Advanced Placement Biology At Argo Community High School

Unit 1 Chemistry of Life

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.

Topic 1.1 Structure of Water and Hydrogen Bonding

Enduring Understanding

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

Learning Objective

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

Essential Knowledge

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

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

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

TOPIC 1.2 Elements of Life

Enduring Understanding

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

Learning Objective

Describe the composition of macromolecules required by living organisms.

Essential Knowledge

Organisms must exchange matter with the environment to grow, reproduce, and maintain organization.
Atoms and molecules from the environment are necessary to build new molecules—
a. Carbon is used to build biological molecules such as carbohydrates, proteins, lipids, and nucleic acids. Carbon is used in storage compounds and cell formation in all organisms.
b. Nitrogen is used to build proteins and nucleic acids. Phosphorus is used to build nucleic acids and certain lipids.

TOPIC 1.3 Introduction to Biological Macromolecules

Enduring Understanding

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

Learning Objective

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

Essential Knowledge

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

Exclusion Statements

The molecular structure of specific nucleotides and amino acids is beyond the scope of the AP Exam.

The molecular structure of specific carbohydrate polymers is beyond the scope of the AP Exam.

TOPIC 1.4 Properties of Biological Macromolecules

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

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

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

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

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

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

d. Lipids are nonpolar macromolecules—
   - i. Differences in saturation determine the structure and function of lipids.
   - ii. Phospholipids contain polar regions that interact with other polar molecules, such as water, and with nonpolar regions that are often hydrophobic.

Exclusion Statement
The molecular structure of specific lipids is beyond the scope of the AP Exam.

TOPIC 1.5: Structure and Function of Biological Macromolecules

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

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

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

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

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

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

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

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

TOPIC 1.6: Nucleic Acids

Enduring Understanding

Heritable information provides for continuity of life.

Learning Objective

Describe the structural similarities and differences between DNA and RNA.

Essential Knowledge

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

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

Unit 2: Cell Structure and Function

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.

TOPIC 2.1: Cell Structure: Subcellular Components

Enduring Understanding

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

Learning Objective

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

Essential Knowledge

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

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

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

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

Exclusion Statement

Specific functions of smooth ER in specialized cells are beyond the scope of the course and the AP Exam.

Essential Knowledge

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

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

Exclusion Statement

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

Essential Knowledge

Mitochondria have a double membrane. The outer membrane is smooth, but the inner membrane is highly convoluted, forming folds.
Lysosomes are membrane-enclosed sacs that contain hydrolytic enzymes.
A vacuole is a membrane-bound sac that plays many and differing roles. In plants, a specialized large vacuole serves multiple functions.
Chloroplasts are specialized organelles that are found in photosynthetic algae and plants. Chloroplasts have a double outer membrane.

TOPIC 2.2: Cell Structure and Function

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

Learning Objective
Explain how subcellular components and organelles contribute to the function of the cell.

Essential Knowledge
Organelles and subcellular structures, and the interactions among them, support cellular function—

a. Endoplasmic reticulum provides mechanical support, carries out protein synthesis on membrane-bound ribosomes, and plays a role in intracellular transport.
b. Mitochondrial double membrane provides compartments for different metabolic reactions.
c. Lysosomes contain hydrolytic enzymes, which are important in intracellular digestion, the recycling of a cell's organic materials, and programmed cell death (apoptosis).
d. Vacuoles have many roles, including storage and release of macromolecules and cellular waste products. In plants, it aids in retention of water for turgor pressure.

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

Essential Knowledge
The folding of the inner membrane increases the surface area, which allows for more ATP to be synthesized.
Within the chloroplast are thylakoids and the stroma
The thylakoids are organized in stacks, called grana.
Membranes contain chlorophyll pigments and electron transport proteins that comprise the photosystems.
The light-dependent reactions of photosynthesis occur in the grana.
The stroma is the fluid within the inner chloroplast membrane and outside of the thylakoid.
The carbon fixation (Calvin-Benson cycle) reactions of photosynthesis occur in the stroma.
The Krebs cycle (citric acid cycle) reactions occur in the matrix of the mitochondria.
Electron transport and ATP synthesis occur on the inner mitochondrial membrane.

TOPIC 2.3: Cell Size

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

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

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

Relevant Equations

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

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

$$Volume\ of\ a\ Rectangular\ Solid: V = lwh$$

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

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

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

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

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

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

Essential Knowledge
The surface area of the plasma membrane must be large enough to adequately exchange materials—

a. These limitations can restrict cell size and shape. Smaller cells typically have a higher surface area-to-volume ratio and more efficient exchange of materials with the environment.
b. As cells increase in volume, the relative surface area decreases and the demand for internal resources increases.
c. More complex cellular structures (e.g., membrane folds) are necessary to adequately exchange materials with the environment.
d. As organisms increase in size, their surface area-to-volume ratio decreases, affecting properties like rate of heat exchange with the environment.

Learning Objective
Explain how specialized structures and strategies are used for the efficient exchange of molecules to the environment.

