay about the topic. |

# TOPIC 2.1
# Cell Structure and Function

## Required Course Content

### BIG IDEA 4

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

#### LEARNING OBJECTIVE

**2.1.A**

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

#### ESSENTIAL KNOWLEDGE

**2.1.A.1**

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

**2.1.A.2**

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

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**SUGGESTED SKILLS**

*Concept Explanation*

**1.A**

Describe biological concepts and processes.

*Argumentation*

**6.A**

Make a scientific claim.

**ILLUSTRATIVE EXAMPLE**

**EK 2.1.A.4**

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

## LEARNING OBJECTIVE

2.1.A

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

## ESSENTIAL KNOWLEDGE

**2.1.A.3**

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

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

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

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

**2.1.A.4**

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

i. Correctly folding and chemically modifying newly synthesized cellular products

ii. Packaging proteins for trafficking

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

**2.1.A.5**

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

**2.1.A.6**

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

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## LEARNING OBJECTIVE

2.1.A

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

## ESSENTIAL KNOWLEDGE

**2.1.A.7**

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

i. In plant cells, a specialized large vacuole maintains turgor pressure through nutrient and water storage.

ii. In animal cells, vacuoles are smaller in size, are more plentiful than in plant cells, and store cellular materials.

**2.1.A.8**

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

**SUGGESTED SKILLS**

*Visual Representations*

**2.D**

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

*Statistical Tests and Data Analysis*

**5.A**

Perform mathematical calculations, including:

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

**ILLUSTRATIVE EXAMPLES**

**EK 2.2.A.1**

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

# TOPIC 2.2
# Cell Size

## Required Course Content

### BIG IDEA 2

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

### LEARNING OBJECTIVE

**2.2.A**

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

### ESSENTIAL KNOWLEDGE

**2.2.A.1**

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

**RELEVANT EQUATIONS**

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

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

Volume of a Rectangular Solid: $V = lwh$

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

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

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

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

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

$r$ = radius

$l$ = length

$h$ = height

$w$ = width

$s$ = length of one side of a cube

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## LEARNING OBJECTIVE

2.2.A

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

## ESSENTIAL KNOWLEDGE

**2.2.A.2**

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

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

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

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

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

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

**SUGGESTED SKILL**

*Visual Representations*

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

# TOPIC 2.3
# Plasma Membrane

## Required Course Content

### BIG IDEA 2

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

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

# TOPIC 2.4
# Membrane Permeability

**SUGGESTED SKILL**

*Statistical Tests and Data Analysis*

**5.D**

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

## Required Course Content

### BIG IDEA 2

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

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

**SUGGESTED SKILL**

*Questions and Methods*

**3.D**

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

# TOPIC 2.5
# Membrane Transport

## Required Course Content

### BIG IDEA 2

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

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

# TOPIC 2.6
# Facilitated Diffusion

**SUGGESTED SKILL**

*Argumentation*

6.E

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

## Required Course Content

### BIG IDEA 2

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

### LEARNING OBJECTIVE

**2.6.A**

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

### ESSENTIAL KNOWLEDGE

**2.6.A.1**

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

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

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

**2.6.A.2**

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

**2.6.A.3**

Aquaporins transport large quantities of water across membranes.

**SUGGESTED SKILL**

*Representing and Describing Data*

**4.A**

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

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

**AVAILABLE RESOURCES**

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

**ILLUSTRATIVE EXAMPLES**

**EK 2.7.A.1**

- Contractile vacuole in protists
- Central vacuole in plant cells

# TOPIC 2.7
# Tonicity and Osmoregulation

## Required Course Content

### BIG IDEA 2

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

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

*continued on next page*

## LEARNING OBJECTIVE

2.7.B

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

## ESSENTIAL KNOWLEDGE

**2.7.B.2**

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

### RELEVANT EQUATION

Solute Potential of a Solution:

$\psi_s = -iCRT$ where:

$i$ = ionization constant

$C$ = molar concentration

$R$ = pressure constant

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

$T$ = temperature in Kelvin (°C + 273)

**SUGGESTED SKILL**

*Concept Explanation*

**1.B**

Explain biological concepts and processes.

# TOPIC 2.8
# Mechanisms of Transport

## Required Course Content

### BIG IDEA 2

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

### LEARNING OBJECTIVE

**2.8.A**

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

### ESSENTIAL KNOWLEDGE

**2.8.A.1**

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

i. Membrane proteins are necessary for active transport.

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

# TOPIC 2.9
# Cell Compartmentalization

**SUGGESTED SKILL**

*Argumentation*

**6.E**

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

## Required Course Content

### BIG IDEA 2

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

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

**SUGGESTED SKILL**

*Argumentation*

6.B

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

# TOPIC 2.10
# Origins of Cell Compartmentalization

## Required Course Content

### BIG IDEA 1

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

### LEARNING OBJECTIVE

**2.10.A**

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

### ESSENTIAL KNOWLEDGE

**2.10.A.1**

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

**2.10.A.2**

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

**2.10.A.3**

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

AP BIOLOGY

# UNIT 3

# Cellular Energetics

**12–16%**
AP EXAM WEIGHTING

**~12–14**
CLASS PERIODS

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

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

## Progress Check 3

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

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

UNIT 3

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

# Cellular Energetics

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

## Developing Understanding

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

## Building Science Practices

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

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

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

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

## Preparing for the AP Exam

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

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

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

# UNIT AT A GLANCE

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

# SAMPLE INSTRUCTIONAL ACTIVITIES

The sample activities on this page are optional ways to incorporate varied instructional approaches in the teaching of this course. You do not need to use these activities or instructional approaches and are encouraged to adapt the activities to best support students in your classroom. The following examples were developed in partnership with teachers from the AP community to share ways that they approach teaching some of the topics in this unit. Please refer to the Instructional Approaches section beginning on p. 171 for more examples of activities and strategies.

| Activity | Topic | Sample Activity |
|---|---|---|
| 1 | 3.2 | **Error Analysis**<br>Perform the "toothpickase" activity with students by placing 100 toothpicks onto a paper towel and asking them to use their fingers to break as many toothpicks as they can in 10-second intervals (without looking). Students should keep both the broken and unbroken toothpicks mixed together on the paper towel. Each toothpick can only be broken once. Have them continue breaking toothpicks for time intervals of 60, 120, and 180 seconds. Students then graph the number of toothpicks broken at each time interval. Once they have graphed their own data, allow students to pair up and compare graphs to determine whether errors have occurred based on expected outcomes in enzyme catalysis. |
| 2 | 3.4 | **Construct an Argument**<br>Provide students with a visual representation of photosystems I and II and have them work in pairs to construct an argument about whether (or why) plants need both photosystems for photosynthesis to occur. |
| 3 | 3.5 | **Graph and Switch**<br>Have students perform a yeast fermentation lab using the sucrose solutions from the Diffusion and Osmosis lab found in the AP Biology lab manual. Students should measure the amount of carbon dioxide produced as the dependent variable. At the conclusion of the lab, collect class data. Have students graph the class data, including error bars on their graphs. |

**SUGGESTED SKILLS**

*Concept Explanation*

**1.B**

Explain biological concepts and processes.