Essential Knowledge
Organisms have evolved highly efficient strategies to obtain nutrients and eliminate wastes. Cells and organisms use specialized exchange surfaces to obtain and release molecules from or into the surrounding environment.

TOPIC 2.4: Plasma Membranes

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

Learning Objective
Describe the roles of each of the components of the cell membrane in maintaining the internal environment of the cell.

Essential Knowledge
Phospholipids have both hydrophilic and hydrophobic regions. The hydrophilic phosphate regions of the phospholipids are oriented toward the aqueous external or internal environments, while the hydrophobic fatty acid regions face each other within the interior of the membrane.

Embedded proteins can be hydrophilic, with charged and polar side groups, or hydrophobic, with nonpolar side groups.

Learning Objective
Describe the Fluid Mosaic Model of cell membranes

Essential Knowledge
Cell membranes consist of a structural framework of phospholipid molecules that is embedded with proteins, steroids (such as cholesterol in eukaryotes), glycoproteins, and glycolipids that can flow around the surface of the cell within the membrane.

TOPIC 2.5: Membrane Permeability

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

Learning Objective
Explain how the structure of biological membranes influences selective permeability.

Essential Knowledge
The structure of cell membranes results in selective permeability.
Cell membranes separate the internal environment of the cell from the external environment.
Selective permeability is a direct consequence of membrane structure, as described by the fluid mosaic model.
Small nonpolar molecules, including N_2, O_2, and CO_2, freely pass across the membrane. Hydrophilic substances, such as large polar molecules and ions, move across the membrane through embedded channel and transport proteins.
Polar uncharged molecules, including H_2O, pass through the membrane in small amounts.

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

Essential Knowledge
Cell walls provide a structural boundary, as well as a permeability barrier for some substances to the internal environments.
Cell walls of plants, prokaryotes, and fungi are composed of complex carbohydrates.

TOPIC 2.6: Membrane Transport

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

Learning Objective
Describe the mechanisms that organisms use to maintain solute and water balance.
Passive transport is the net movement of molecules from high concentration to low concentration without the direct input of metabolic energy.
Passive transport plays a primary role in the import of materials and the export of wastes.
Active transport requires the direct input of energy to move molecules from regions of low concentration to regions of high concentration.

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

Essential Knowledge
The selective permeability of membranes allows for the formation of concentration gradients of solutes across the membrane.
The processes of endocytosis and exocytosis require energy to move large molecules into and out of cells—

a. In exocytosis, internal vesicles fuse with the plasma membrane and secrete large macromolecules out of the cell.
b. In endocytosis, the cell takes in macromolecules and particulate matter by forming new vesicles derived from the plasma membrane.

TOPIC 2.7: Facilitated Diffusion

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

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

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

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

Membrane proteins are necessary for active transport.
Metabolic energy (such as from ATP) is required for active transport of molecules and/ or ions across the membrane and to establish and maintain concentration gradients.
The Na^+/K^+ ATPase contributes to the maintenance of the membrane potential.

TOPIC 2.8: Tonicity and Osmoregulation

Enduring Understanding

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

Learning Objective

Explain how concentration gradients affect the movement of molecules across membranes

Essential Knowledge

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

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

Relevant Equation:

Water Potential:

$$\Psi = \Psi_p + \Psi_s$$

Ψ_p = pressure potential

Ψ_s = solute potential

Learning Objective

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

Essential Knowledge

Growth and homeostasis are maintained by the constant movement of molecules across membranes.
Osmoregulation maintains water balance and allows organisms to control their internal solute composition/water potential.

Relevant Equation:

$$\Psi_s = -iCRT$$

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 (℃ + 273)

TOPIC 2.9: Mechanisms of Transport

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

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

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

TOPIC 2.10: Compartmentalization

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

Learning Objective
Describe the membrane- bound structures of the eukaryotic cell.

Essential Knowledge
Membranes and membrane-bound organelles in eukaryotic cells compartmentalize intracellular metabolic processes and specific enzymatic reactions
Explain how internal membranes and membrane- bound organelles contribute to compartmentalization of eukaryotic cell functions.
Internal membranes facilitate cellular processes by minimizing competing interactions and by increasing surface areas where reactions can occur.

TOPIC 2.11: Origins of Cell Compartmentalization

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

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

Essential Knowledge
Membrane-bound organelles evolved from once free-living prokaryotic cells via endosymbiosis.
Prokaryotes generally lack internal membrane- bound organelles but have internal regions with specialized structures and functions.
Eukaryotic cells maintain internal membranes that partition the cell into specialized regions.

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

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

Unit 3: Cellular Energetics

TOPIC 3.1: Enzyme Structure

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

Learning Objective
Describe the properties of enzymes.

Essential Knowledge
The structure of enzymes includes the active site that specifically interacts with substrate molecules.
For an enzyme-mediated chemical reaction to occur, the shape and charge of the substrate must be compatible with the active site of the enzyme.

TOPIC 3.2: Enzyme Catalysis

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

Learning Objective
Explain how enzymes affect the rate of biological reactions.

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

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

TOPIC 3.3: Environmental Impacts on Enzyme Function

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

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

Essential Knowledge
Change to the molecular structure of a component in an enzymatic system may result in a change of the function or efficiency of the system—

a. Denaturation of an enzyme occurs when the protein structure is disrupted, eliminating the ability to catalyze reactions.
b. Environmental temperatures and pH outside the optimal range for a given enzyme will cause changes to its structure, altering the efficiency with which it catalyzes reactions.

In some cases, enzyme denaturation is reversible, allowing the enzyme to regain activity.

Learning Objective
Explain how the cellular environment affects enzyme activity.

Essential Knowledge
Environmental pH can alter the efficiency of enzyme activity, including through disruption of hydrogen bonds that provide enzyme structure.

Relevant Equation:

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

Exclusion Statement:
Students must understand the underlying concepts and applications of this equation, but performing calculations using this equation are beyond the scope of the course and the AP Exam.

The relative concentrations of substrates and products determine how efficiently an enzymatic reaction proceeds.
Higher environmental temperatures increase the speed of movement of molecules in a solution, increasing the frequency of collisions between enzymes and substrates and therefore increasing the rate of reaction.
Competitive inhibitor molecules can bind reversibly or irreversibly to the active site of the enzyme. Noncompetitive inhibitors can bind allosteric sites, changing the activity of the enzyme.

TOPIC 3.4: Cellular Energy

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

Learning Objective
Describe the role of energy in living organisms.

Essential Knowledge
All living systems require constant input of energy.
Life requires a highly ordered system and does not violate the second law of thermodynamics—

a. Energy input must exceed energy loss to maintain order and to power cellular processes.
b. Cellular processes that release energy may be coupled with cellular processes that require energy.
c. Loss of order or energy flow results in death.

Exclusion Statement
Students will need to understand the concept of energy, but the equation for Gibbs free energy is beyond the scope of the course and the AP Exam.

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

TOPIC 3.5: Photosynthesis

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

Learning Objective
Describe the photosynthetic processes that allow organisms to capture and store energy.

Essential Knowledge
Organisms capture and store energy for use in biological processes—

a. Photosynthesis captures energy from the sun and produces sugars.
    i. Photosynthesis first evolved in prokaryotic organisms.
    ii. Scientific evidence supports the claim that prokaryotic (cyanobacterial) photosynthesis was responsible for the production of an oxygenated atmosphere.
    iii. Prokaryotic photosynthetic pathways were the foundation of eukaryotic photosynthesis.

The light-dependent reactions of photosynthesis in eukaryotes involve a series of coordinated reaction pathways that capture energy present in light to yield ATP and NADPH, which power the production of organic molecules.

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

Essential Knowledge
During photosynthesis, chlorophylls absorb energy from light, boosting electrons to a higher energy level in photosystems I and II.
Photosystems I and II are embedded in the internal membranes of chloroplasts and are connected by the transfer of higher energy electrons through an electron transport chain (ETC).
When electrons are transferred between molecules in a sequence of reactions as they pass through the ETC, an electrochemical gradient of protons (hydrogen ions) is established across the internal membrane.
The formation of the proton gradient is linked to the synthesis of ATP from ADP and inorganic phosphate via ATP synthase.
The energy captured in the light reactions and transferred to ATP and NADPH powers the production of carbohydrates from carbon dioxide in the Calvin cycle, which occurs in the stroma of the chloroplast.

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

TOPIC 3.6: Cellular Respiration

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

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

Essential Knowledge
Fermentation and cellular respiration use energy from biological macromolecules to produce ATP. Respiration and fermentation are characteristic of all forms of life.
Cellular respiration in eukaryotes involves a series of coordinated enzyme-catalyzed reactions that capture energy from biological macromolecules.
The electron transport chain transfers energy from electrons in a series of coupled reactions that establish an electrochemical gradient across membranes—

a. Electron transport chain reactions occur in chloroplasts, mitochondria, and prokaryotic plasma membranes.
b. In cellular respiration, electrons delivered by NADH and FADH2 are passed to a series of electron acceptors as they move toward the terminal electron acceptor, oxygen. In photosynthesis, the terminal electron acceptor is NADP+. Aerobic prokaryotes use oxygen as a terminal electron acceptor, while anaerobic prokaryotes use other molecules
c. The transfer of electrons is accompanied by the formation of a proton gradient across the inner mitochondrial membrane or the internal membrane of chloroplasts, with the membrane(s) separating a region of high proton concentration from a region of low proton concentration. In prokaryotes, the passage of electrons is accompanied by the movement of protons across the plasma membrane.
d. The flow of protons back through membrane-bound ATP synthase by chemiosmosis drives the formation of ATP from ADP and inorganic phosphate. This is known as oxidative phosphorylation in cellular respiration, and photophosphorylation in photosynthesis.
e. In cellular respiration, decoupling oxidative phosphorylation from electron transport generates heat. This heat can be used by endothermic organisms to regulate body temperature.

Exclusion Statement
The names of the specific electron carriers in the electron transport chain are beyond the scope of the course and the AP Exam.