*Questions and Methods*

**3.C**

Identify experimental procedures that align with the question, including:

i. identifying dependent and independent variables

ii. identifying appropriate controls

iii. justifying appropriate controls

# TOPIC 3.1
# Enzymes

## Required Course Content

### BIG IDEA 2

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

### LEARNING OBJECTIVE

**3.1.A**

Explain how enzymes affect the rate of biological reactions.

### ESSENTIAL KNOWLEDGE

**3.1.A.1**

The structure and function of enzymes contribute to the regulation of biological processes. Enzymes are proteins that are biological catalysts that facilitate chemical reactions in cells by lowering the activation energy.

**3.1.A.2**

For an enzyme-mediated chemical reaction to occur, the shape and charge of the substrate must be compatible with the active site of the enzyme. This is illustrated by the enzyme-substrate complex model.

# TOPIC 3.2
# Environmental Impacts on Enzyme Function

## Required Course Content

### BIG IDEA 2

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

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

**SUGGESTED SKILL**

*Argumentation*

**6.E**

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

**AVAILABLE RESOURCES**

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

## LEARNING OBJECTIVE

3.2.B

Explain how the cellular environment affects enzyme activity.

## ESSENTIAL KNOWLEDGE

**3.2.B.2**

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

**3.2.B.3**

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

# TOPIC 3.3
# Cellular Energy

**SUGGESTED SKILL**

*Argumentation*

6.C

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

## Required Course Content

### BIG IDEA 2

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

### LEARNING OBJECTIVE

**3.3.A**

Describe the role of energy in living organisms.

### ESSENTIAL KNOWLEDGE

**3.3.A.1**

All living systems require an input of energy.

**3.3.A.2**

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

i. Energy input must exceed energy loss to maintain order and to power cellular processes.
ii. Cellular processes that release energy may be coupled with cellular processes that require energy.
iii. Significant loss of order or energy flow results in death.

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

**3.3.A.3**

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

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

# TOPIC 3.4
# Photosynthesis

**SUGGESTED SKILL**

*Argumentation*

6.B

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

**AVAILABLE RESOURCES**

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

## Required Course Content

### BIG IDEA 2

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

### LEARNING OBJECTIVE

3.4.A

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

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

### ESSENTIAL KNOWLEDGE

3.4.A.1

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

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

ii. Photosynthesis first evolved in prokaryotic organisms.

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

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

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

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## LEARNING OBJECTIVE

**3.4.B**

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

## ESSENTIAL KNOWLEDGE

**3.4.B.3**

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

**3.4.B.4**

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

**3.4.B.5**

The formation of the proton gradient is linked to the synthesis of ATP from ADP and inorganic phosphate via ATP synthase. The flow of protons back through membrane-bound ATP synthase by chemiosmosis drives the formation of ATP from ADP and inorganic phosphate; this is known as photophosphorylation.

**3.4.B.6**

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

**SUGGESTED SKILL**

*Representing and Describing Data*

**4.A**

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

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

**AVAILABLE RESOURCES**

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

# TOPIC 3.5
# Cellular Respiration

## Required Course Content

### BIG IDEA 2

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

### LEARNING OBJECTIVE

**3.5.A**

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

### ESSENTIAL KNOWLEDGE

**3.5.A.1**

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

**3.5.A.2**

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

**3.5.A.3**

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

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

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## LEARNING OBJECTIVE

**3.5.A**

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

## ENDURING UNDERSTANDING

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

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

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

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

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

**3.5.B**

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

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

**3.5.B.1**

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

**3.5.B.2**

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

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## LEARNING OBJECTIVE

**3.5.B**

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

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

## ESSENTIAL KNOWLEDGE

**3.5.B.3**

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

**3.5.B.4**

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

**3.5.B.5**

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

**3.5.B.6**

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

AP BIOLOGY

# UNIT 4

# Cell Communication and Cell Cycle

**10–15%**
AP EXAM WEIGHTING

**~12–14**
CLASS PERIODS

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

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

## Progress Check 4

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

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

UNIT 4

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

# Cell Communication and Cell Cycle

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

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

## Developing Understanding

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

## Building Science Practices

1.A 1.B 4.B 5.A 6.C 6.E

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

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

## Preparing for the AP Exam

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

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

# UNIT AT A GLANCE

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

# SAMPLE INSTRUCTIONAL ACTIVITIES

The sample activities on this page are optional ways to incorporate varied instructional approaches in the teaching of this course. You do not need to use these activities or instructional approaches and are encouraged to adapt the activities to best support students in your classroom. The following examples were developed in partnership with teachers from the AP community to share ways that they approach teaching some of the topics in this unit. Please refer to the Instructional Approaches section beginning on p. 171 for more examples of activities and strategies.

| Activity | Topic | Sample Activity |
|---|---|---|
| 1 | 4.1 | **One-Minute Essay**<br>Have students conduct online research (provide reputable websites for them to use) to learn about diseases that result from a breakdown in cell communication. Assign students a one-minute essay with a prompt that allows a formative assessment of their understanding, such as, "Describe an example of communication between two cells." |
| 2 | 4.2 | **Ask the Expert**<br>Divide students into three groups and assign them to complete one of the three sections of the Signal Transduction POGIL. After a debrief with each group to clarify misconceptions, students should rotate between groups. Student "experts" can share their understanding of the model they studied and answer any questions from their classmates. Clarify any outstanding misconceptions at the end of class. |
| 3 | 4.4 | **Fishbowl**<br>Share the HHMI case study entitled "The Biochemistry and Cell Signaling Pathway of MC1R" with students. Ask them to read it and answer the questions that accompany the case study. Then set up a fishbowl for students to discuss what they learned from the case study and the applications to real life. |

**SUGGESTED SKILL**

*Concept Explanation*

**1.B**

Explain biological concepts and processes.

**AVAILABLE RESOURCE**

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

**ILLUSTRATIVE EXAMPLES**

**EK 4.1.A.1**

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

**EK 4.1.B.1**

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

**EK 4.1.B.2**

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

# TOPIC 4.1
# Cell Communication

## Required Course Content

### BIG IDEA 3

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

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

# TOPIC 4.2
# Introduction to Signal Transduction

**SUGGESTED SKILL**

*Concept Explanation*

1.A

Describe biological concepts and processes.