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

Essential Knowledge
Glycolysis is a biochemical pathway that releases energy in glucose to form ATP from ADP and inorganic phosphate, NADH from NAD+, and pyruvate.
Pyruvate is transported from the cytosol to the mitochondrion, where further oxidation occurs.
In the Krebs cycle, carbon dioxide is released from organic intermediates, ATP is synthesized from ADP and inorganic phosphate, and electrons are transferred to the coenzymes NADH and FADH2.
Electrons extracted in glycolysis and Krebs cycle reactions are transferred by NADH and FADH2 to the electron transport chain in the inner mitochondrial membrane.
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.
Fermentation allows glycolysis to proceed in the absence of oxygen and produces organic molecules, including alcohol and lactic acid, as waste products.
The conversion of ATP to ADP releases energy, which is used to power many metabolic processes.

Exclusion Statement
Specific steps, names of enzymes, and intermediates of the pathways for these processes are beyond the scope of the course and the AP Exam.

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

TOPIC 3.7 Fitness

Enduring Understanding

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

Learning Objective

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

Essential Knowledge

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

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

UNIT 4: Cell Communication and Cell Cycle

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.

TOPIC 4.1: Cell Communication

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

Learning Objective
Describe the ways that cells can communicate with one another.

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

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

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

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

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

TOPIC 4.2: Introduction to Signal Transduction

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

Learning Objective
Describe the components of a signal transduction pathway.

Essential Knowledge
Signal transduction pathways link signal reception with cellular responses.
Many signal transduction pathways include protein modification and phosphorylation cascades.

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

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

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

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

a. After the ligand binds, the intracellular domain of a receptor protein changes shape, initiating transduction of the signal.
b. Second messengers (such as cyclic AMP) are molecules that relay and amplify the intracellular signal.
c. Binding of ligand-to-ligand-gated channels can cause the channel to open or close.

TOPIC 4.3: Signal Transduction

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

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

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

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

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

TOPIC 4.4: Changes in Signal Transduction Pathways

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

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

Essential Knowledge
Changes in signal transduction pathways can alter cellular response—

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

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

TOPIC 4.5: Feedback

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

Learning Objective
Describe positive and/ or negative feedback mechanisms.

Essential Knowledge
Organisms use feedback mechanisms to maintain their internal environments and respond to internal and external environmental changes.

Learning Objective
Explain how negative feedback helps to maintain homeostasis.

Essential Knowledge
Negative feedback mechanisms maintain homeostasis for a particular condition by regulating physiological processes. If a system is perturbed, negative feedback mechanisms return the system back to its target set point. These processes operate at the molecular and cellular levels.

Learning Objective
Explain how positive feedback affects homeostasis.

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

TOPIC 4.6: Cell Cycle

Enduring Understanding
Heritable information provides for continuity of life.

Learning Objective
Describe the events that occur in the cell cycle.

Essential Knowledge
In eukaryotes, cells divide and transmit genetic information via two highly regulated processes.

Essential Knowledge
The cell cycle is a highly regulated series of events for the growth and reproduction of cells—

a. The cell cycle consists of sequential stages of interphase (G1, S, G2), mitosis, and cytokinesis.
b. A cell can enter a stage (G0) where it no longer divides, but it can reenter the cell cycle in response to appropriate cues. Nondividing cells may exit the cell cycle or be held at a particular stage in the cell cycle.

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

Essential Knowledge
Mitosis is a process that ensures the transfer of a complete genome from a parent cell to two genetically identical daughter cells—

a. Mitosis plays a role in growth, tissue repair, and asexual reproduction.
b. Mitosis alternates with interphase in the cell cycle.
c. Mitosis occurs in a sequential series of steps (prophase, metaphase, anaphase, telophase).

TOPIC 4.7: Regulation of Cell Cycle

Enduring Understanding
Heritable information provides for continuity of life.

Learning Objective
Describe the role of checkpoints in regulating the cell cycle.

Essential Knowledge
A number of internal controls or checkpoints regulate progression through the cycle.
Interactions between cyclins and cyclin- dependent kinases control the cell cycle.

Exclusion Statement
Knowledge of specific cyclin-CdK pairs or growth factors is beyond the scope of the course and the AP Exam.

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

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

UNIT 5: HEREDITY

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

TOPIC 5.1: Meiosis

Enduring Understanding

Heritable information provides for continuity of life.

Learning Objective

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

Essential Knowledge

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

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

Learning Objective

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

Essential Knowledge

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

TOPIC 5.2: Meiosis and Genetic Diversity

Enduring Understanding

Heritable information provides for continuity of life.

Learning Objective

Explain how the process of meiosis generates genetic diversity.

Essential Knowledge

Separation of the homologous chromosomes in meiosis I ensures that each gamete receives a haploid (1n) set of chromosomes that comprises both maternal and paternal chromosomes.
During meiosis I, homologous chromatids exchange genetic material via a process called "crossing over" (recombination), which increases genetic diversity among the resultant gametes.
Sexual reproduction in eukaryotes involving gamete formation—including crossing over, the random assortment of chromosomes during meiosis, and subsequent fertilization of gametes—serves to increase variation.