**AVAILABLE RESOURCE**

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

## Required Course Content

### BIG IDEA 3

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

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

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## LEARNING OBJECTIVE

4.2.B

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

## ESSENTIAL KNOWLEDGE

**4.2.B.2**

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

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

ii. Enzymes and second messengers such as cyclic AMP (cAMP) relay and amplify the intracellular signal.

iii. Hormones are an example of a signaling messenger that can travel long distances in the bloodstream.

iv. The binding of ligands to ligand-gated channels can cause the channel to open or close.

# TOPIC 4.3
# Signal Transduction Pathways

## Required Course Content

### BIG IDEA 3

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

| LEARNING OBJECTIVE | ESSENTIAL KNOWLEDGE |
|---|---|
| **4.3.A** Describe the different types of cellular responses elicited by a signal transduction pathway. | **4.3.A.1** Signal transduction may result in changes in gene expressions and cell function, which may alter phenotype or result in programmed cell death (apoptosis). |
| **4.3.B** Explain how a change in the structure of any signaling molecule affects the activity of the signaling pathway. | **4.3.B.1** Changes in signal transduction pathways can alter cellular responses. Mutations in any domain of the receptor protein or in any component of the signaling pathway may affect the downstream components by altering the subsequent transduction of the signal.<br>**4.3.B.2** Chemicals that interact with any component of the signaling pathway may activate or inhibit the pathway. |

**SUGGESTED SKILL**

*Argumentation*

**6.C**

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

**AVAILABLE RESOURCE**

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

**ILLUSTRATIVE EXAMPLES**

**EK 4.3.A.1**

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

**EK 4.3.B.1**

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

**SUGGESTED SKILL**

*Argumentation*

**6.E**

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

**AVAILABLE RESOURCE**

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

**ILLUSTRATIVE EXAMPLES**

**EK 4.4.A.1.i**

- Blood sugar regulation by insulin/glucagon

**EK 4.4.A.1.ii**

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

# TOPIC 4.4
# Feedback

## Required Course Content

### BIG IDEA 2

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

### LEARNING OBJECTIVE

**4.4.A**

Explain how positive and negative feedback helps maintain homeostasis.

### ESSENTIAL KNOWLEDGE

**4.4.A.1**

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

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

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

# TOPIC 4.5
# Cell Cycle

## Required Course Content

### BIG IDEA 3

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

#### LEARNING OBJECTIVE

**4.5.A**

Describe the events that occur in the cell cycle.

#### ESSENTIAL KNOWLEDGE

**4.5.A.1**

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

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

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

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

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

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

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

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**SUGGESTED SKILLS**

*Representing and Describing Data*

**4.B**

Describe data from a table or graph, including:

i. identifying specific data points

ii. describing trends and patterns in the data

iii. describing relationships between variables

*Statistical Tests and Data Analysis*

**5.A**

Perform mathematical calculations, including:

i. mathematical equations in the curriculum

ii. means

iii. rates

iv. ratios

v. percentages and percent changes

**AVAILABLE RESOURCE**

- AP Central > AP Biology Lab Manual > Mitosis Lab

## LEARNING OBJECTIVE

**4.5.B**

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

## ESSENTIAL KNOWLEDGE

**4.5.B.1**

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

i. Mitosis plays a role in growth, tissue repair, and asexual reproduction.
ii. Mitosis occurs in sequential steps (prophase, metaphase, anaphase, telophase) and alternates with interphase in the cell cycle.
iii. Prophase: Sister chromatids condense, mitotic spindle begins to form, and centrosomes move to opposite poles of the cell.
iv. Metaphase: Spindle fibers align chromosomes along the equator of the cell.
v. Anaphase: Paired sister chromatids separate as spindle fibers pull chromatids toward poles.
vi. Telophase: Mitotic spindle breaks down, a new nuclear envelope develops, and then the cytoplasm divides.
vii. Cytokinesis: A cleavage furrow forms in animal cells or a cell plate forms in plant cells, resulting in two new daughter cells.

# TOPIC 4.6
# Regulation of Cell Cycle

**SUGGESTED SKILL**

*Argumentation*

6.E

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

## Required Course Content

### BIG IDEA 3

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

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

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AP BIOLOGY

# UNIT 5

# Heredity

**8–11%**
AP EXAM WEIGHTING

**~8–10**
CLASS PERIODS

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

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

## Progress Check 5

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

- Interpreting and Evaluating Experimental Results with Graphing
- Conceptual Analysis

UNIT 5

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

# Heredity

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

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

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

## Developing Understanding

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

## Building Science Practices

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

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

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

## Preparing for the AP Exam

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

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

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

# UNIT AT A GLANCE

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

# SAMPLE INSTRUCTIONAL ACTIVITIES

The sample activities on this page are optional ways to incorporate varied instructional approaches in the teaching of this course. You do not need to use these activities or instructional approaches and are encouraged to adapt the activities to best support students in your classroom. The following examples were developed in partnership with teachers from the AP community to share ways that they approach teaching some of the topics in this unit. Please refer to the Instructional Approaches section beginning on p. 171 for more examples of activities and strategies.

| Activity | Topic | Sample Activity |
|---|---|---|
| 1 | 5.1 | **Think-Pair-Share**<br>Have students construct simulated chromosomes with pop beads or pipe cleaners and manipulate them through the stages of meiosis. As students model the process, ask them to make a sketch or take a photograph of each stage. They should begin with either a $2n = 4$ or a $2n = 6$ "cell" so that they can build their understanding using a simpler system before applying what they have learned to meiosis in humans. Then, have students turn to a classmate to share their sketches or photographs and discuss what they now understand about meiosis in humans. Conduct a whole-class discussion where one student from each pair shares their collective understanding. |
| 2 | 5.3 | **Construct an Argument**<br>Instruct students that they can use genetically modified corn to apply the chi-square test to a dihybrid cross. First, students should calculate the expected genotypic and phenotypic ratios using a Punnett square. They should then formulate null hypotheses for the cross and perform a chi-square test. Have them conclude the exercise by stating whether they should reject or fail to reject the null hypothesis and ask that they justify their reasoning. |
| 3 | 5.5 | **One-Minute Essay**<br>Direct students to read an article about an organism that exhibits phenotypic plasticity. After reading, provide a prompt about this inheritance process, and ask them to respond to it in one minute or less. |

**SUGGESTED SKILL**

*Concept Explanation*

**1.B**

Explain biological concepts and processes.

**AVAILABLE RESOURCE**

- AP Central > AP Biology Lab Manual > Meiosis Lab

# TOPIC 5.1
# Meiosis

## Required Course Content

### BIG IDEA 3

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

### LEARNING OBJECTIVE

**5.1.A**

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

### ESSENTIAL KNOWLEDGE

**5.1.A.1**

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

**5.1.A.2**

Meiosis I involves the following steps:

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

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

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

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

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

**SUGGESTED SKILL**

*Questions and Methods*

**3.A**

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

**AVAILABLE RESOURCE**

- AP Central > AP Biology Lab Manual > Meiosis Lab

# TOPIC 5.2
# Meiosis and Genetic Diversity

## Required Course Content

### BIG IDEA 3

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

### LEARNING OBJECTIVE

**5.2.A**

Explain how the process of meiosis generates genetic diversity.

### ESSENTIAL KNOWLEDGE

**5.2.A.1**

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

**5.2.A.2**

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

**5.2.A.3**

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

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

# TOPIC 5.3
# Mendelian Genetics

**SUGGESTED SKILLS**

*Statistical Tests and Data Analysis*

**5.C**

Perform chi-square hypothesis testing.

*Argumentation*

**6.E**

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

## Required Course Content

### BIG IDEA 1

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

### BIG IDEA 3

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

| LEARNING OBJECTIVE | ESSENTIAL KNOWLEDGE |
|---|---|
| **5.3.A** Explain the inheritance of genes and traits as described by Mendel's laws. | **5.3.A.1** Mendel's laws of segregation and independent assortment can be applied to genes that are on different chromosomes. |
| | **5.3.A.2** In most cases, fertilization involves the fusion of two haploid gametes, restoring the diploid number of chromosomes and increasing genetic variation in populations by creating new combinations of alleles in the zygote. |

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

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

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

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

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## LEARNING OBJECTIVE

5.3.A

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

## ESSENTIAL KNOWLEDGE

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

### RELEVANT EQUATIONS

Laws of Probability:

If *A* and *B* are mutually exclusive, then:
$P(A \text{ or } B) = P(A) + P(B)$

If *A* and *B* are independent, then:
$P(A \text{ and } B) = P(A) \times P(B)$

# TOPIC 5.4
# Non-Mendelian Genetics

## Required Course Content

### BIG IDEA 3

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

#### LEARNING OBJECTIVE

**5.4.A**

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

#### ESSENTIAL KNOWLEDGE

**5.4.A.1**

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

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

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

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

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#### SUGGESTED SKILLS

*Statistical Tests and Data Analysis*

**5.A**

Perform mathematical calculations, including:

i. mathematical equations in the curriculum

ii. means

iii. rates

iv. ratios

v. percentages and percent changes

**5.C**

Perform chi-square hypothesis testing.

#### ILLUSTRATIVE EXAMPLES

**EK 5.4.A.2**

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

## LEARNING OBJECTIVE

5.4.A

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

## ESSENTIAL KNOWLEDGE

**5.4.A.2**

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

**5.4.A.3**

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

**5.4.A.4**

Some traits result from non-nuclear inheritance.

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

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

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

# TOPIC 5.5
# Environmental Effects on Phenotype

## Required Course Content

### BIG IDEA 4

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

### LEARNING OBJECTIVE

**5.5.A**

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

### ESSENTIAL KNOWLEDGE

**5.5.A.1**

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

**SUGGESTED SKILL**

*Concept Explanation*

**1.C**

Explain biological concepts and processes in applied contexts.

**ILLUSTRATIVE EXAMPLES**

**EK 5.5.A.1**

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

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AP BIOLOGY

# UNIT 6

# Gene Expression and Regulation

**12–16%**
AP EXAM WEIGHTING

**~18–20**
CLASS PERIODS

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

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

## Progress Check 6

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

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

UNIT 6

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

# Gene Expression and Regulation

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

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

## Developing Understanding

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

## Building Science Practices

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

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

Throughout the course, students should be given multiple opportunities to make a claim, support it with evidence, and provide reasoning to support the claim. In this unit and throughout the course, students should become proficient in argumentation by predicting the causes or effects of a change in, or disruption to, one or more components in a biological system.

## Preparing for the AP Exam

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

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

# UNIT AT A GLANCE

| Topic | Suggested Skills | Class Periods<br>~18–20 CLASS PERIODS |
|---|---|---|
| **6.1 DNA and RNA Structure** | 1.C Explain biological concepts and processes in applied contexts. | |
| **6.2 DNA Replication** | 2.B Explain relationships between characteristics of biological models in both theoretical and applied contexts. | |
| **6.3 Transcription and RNA Processing** | 2.B Explain relationships between characteristics of biological models in both theoretical and applied contexts. | |
| **6.4 Translation** | 2.D Represent relationships within biological models, including mathematical models, diagrams, flowcharts, and systems.<br><br>6.E Predict the causes or effects of a change in, or disruption to, one or more components in a biological system. | |
| **6.5 Regulation of Gene Expression** | 6.A Make a scientific claim. | |
| **6.6 Gene Expression and Cell Specialization** | 6.B Support a claim with evidence from biological principles, concepts, processes, and data. | |
| **6.7 Mutations** | 2.C Explain how biological models relate to larger principles, concepts, processes, systems, or theories. | |
| **6.8 Biotechnology** | 6.D Explain the relationship between experimental results and larger biological concepts, processes, or theories. | |
| Go to **AP Classroom** to assign the **Progress Check** for Unit 6. Review the results in class to identify and address any student misunderstandings. | | |

# SAMPLE INSTRUCTIONAL ACTIVITIES

The sample activities on this page are optional ways to incorporate varied instructional approaches in the teaching of this course. You do not need to use these activities or instructional approaches and are encouraged to adapt the activities to best support students in your classroom. The following examples were developed in partnership with teachers from the AP community to share ways that they approach teaching some of the topics in this unit. Please refer to the Instructional Approaches section beginning on p. 171 for more examples of activities and strategies.

| Activity | Topic | Sample Activity |
|---|---|---|
| 1 | 6.2 | **Misconception Check**<br>Distribute diagrams of nucleotides (which can be found on the internet and photocopied), and ask students to model the process of replication, explaining what is happening as they go. Circulate around the room as they're working and observe the results of replication that students produce. Correct any misunderstandings when you see them. |
| 2 | 6.3 | **Think-Pair-Share**<br>Have students build a model of transcription using pool noodles (which can usually be purchased at a dollar store). Instruct pairs of students to use everyday materials, such as tape, colored paper, yarn (or string), and markers to identify the promoter region, TATA box, transcription start site, and terminal sequence. They should describe the process of transcription from the initial binding of the transcription factors to the production of the transcript. At the end of class, invite one student from each pair to share their model with the whole class. |
| 3 | 6.4 | **Construct an Argument**<br>Ask students to develop a skit to demonstrate the process of translation. Once they have an understanding of the process, challenge them to act out what might happen if there were a change in the DNA sequence or if one of the needed components was unavailable. Debrief by having students explain the rationale for the modifications they made in their skit. |

**SUGGESTED SKILL**

*Concept Explanation*

**1.C**

Explain biological concepts and processes in applied contexts.