Exclusion Statement

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

TOPIC 5.3: Mendelian Genetics

Enduring Understanding
Organisms are linked by lines of descent from common ancestry.
Heritable information provides for continuity of life.

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

Essential Knowledge
DNA and RNA are carriers of genetic information.
Ribosomes are found in all forms of life.
Major features of the genetic code are shared by all modern living systems.
Core metabolic pathways are conserved across all currently recognized domains.

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

Essential Knowledge
Mendel's laws of segregation and independent assortment can be applied to genes that are on different chromosomes.
Fertilization involves the fusion of two haploid gametes, restoring the diploid number of chromosomes and increasing genetic variation in populations by creating new combinations of alleles in the zygote—

a. Rules of probability can be applied to analyze passage of single-gene traits from parent to offspring.
b. The pattern of inheritance (monohybrid, dihybrid, sex-linked, and genetically linked genes) can often be predicted from data, including pedigree, that give the parent genotype/phenotype and the offspring genotypes/phenotypes.

Relevant Equation

Laws of Probability –
If A and B are mutually exclusive, then:
P(A or B) = P(A) + P(B)
If A and B are independent, then:
P(A and B) = P(A) x P(B)

TOPIC 5.4: Non-Mendelian Genetics

Enduring Understanding
Heritable information provides for continuity of life

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

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

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

Some traits are determined by genes on sex chromosomes and are known as sex- linked traits. The pattern of inheritance of sex-linked traits can often be predicted from data, including pedigree, indicating the parent genotype/phenotype and the offspring genotypes/phenotypes.
Many traits are the product of multiple genes and/or physiological processes acting in combination; these traits therefore do not segregate in Mendelian patterns.
Some traits result from non-nuclear inheritance—

a. Chloroplasts and mitochondria are randomly assorted to gametes and daughter cells; thus, traits determined by chloroplast and mitochondrial DNA do not follow simple Mendelian rules.
b. In animals, mitochondria are transmitted by the egg and not by sperm; as such, traits determined by the mitochondrial DNA are maternally inherited.

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

TOPIC 5.5: Environmental Effect on Phenotype

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

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

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

TOPIC 5.6: Chromosomal Inheritance

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

Learning Objective
Explain how chromosomal inheritance generates genetic variation in sexual reproduction.

Essential Knowledge
Segregation, independent assortment of chromosomes, and fertilization result in genetic variation in populations.
The chromosomal basis of inheritance provides an understanding of the pattern of transmission of genes from parent to offspring.
Certain human genetic disorders can be attributed to the inheritance of a single affected or mutated allele or specific chromosomal changes, such as nondisjunction.

Unit 6: Gene Expression And Regulation

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

TOPIC 6.1: DNA and RNA Structure

Enduring Understanding

Heritable information provides for continuity of life.

Learning Objective

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

Essential Knowledge

DNA, and in some cases RNA, is the primary source of heritable information.

Genetic information is transmitted from one generation to the next through DNA or RNA—

a. Genetic information is stored in and passed to subsequent generations through DNA molecules and, in some cases, RNA molecules.
b. Prokaryotic organisms typically have circular chromosomes, while eukaryotic organisms typically have multiple linear chromosomes.

Prokaryotes and eukaryotes can contain plasmids, which are small extrachromosomal, double-stranded, circular DNA molecules.

Learning Objective

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

Essential Knowledge

DNA, and sometimes RNA, exhibits specific nucleotide base pairing that is conserved through evolution: adenine pairs with thymine or uracil (A-T or A-U) and cytosine pairs with guanine (C-G)—

a. Purines (G and A) have a double ring structure.
b. Pyrimidines (C, T, and U) have a single ring structure.

TOPIC 6.2: Replication

Enduring Understanding

Heritable information provides for continuity of life.

Learning Objective

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

Essential Knowledge

DNA replication ensures continuity of hereditary information—

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

Exclusion Statement

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

TOPIC 6.3: Transcription and RNA Processing

Enduring Understanding
Heritable information provides for continuity of life.

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

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

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

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

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

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

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.

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

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

TOPIC 6.4: Translation

Enduring Understanding
Heritable information provides for continuity of life.

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

Essential Knowledge
Translation of the mRNA to generate a polypeptide occurs on ribosomes that are present in the cytoplasm of both prokaryotic and eukaryotic cells and on the rough endoplasmic reticulum of eukaryotic cells.
In prokaryotic organisms, translation of the mRNA molecule occurs while it is being transcribed.
Translation involves energy and many sequential steps, including initiation, elongation, and termination.

Exclusion Statement
The details and names of the enzymes and factors involved in each of these steps are beyond the scope of the course and the AP Exam.