**AVAILABLE RESOURCES**

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

# TOPIC 6.1
# DNA and RNA Structure

## Required Course Content

### BIG IDEA 3

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

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

# TOPIC 6.2
# DNA Replication

## Required Course Content

### BIG IDEA 3

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

### LEARNING OBJECTIVE

**6.2.A**

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

### ESSENTIAL KNOWLEDGE

**6.2.A.1**

DNA replication ensures continuity of hereditary information.

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

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

iii. Helicase unwinds the DNA strands.

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

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

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

vii. Ligase joins the fragments on the lagging strand.

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

**SUGGESTED SKILL**

*Visual Representations*

**2.B**

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

**AVAILABLE RESOURCE**

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

**SUGGESTED SKILL**

*Visual Representations*

**2.B**

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

**AVAILABLE RESOURCE**

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

# TOPIC 6.3
# Transcription and RNA Processing

## Required Course Content

### BIG IDEA 3

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

### LEARNING OBJECTIVE

**6.3.A**

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

### ESSENTIAL KNOWLEDGE

**6.3.A.1**

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

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

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

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

**6.3.A.2**

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

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## LEARNING OBJECTIVE

**6.3.A**

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

## ESSENTIAL KNOWLEDGE

**6.3.A.3**

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

**6.3.A.4**

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

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

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

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

**SUGGESTED SKILLS**

*Visual Representations*

**2.D**

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

*Argumentation*

**6.E**

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

**AVAILABLE RESOURCE**

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

# TOPIC 6.4
# Translation

## Required Course Content

### BIG IDEA 3

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

### LEARNING OBJECTIVE

**6.4.A**

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

### ESSENTIAL KNOWLEDGE

**6.4.A.1**

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

**6.4.A.2**

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

**6.4.A.3**

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

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

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

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

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

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## LEARNING OBJECTIVE

6.4.A

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

## ESSENTIAL KNOWLEDGE

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

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

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

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

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

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

**6.4.A.4**

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

**SUGGESTED SKILL**

*Argumentation*

6.A

Make a scientific claim

**AVAILABLE RESOURCE**

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

# TOPIC 6.5
# Regulation of Gene Expression

## Required Course Content

### BIG IDEA 3

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

### LEARNING OBJECTIVE

**6.5.A**

Describe the types of interactions that regulate gene expression.

### ESSENTIAL KNOWLEDGE

**6.5.A.1**

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

**6.5.A.2**

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

**6.5.A.3**

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

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

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

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

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## LEARNING OBJECTIVE

**6.5.B**

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

## ESSENTIAL KNOWLEDGE

**6.5.B.1**

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

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

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

**SUGGESTED SKILL**

*Argumentation*

6.B

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

**AVAILABLE RESOURCE**

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

# TOPIC 6.6
# Gene Expression and Cell Specialization

## Required Course Content

### BIG IDEA 3

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

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

# TOPIC 6.7
# Mutations

## Required Course Content

### BIG IDEA 3

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

### LEARNING OBJECTIVE

**6.7.A**

Describe the various types of mutation.

### ESSENTIAL KNOWLEDGE

**6.7.A.1**

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

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

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

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

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

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

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**SUGGESTED SKILL**

*Visual Representations*

**2.C**

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

**AVAILABLE RESOURCE**

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

**ILLUSTRATIVE EXAMPLES**

**EK 6.7.A.1**

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

**EK 6.7.C.1**

- Sickle cell anemia

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

# TOPIC 6.8
# Biotechnology

## Required Course Content

### BIG IDEA 3

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

### LEARNING OBJECTIVE

**6.8.A**

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

### ESSENTIAL KNOWLEDGE

**6.8.A.1**

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

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

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

iii. Bacterial transformation introduces foreign DNA into bacterial cells.

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

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

**SUGGESTED SKILL**

*Argumentation*

**6.D**

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

**AVAILABLE RESOURCES**

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

**ILLUSTRATIVE EXAMPLES**

**EK 6.8.A.1**

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

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AP BIOLOGY

# UNIT 7

# Natural Selection

**13–20%**
AP EXAM WEIGHTING

**~19–21**
CLASS PERIODS

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

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

## Progress Check 7

**Multiple-choice: ~48 questions (2 parts)**

**Free-response: 2 questions**

- Interpreting and Evaluating Experimental Results with Graphing
- Analyze Data

UNIT 7

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

# Natural Selection

**BIG IDEA 1**
***Evolution***
- What conditions in a population make it more or less likely to evolve?
- Scientifically defend the theory of evolution.

**BIG IDEA 4**
***Systems Interactions***
- How does species interaction encourage or slow changes in species?

## Developing Understanding

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

## Building Science Practices

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

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

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

## Preparing for the AP Exam

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

# UNIT AT A GLANCE

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

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# UNIT AT A GLANCE *(cont'd)*

| Topic | Suggested Skills | Class Periods<br>~19–21 CLASS PERIODS |
|---|---|---|
| **7.7 Common Ancestry** | 6.E Predict the causes or effects of a change in, or disruption to, one or more components in a biological system. | |
| **7.8 Continuing Evolution** | 3.D Propose a new investigation based on an evaluation of the experimental design or evidence. | |
| **7.9 Phylogeny** | 2.D Represent relationships within biological models, including mathematical models, diagrams, flowcharts, and systems. | |
| **7.10 Speciation** | 2.B Explain relationships between characteristics of biological models in both theoretical and applied contexts.<br><br>6.E Predict the causes or effects of a change in, or disruption to, one or more components in a biological system. | |
| **7.11 Variations in Populations** | 6.C Provide reasoning to justify a claim by connecting evidence to biological theories. | |
| **7.12 Origins of Life on Earth** | 3.B State the null hypothesis or predict the results of an experiment. | |
| Go to **AP Classroom** to assign the **Progress Check** for Unit 7. Review the results in class to identify and address any student misunderstandings. | | |

# SAMPLE INSTRUCTIONAL ACTIVITIES

The sample activities on this page are optional ways to incorporate varied instructional approaches in the teaching of this course. You do not need to use these activities or instructional approaches and are encouraged to adapt the activities to best support students in your classroom. The following examples were developed in partnership with teachers from the AP community to share ways that they approach teaching some of the topics in this unit. Please refer to the Instructional Approaches section beginning on p. 171 for more examples of activities and strategies.

| Activity | Topic | Sample Activity |
|---|---|---|
| 1 | 7.2 | **Misconception Check**<br>Using one of many available online resources, have students learn about the work of Peter and Rosemary Grant. Using data from the Grants' work, help students to build their graphing and statistical analysis skills. This is a good opportunity for students to practice explaining trends in data and supporting their claims with evidence. Through their work of supporting their claims, misconceptions will come up and can be corrected. |
| 2 | 7.3 | **Graph and Switch**<br>Place students into groups of 3–5 and have them perform a brine shrimp lab, placing groups of brine shrimp eggs in petri dishes with various concentrations of salt in the water. They should monitor the number of eggs and swimming shrimp in the petri dishes at regular time intervals over a period of 2–3 days. Ask students to then calculate the hatching viability in each petri dish and graph their data. Chi-square can be used to analyze the null hypothesis. Have students then switch graphs with classmates to compare findings. |
| 3 | 7.5 | **Construct an Argument**<br>Have students use one of the Rock Pocket Mice activities available online to learn the principles of the Hardy–Weinberg equilibrium and to calculate allele frequencies in a population. Once students have completed their calculations, have them construct an argument about whether and how the mice populations are evolving. |
| 4 | 7.10 | **Ask the Expert**<br>Show students a cartoon image of an isolating mechanism that leads to speciation. Discuss with them what is happening in the cartoon and how it relates to speciation. Place students into groups and have them conduct research on other isolating mechanisms and draw their own cartoons to illustrate what they learned. Ask students to move around to other groups, sharing their cartoons and answering any questions from their classmates. |

# TOPIC 7.1
# Introduction to Natural Selection

**SUGGESTED SKILL**

*Visual Representations*

**2.A**

Describe characteristics of visual representations of biological concepts and processes.

**AVAILABLE RESOURCES**

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

## Required Course Content

### BIG IDEA 1

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

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

**SUGGESTED SKILL**

*Concept Explanation*

**1.B**

Explain biological concepts and processes.

**AVAILABLE RESOURCE**

- AP Central > Classroom Resources > Evolution and Change

**ILLUSTRATIVE EXAMPLES**

**EK 7.2.A.2**

- Flowering time in relation to global climate change

**EK 7.2.A.3**

- Sickle cell anemia
- DDT resistance in insects

# TOPIC 7.2
# Natural Selection

## Required Course Content

### BIG IDEA 1

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

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

# TOPIC 7.3
# Artificial Selection

## Required Course Content

### BIG IDEA 1

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

| LEARNING OBJECTIVE | ESSENTIAL KNOWLEDGE |
| --- | --- |
| 7.3.A<br>Explain how humans can affect diversity within a population. | 7.3.A.1<br>Through artificial selection, humans affect variation in other species. |

**SUGGESTED SKILL**

*Representing and Describing Data*

**4.B**

Describe data from a table or graph, including:

i. identifying specific data points

ii. describing trends and patterns in the data

iii. describing relationships between variables

**AVAILABLE RESOURCES**

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

**SUGGESTED SKILL**

*Questions and Methods*

**3.B**

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

**AVAILABLE RESOURCE**

- AP Central > Classroom Resources > Evolution and Change

# TOPIC 7.4
# Population Genetics

## Required Course Content

### BIG IDEA 1

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

#### LEARNING OBJECTIVE

**7.4.A**

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

#### ESSENTIAL KNOWLEDGE

**7.4.A.1**

Evolution is also driven by random occurrences.

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

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

**SUGGESTED SKILLS**

*Concept Explanation*

**1.C**

Explain biological concepts and processes in applied contexts.

*Statistical Tests and Data Analysis*

**5.A**

Perform mathematical calculations, including:

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

**AVAILABLE RESOURCES**

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

**ILLUSTRATIVE EXAMPLE**

**EK 7.5.A.2**

- Graphic analysis of allele frequencies in a population

# TOPIC 7.5
# Hardy–Weinberg Equilibrium

## Required Course Content

### BIG IDEA 1

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

### LEARNING OBJECTIVE

**7.5.A**

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

### ESSENTIAL KNOWLEDGE

**7.5.A.1**

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

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

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

**7.5.A.2**

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

**RELEVANT EQUATIONS**

Hardy–Weinberg Equation—

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

$$p + q = 1,$$

where:

$p$ = frequency of allele 1 in the population

$q$ = frequency of allele 2 in the population

# TOPIC 7.6
# Evidence of Evolution

## Required Course Content

### BIG IDEA 1

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

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

**SUGGESTED SKILL**

*Representing and Describing Data*

**4.B**

Describe data from a table or graph, including:

i. identifying specific data points

ii. describing trends and patterns in the data

iii. describing relationships between variables

**AVAILABLE RESOURCE**

- AP Central > Classroom Resources > Evolution and Change

**SUGGESTED SKILL**

*Argumentation*

**6.E**

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

**AVAILABLE RESOURCE**

- AP Central > Classroom Resources > Evolution and Change

# TOPIC 7.7
# Common Ancestry

## Required Course Content

### BIG IDEA 1

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

### LEARNING OBJECTIVE

**7.7.A**

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

### ESSENTIAL KNOWLEDGE

**7.7.A.1**

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

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

# TOPIC 7.8
# Continuing Evolution

## Required Course Content

### BIG IDEA 1

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

#### LEARNING OBJECTIVE

**7.8.A**

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

#### ESSENTIAL KNOWLEDGE

**7.8.A.1**

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

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

**SUGGESTED SKILL**

*Questions and Methods*

**3.D**

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

**AVAILABLE RESOURCE**

- AP Central > Classroom Resources > Evolution and Change

**SUGGESTED SKILL**

*Visual Representations*

**2.D**

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

**AVAILABLE RESOURCE**

- AP Central > Classroom Resources > Evolution and Change

# TOPIC 7.9
# Phylogeny

## Required Course Content

### BIG IDEA 1

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

### LEARNING OBJECTIVE

**7.9.A**

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

### ESSENTIAL KNOWLEDGE

**7.9.A.1**

Phylogenetic trees and cladograms show hypothetical evolutionary relationships among lineages that can be tested.

**7.9.A.2**

Phylogenetic trees show the amount of change over time calibrated by fossils or a molecular clock, whereas cladograms do not show time scale or the evolutionary difference between groups.

**7.9.A.3**

Traits that are either gained or lost during evolution can be used to construct phylogenetic trees and cladograms. The out-group represents the lineage that is least closely related to the remainder of the organisms in the phylogenetic tree or cladogram.

i. Shared derived characters can be present in more than one lineage and indicate common ancestry. These are informative for the construction of phylogenetic trees and cladograms.