The salient features of translation include—

a. Translation is initiated when the rRNA in the ribosome interacts with the mRNA at the start codon.
b. The sequence of nucleotides on the mRNA is read in triplets called codons.
c. Each codon encodes a specific amino acid, which can be deduced by using a genetic code chart. Many amino acids are encoded by more than one codon.
d. Nearly all living organisms use the same genetic code, which is evidence for the common ancestry of all living organisms.
e. tRNA brings the correct amino acid to the correct place specified by the codon on the mRNA.
f. The amino acid is transferred to the growing polypeptide chain.
g. The process continues along the mRNA until a stop codon is reached.
h. The process terminates by release of the newly synthesized polypeptide/protein.

Exclusion Statement
Memorization of the genetic code is beyond the scope of the course and the AP Exam.

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

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

TOPIC 6.5: Regulation of Gene Expression

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

Learning Objective
Describe the types of interactions that regulate gene expression.

Essential Knowledge
Regulatory sequences are stretches of DNA that interact with regulatory proteins to control transcription.
Epigenetic changes can affect gene expression through reversible modifications of DNA or histones.
The phenotype of a cell or organism is determined by the combination of genes that are expressed and the levels at which they are expressed—

a. Observable cell differentiation results from the expression of genes for tissue-specific proteins.
b. Induction of transcription factors during development results in sequential gene expression.

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

Essential Knowledge
Both prokaryotes and eukaryotes have groups of genes that are coordinately regulated—

a. In prokaryotes, groups of genes called operons are transcribed in a single mRNA molecule. The lac operon is an example of an inducible system.
b. In eukaryotes, groups of genes may be influenced by the same transcription factors to coordinately regulate expression.

TOPIC 6.6: Gene Expression and Cell Specialization

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

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

Essential Knowledge
Promoters are DNA sequences upstream of the transcription start site where RNA polymerase and transcription factors bind to initiate transcription.
Negative regulatory molecules inhibit gene expression by binding to DNA and blocking transcription.

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

Essential Knowledge
Gene regulation results in differential gene expression and influences cell products and function.
Certain small RNA molecules have roles in regulating gene expression.

TOPIC 6.7: Mutations

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

Learning Objective
Describe the various types of mutation.

Essential Knowledge
Changes in genotype can result in changes in phenotype—

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

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

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

Learning Objective
Explain how changes in genotype may result in changes in phenotype.

Essential Knowledge
Errors in DNA replication or DNA repair mechanisms, and external factors, including radiation and reactive chemicals, can cause random mutations in the DNA—

a. Whether a mutation is detrimental, beneficial, or neutral depends on the environmental context.
b. Mutations are the primary source of genetic variation.

Errors in mitosis or meiosis can result in changes in phenotype—

a. Changes In Chromosome Number Often Result in new phenotypes, including sterility caused by triploidy, and increased vigor of other polyploids.
b. Changes in chromosome number often result in human disorders with developmental limitations, including Down syndrome/ Trisomy 21 and Turner syndrome.

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

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

a. The horizontal acquisitions of genetic information primarily in prokaryotes via transformation (uptake of naked DNA), transduction (viral transmission of genetic information), conjugation (cell-to-cell transfer of DNA), and transposition (movement of DNA segments within and between DNA molecules) increase variation.
b. Related viruses can combine/recombine genetic information if they infect the same host cell.
c. Reproduction processes that increase genetic variation are evolutionarily conserved and are shared by various organisms.

TOPIC 6.8: Biotechnology

Enduring Understanding
Heritable information provides for continuity of life.

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

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

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

Exclusion Statement
The details of these processes are beyond the scope of this course. The focus should be on the conceptual understanding of the application of these techniques.

Unit 7: Natural Selection

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

TOPIC 7.1: Introduction to Natural Selection

Enduring Understanding

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

Learning Objective

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

Essential Knowledge

An adaptation is a genetic variation that is favored by selection and is manifested as a trait that provides an advantage to an organism in a particular environment.
Mutations are random and are not directed by specific environmental pressures.

Learning Objective

Describe the causes of natural selection.

Essential Knowledge

Natural selection is a major mechanism of evolution.
According to Darwin's theory of natural selection, competition for limited resources results in differential survival. Individuals with more favorable phenotypes are more likely to survive and produce more offspring, thus passing traits to subsequent generations.

Learning Objective

Explain how natural selection affects populations.

Essential Knowledge

Evolutionary fitness is measured by reproductive success.
Biotic and abiotic environments can be more or less stable/fluctuating, and this affects the rate and direction of evolution; different genetic variations can be selected in each generation.

TOPIC 7.2: Natural Selection

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

Learning Objective

Describe the importance of phenotypic variation in a population.

Essential Knowledge

Natural selection acts on phenotypic variations in populations.
Environments change and apply selective pressures to populations.
Some phenotypic variations significantly increase or decrease fitness of the organism in particular environments.

TOPIC 7.3: Artificial Selection

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

Learning Objective
Explain how humans can affect diversity within a population.

Essential Knowledge
Through artificial selection, humans affect variation in other species.

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

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

TOPIC 7.4: Population Genetics

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

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

Essential Knowledge
Evolution is also driven by random occurrences—

a. Mutation is a random process that contributes to evolution.
b. Genetic drift is a nonselective process occurring in small populations—
    i. Bottlenecks.
    ii. Founder effect.
c. Migration/gene flow can drive evolution

Learning Objective
Describe the role of random processes in the evolution of specific populations.