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

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## LEARNING OBJECTIVE

**7.9.B**

Explain how phylogenetic trees and cladograms can be used to infer evolutionary relatedness.

## ESSENTIAL KNOWLEDGE

**7.9.B.1**

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

**7.9.B.2**

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

**7.9.B.3**

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

**SUGGESTED SKILLS**

*Visual Representations*

**2.B**

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

*Argumentation*

**6.E**

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

**AVAILABLE RESOURCE**

- AP Central > Classroom Resources > Evolution and Change

**ILLUSTRATIVE EXAMPLES**

**LO 7.10.C**

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

# TOPIC 7.10
# Speciation

## Required Course Content

### BIG IDEA 1

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

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

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# Natural Selection

## LEARNING OBJECTIVE

**7.10.C**

Explain the processes and mechanisms that drive speciation.

## ESSENTIAL KNOWLEDGE

**7.10.C.1**

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

**7.10.C.2**

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

**SUGGESTED SKILL**

*Argumentation*

6.C

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

**AVAILABLE RESOURCE**

- AP Central > Classroom Resources > Evolution and Change

**ILLUSTRATIVE EXAMPLES**

EK 7.11.A.1

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

# TOPIC 7.11
# Variations in Populations

## Required Course Content

### BIG IDEA 4

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

### LEARNING OBJECTIVE

7.11.A

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

### ESSENTIAL KNOWLEDGE

7.11.A.1

The level of variation in a population affects population dynamics.

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

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

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

# TOPIC 7.12
# Origins of Life on Earth

**SUGGESTED SKILL**

*Questions and Methods*

**3.B**

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

**AVAILABLE RESOURCE**

- AP Central > Classroom Resources > Evolution and Change

## Required Course Content

### BIG IDEA 4

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

### LEARNING OBJECTIVE

**7.12.A**

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

### ESSENTIAL KNOWLEDGE

**7.12.A.1**

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

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

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

**7.12.A.2**

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

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

ii. Base-pairing is necessary for replication.

iii. Genetically encoded proteins were not involved as catalysts.

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AP BIOLOGY

# UNIT 8

# Ecology

**10–15%**
AP EXAM WEIGHTING

**~19–21**
CLASS PERIODS

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

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

## Progress Check 8

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

- Interpreting and Evaluating Experimental Results with Graphing
- Scientific Investigation

UNIT 8

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

# Ecology

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

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

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

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

## Developing Understanding

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

## Building Science Practices

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

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

## Preparing for the AP Exam

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

Throughout the course, students should have practiced providing support for their claims about biological systems. Making connections to ecology are fundamental and will help students to build this skill.

# UNIT AT A GLANCE

| Topic | Suggested Skill | Class Periods<br>~19–21 CLASS PERIODS |
|---|---|---|
| **8.1 Responses to the Environment** | 3.C Identify experimental procedures that align with the question, including:<br>i. identifying dependent and independent variables<br>ii. identifying appropriate controls<br>iii. justifying appropriate controls | |
| **8.2 Energy Flow Through Ecosystems** | 6.D Explain the relationship between experimental results and larger biological concepts, processes, or theories. | |
| **8.3 Population Ecology** | 4.A Construct a graph to represent the data, including: x-y graphs (bar, histogram, line, log scale, dual y), scatter plot, box and whisker plot, and pie chart. The graph should include the following components:<br>i. type of graph appropriate for the data<br>ii. axis labeling, including appropriate units and legend<br>iii. scaling<br>iv. accurately plotted data (including error bars when appropriate)<br>v. trend line (when appropriate) | |
| **8.4 Effect of Density on Populations** | 5.A Perform mathematical calculations, including:<br>i. mathematical equations in the curriculum<br>ii. means<br>iii. rates<br>iv. ratios<br>v. percentages and percent changes | |
| **8.5 Community Ecology** | 5.B Use confidence intervals and error bars to estimate whether sample means are statistically different. | |
| **8.6 Biodiversity** | 6.E Predict the causes or effects of a change in, or disruption to, one or more components in a biological system. | |
| **8.7 Disruptions in Ecosystems** | 5.D Use data to evaluate a hypothesis or prediction, including rejecting or failing to reject the null hypothesis. | |
| Go to **AP Classroom** to assign the **Progress Check** for Unit 8. Review the results in class to identify and address any student misunderstandings. | | |

# SAMPLE INSTRUCTIONAL ACTIVITIES

The sample activities on this page are optional ways to incorporate varied instructional approaches in the teaching of this course. You do not need to use these activities or instructional approaches and are encouraged to adapt the activities to best support students in your classroom. The following examples were developed in partnership with teachers from the AP community to share ways that they approach teaching some of the topics in this unit. Please refer to the Instructional Approaches section beginning on p. 171 for more examples of activities and strategies.

| Activity | Topic | Sample Activity |
|---|---|---|
| 1 | 8.1 | **Construct an Argument**<br>Have students perform an animal behavior lab using pill bugs. They should use choice chambers to study the responses of pill bugs to the levels of moisture in the given chambers, creating different environments on either side of the choice chamber and placing the same number of pill bugs on both sides. Have them count the number of pill bugs on both sides of the choice chamber at regular intervals for a defined period of time. Chi-square can be used to evaluate the null hypothesis. Once a hypothesis is evaluated, students can construct arguments in support of ways to keep pill bugs out of places where they are unwanted. |
| 2 | 8.5 | **Graph and Switch**<br>Ask students to read about the moose and wolves of Isle Royale to obtain background information on the two organisms. Then have them download a data spreadsheet from the internet and use it to graph data about the two populations. They should use their graph to make and justify predictions about how the two populations can change relative to each other. |
| 3 | 8.6 | **Index Card Summaries/Questions**<br>To facilitate the hula hoop diversity activity, divide students into groups and give each group a hula hoop and a magnifying glass. Ask students to place their hula hoops in a grassy, woodsy, or garden area and make observations and collect a variety of data about the plants, animals, and abiotic factors inside the hula hoop area. They should record their observations, collected data, and any questions on index cards. Once students have collected all their data and made their observations, have them predict what will happen to organisms in an ecosystem when its biodiversity changes. As a class, discuss the relationship between biodiversity and species endangerment, and predict what changes might occur in an ecosystem when a biotic or abiotic factor changes. |