Essential Knowledge
Reduction of genetic variation within a given population can increase the differences between population

Learning Objective
Describe the change in the genetic makeup of a population over time.

Essential Knowledge
Mutation results in genetic variation, which provides phenotypes on which natural selection acts.

TOPIC 7.5: Hardy-Weinberg Equilibrium

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

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

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

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

Essential Knowledge
Changes in allele frequencies provide evidence for the occurrence of evolution in a population.
Small populations are more susceptible to random environmental impact than large populations.

TOPIC 7.6: Evidence of Evolution

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

Learning Objective
Describe the types of data that provide evidence
for evolution.

Essential Knowledge
Evolution is supported by scientific evidence from many disciplines (geographical, geological, physical, biochemical, and mathematical data).

Learning Objective
Explain how morphological, biochemical, and geological data provide evidence that organisms have changed over time.

Essential Knowledge
Molecular, morphological, and genetic evidence from extant and extinct organisms adds to our understanding of evolution—

a. Fossils can be dated by a variety of methods. These include:
    i. The age of the rocks where a fossil is found
    ii. The rate of decay of isotopes including carbon-14
    iii. Geographical data

b. Morphological homologies, including vestigial structures, represent features shared by common ancestry.

A comparison of DNA nucleotide sequences and/or protein amino acid sequences provides evidence for evolution and common ancestry.

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

Essential Knowledge
Many fundamental molecular and cellular features and processes are conserved across organisms.
Structural and functional evidence supports the relatedness of organisms in all domains.

TOPIC 7.7: Common Ancestry

Enduring Understanding
Organisms are linked by lines of descent from common ancestry.

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

Essential Knowledge
DNA and RNA are carriers of genetic information.
Ribosomes are found in all forms of life.
Major features of the genetic code are shared by all modern living systems.
Core metabolic pathways are conserved across all currently recognized domains.

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

Essential Knowledge
Structural evidence indicates common ancestry of all eukaryotes—

a. Membrane-bound organelles
b. Linear chromosomes
c. Genes that contain introns

TOPIC 7.8: Continuing Evolution

Enduring Understanding
Life continues to evolve within a changing environment.

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

Essential Knowledge
Populations of organisms continue to evolve.
All species have evolved and continue to evolve—

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

TOPIC 7.9: Phylogeny

Enduring Understanding
Life continues to evolve within a changing environment.

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

Essential Knowledge
Phylogenetic trees and cladograms show evolutionary relationships among lineages—

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

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

Essential Knowledge
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.
Phylogenetic trees and cladograms can be constructed from morphological similarities of living or fossil species and from DNA and protein sequence similarities.
Phylogenetic trees and cladograms represent hypotheses and are constantly being revised, based on evidence.

TOPIC 7.10: Speciation

Enduring Understanding
Life continues to evolve within a changing environment.

Learning Objective
Describe the conditions under which new species may arise.

Essential Knowledge
Speciation may occur when two populations become reproductively isolated from each other.
The biological species concept provides a commonly used definition of species for sexually reproducing organisms. It states that species can be defined as a group capable of interbreeding and exchanging genetic information to produce viable, fertile offspring.

Learning Objective
Describe the rate of evolution and speciation under different ecological conditions.

Essential Knowledge
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.
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.

Learning Objective
Explain the processes and mechanisms that drive speciation.

Essential Knowledge
Speciation results in diversity of life forms.

Speciation may be sympatric or allopatric.
Various prezygotic and postzygotic mechanisms can maintain reproductive isolation and prevent gene flow between populations.

TOPIC 7.11: Extinction

Enduring Understanding
Life continues to evolve within a changing environment.

Learning Objective
Describe factors that lead to the extinction of a population

Essential Knowledge
Extinctions have occurred throughout Earth's history.
Extinction rates can be rapid during times of ecological stress.

Learning Objective
Explain how the risk of extinction is affected by changes in the environment.

Essential Knowledge
Human activity can drive changes in ecosystems that cause extinctions.

Learning Objective
Explain species diversity in an ecosystem as a function of speciation and extinction rates.

Essential Knowledge
The amount of diversity in an ecosystem can be determined by the rate of speciation and the rate of extinction.

Learning Objective
Explain how extinction can make new environments available for adaptive radiation.

Essential Knowledge
Extinction provides newly available niches that can then be exploited by different species.

TOPIC 7.12: Variations in Populations

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

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

Essential Knowledge
The level of variation in a population affects population dynamics—

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

TOPIC 7.13: Origins of Life on Earth

Enduring Understanding

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

Learning Objective

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

Essential Knowledge

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

a. Geological evidence provides support for models of the origin of life on Earth.
    i. Earth formed approximately 4.6 billion years ago (bya). The environment was too hostile for life until 3.9 bya, and the earliest fossil evidence for life dates to 3.5 bya. Taken together, this evidence provides a plausible range of dates when the origin of life could have occurred.
b. There are several models about the origin of life on Earth—
    i. Primitive Earth provided inorganic precursors from which organic molecules could have been synthesized because of the presence of available free energy and the absence of a significant quantity of atmospheric oxygen ($O2$).
    ii. Organic molecules could have been transported to Earth by a meteorite or other celestial event.
c. Chemical experiments have shown that it is possible to form complex organic molecules from inorganic molecules in the absence of life.
    i. Inorganic molecules/monomers served as building blocks for the formation of more complex molecules, including amino acids and nucleotides.
    ii. The joining of these monomers produced polymers with the ability to replicate, store, and transfer information.