**SUGGESTED SKILL**

*Questions and Methods*

**3.C**

Identify experimental procedures that align with the question, including:

i. identifying dependent and independent variables

ii. identifying appropriate controls

iii. justifying appropriate controls

**AVAILABLE RESOURCES**

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

**ILLUSTRATIVE EXAMPLES**

**EK 8.1.A.1**

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

**EK 8.1.A.2**

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

**EK 8.1.B.1**

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

# TOPIC 8.1
# Responses to the Environment

## Required Course Content

### BIG IDEA 2

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

### LEARNING OBJECTIVE

**8.1.A**

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

### ESSENTIAL KNOWLEDGE

**8.1.A.1**

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

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

**8.1.A.2**

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

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## BIG IDEA 3

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

### LEARNING OBJECTIVE

**8.1.B**

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

### ESSENTIAL KNOWLEDGE

**8.1.B.1**

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

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

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

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

**8.1.B.2**

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

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

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

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

#### ILLUSTRATIVE EXAMPLES

**EK 8.1.B.2.i**

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

**EK 8.1.B.2.ii**

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

**SUGGESTED SKILL**

*Argumentation*

6.D

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

**AVAILABLE RESOURCES**

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

**ILLUSTRATIVE EXAMPLES**

LO 8.2.A

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

EK 8.2.C.1

- Food chains/webs
- Trophic pyramids/ diagrams

# TOPIC 8.2
# Energy Flow Through Ecosystems

## Required Course Content

### BIG IDEA 2

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

### LEARNING OBJECTIVE

**8.2.A**

Describe the strategies organisms use to acquire and use energy.

### ESSENTIAL KNOWLEDGE

**8.2.A.1**

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

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

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

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

**8.2.A.2**

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

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## LEARNING OBJECTIVE

**8.2.B**

Explain how energy flows and matter cycles through trophic levels.

## ESSENTIAL KNOWLEDGE

**8.2.B.1**

Ecological levels of organization include populations, communities, ecosystems, and biomes.

**8.2.B.2**

Energy flows through ecosystems, while matter and nutrients cycle between the environment and organisms via biogeochemical cycles. The cycles are essential for life, and each cycle demonstrates the conservation of matter. The cycles are interdependent.

**8.2.B.3**

Biogeochemical cycles include abiotic and biotic reservoirs, as well as processes that cycle matter between reservoirs.

**8.2.B.4**

The hydrologic (water) cycle involves water movement and storage within the hydrosphere. Reservoirs include oceans, surface water, the atmosphere, and living organisms. Processes include evaporation, condensation, precipitation, and transpiration.

**8.2.B.5**

The carbon cycle involves recycling carbon atoms through Earth's biosphere into organisms as carbohydrates and back into the atmosphere as carbon dioxide $(CO_2)$. At the highest levels of organization, the carbon cycle can be simplified into four parts: photosynthesis, cellular respiration, decomposition, and combustion.

**8.2.B.6**

The nitrogen cycle involves several steps, including nitrogen fixation, assimilation, ammonification, nitrification, and denitrification. These steps are performed by microorganisms in the soil. The largest reservoir of nitrogen is the atmosphere. In nitrogen fixation, nitrogen gas $(N_2)$ is fixed into ammonia $(NH_3)$, which ionizes to ammonium $(NH_4^+)$ by acquiring hydrogen ions from the soil solution.

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

# TOPIC 8.3
# Population Ecology

## Required Course Content

### BIG IDEA 3

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

#### LEARNING OBJECTIVE

**8.3.A**

Describe factors that influence growth dynamics of populations.

#### ESSENTIAL KNOWLEDGE

**8.3.A.1**

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

**8.3.A.2**

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

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

**RELEVANT EQUATION**

Population Growth—

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

where

$dt$ = chage in time

$B$ = birth rate

$D$ = death rate

$N$ = population size

$dN$ = change in population size

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**SUGGESTED SKILL**

*Representing and Describing Data*

**4.A**

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

i. type of graph appropriate for the data

ii. axis labeling, including appropriate units and legend

iii. scaling

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

v. trend line (when appropriate)

**AVAILABLE RESOURCE**

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

## LEARNING OBJECTIVE

8.3.A

Describe factors that influence growth dynamics of populations.

## ESSENTIAL KNOWLEDGE

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

**RELEVANT EQUATION**

Exponential Growth—

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

where

$dt$ = change in time

$N$ = population size

$dN$ = change in population size

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

# TOPIC 8.4
# Effect of Density on Populations

## Required Course Content

### BIG IDEA 4

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

### LEARNING OBJECTIVE

**8.4.A**

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

### ESSENTIAL KNOWLEDGE

**8.4.A.1**

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

**8.4.A.2**

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

**RELEVANT EQUATION**

Logistical Growth—

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

where

$dt$ = change in time

$N$ = population size

$dN$ = change in population size

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

$K$ = carrying capacity

**SUGGESTED SKILL**

*Statistical Tests and Data Analysis*

**5.A**

Perform mathematical calculations, including:

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

**SUGGESTED SKILL**

*Statistical Tests and Data Analysis*

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

# TOPIC 8.5
# Community Ecology

## Required Course Content

### BIG IDEA 2

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

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

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| LEARNING OBJECTIVE | ESSENTIAL KNOWLEDGE |
| --- | --- |
| 8.5.B<br>Explain how interactions within and among populations influence community structure. | **8.5.B.3**<br>Relationships among interacting populations can be characterized by positive and negative effects and can be modeled. Examples include predator/prey interactions, cooperation, trophic cascades, and niche partitioning.<br><br>**8.5.B.4**<br>Competition, predation, and symbioses, including parasitism, mutualism, and commensalism, can drive population dynamics. |

**SUGGESTED SKILL**

*Argumentation*

6.E

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

# TOPIC 8.6
# Biodiversity

## Required Course Content

### BIG IDEA 4

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

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

# TOPIC 8.7
# Disruptions in Ecosystems

## Required Course Content

### BIG IDEA 1

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

#### LEARNING OBJECTIVE

**8.7.A**

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

#### ESSENTIAL KNOWLEDGE

**8.7.A.1**

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

**8.7.A.2**

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

**8.7.A.3**

Mutations are not directed by specific environmental pressures.

### BIG IDEA 4

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

#### LEARNING OBJECTIVE

**8.7.B**

Explain how invasive species affect ecosystem dynamics.

#### ESSENTIAL KNOWLEDGE

**8.7.B.1**

The intentional or unintentional introduction of an invasive species can allow the species to exploit a new niche free of predators or competitors or to outcompete native species for resources.

**SUGGESTED SKILL**

*Statistical Tests and Data Analysis*

**5.D**

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

**ILLUSTRATIVE EXAMPLES**

**EK 8.7.B.1**
- Kudzu
- Zebra mussels

**EK 8.7.C.1**
- Dutch elm disease
- Potato blight

**EK 8.7.D.1**
- Global climate change
- Logging
- Urbanization
- Monocropping
- El Nino
- Continental drift
- Meteor impact on dinosaurs

# Ecology

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