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

Unit 8: Ecology

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

TOPIC 8.1: Responses to the Environment

Enduring Understanding

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

Learning Objective

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

Essential Knowledge

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

Exclusion Statement

No specific behavioral or physiological mechanism is required for teaching this concept.

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

Learning Objective

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

Essential Knowledge

Individuals can act on information and communicate it to others.

Communication occurs through various mechanisms—

a. Organisms have a variety of signaling behaviors that produce changes in the behavior of other organisms and can result in differential reproductive success.
b. Animals use visual, audible, tactile, electrical, and chemical signals to indicate dominance, find food, establish territory, and ensure reproductive success.

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

a. Natural selection favors innate and learned behaviors that increase survival and reproductive fitness.
b. Cooperative behavior tends to increase the fitness of the individual and the survival of the population.

Exclusion Statement

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

TOPIC 8.2: Energy Flow Through Ecosystems

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

Learning Objective
Describe the strategies organisms use to acquire and use energy.

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

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

b. Different organisms use various reproductive strategies in response to energy availability.

c. There is a relationship between metabolic rate per unit body mass and the size of multicellular organisms—generally, the smaller the organism, the higher the metabolic rate.

d. A net gain in energy results in energy storage or the growth of an organism.

e. A net loss of energy results in loss of mass and, ultimately, the death of an organism.

Learning Objective
Explain how changes in energy availability affect populations and ecosystems.

Essential Knowledge
Changes in energy availability can result in changes in population size.

Changes in energy availability can result in disruptions to an ecosystem—

a. A change in energy resources such as sunlight can affect the number and size of the trophic levels.

b. A change in the producer level can affect the number and size of other trophic levels.

Learning Objective
Explain how the activities of autotrophs and heterotrophs enable the flow of energy within an ecosystem.

Essential Knowledge
Autotrophs capture energy from physical or chemical sources in the environment—

a. Photosynthetic organisms capture energy present in sunlight.

b. Chemosynthetic organisms capture energy from small inorganic molecules present in their environment, and this process can occur in the absence of oxygen.

Heterotrophs capture energy present in carbon compounds produced by other organisms.

a. Heterotrophs may metabolize carbohydrates, lipids, and proteins as sources of energy by hydrolysis.

TOPIC 8.3: Population Ecology

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

Learning Objective
Describe factors that influence growth dynamics of populations.

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

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

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

Relevant Equation:

Population Growth −

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

where:
dt = change in time
B = birth rate
D = death rate
N = population size

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

TOPIC 8.4: Effect of Density of Populations

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

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

Essential Knowledge
A population can produce a density of individuals that exceeds the system's resource availability.
As limits to growth due to density-dependent and density-independent factors are imposed, a logistic growth model generally ensues

Relevant Equation:

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

where:
dt = change in time
N = population size
r_{max} = maximum per capita growth rate of population
K = carrying capacity

TOPIC 8.5: Community Ecology

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

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

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

Relevant Equation:

Simpson's Diversity Index –

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

where:
n = the total number of organisms of a particular species
N = total number of organisms of all species

Learning Objective
Explain how interactions within and among populations influence community structure.

Essential Knowledge
Communities change over time depending on interactions between populations.
Interactions among populations determine how they access energy and matter within a community.
Relationships among interacting populations can be characterized by positive and negative effects and can be modeled. Examples include predator/prey interactions, trophic cascades, and niche partitioning.
Competition, predation, and symbioses, including parasitism, mutualism, and commensalism, can drive population dynamics.

Learning Objective
Explain how community structure is related to energy availability in the environment.

Essential Knowledge
Cooperation or coordination between organisms, populations, and species can result in enhanced movement of, or access to, matter and energy.

TOPIC 8.6: Biodiversity

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

Learning Objective
Describe the relationship between ecosystem diversity and its resilience to changes in the environment.

Essential Knowledge
Natural and artificial ecosystems with fewer component parts and with little diversity among the parts are often less resilient to changes in the environment.
Keystone species, producers, and essential abiotic and biotic factors contribute to maintaining the diversity of an ecosystem.

Learning Objective
Explain how the addition or removal of any component of an ecosystem will affect its overall short-term and long- term structure.

Essential Knowledge
The diversity of species within an ecosystem may influence the organization of the ecosystem.
The effects of keystone species on the ecosystem are disproportionate relative to their abundance in the ecosystem, and when they are removed from the ecosystem, the ecosystem often collapses.

TOPIC 8.7: Disruptions to Ecosystems

Enduring Understanding
Competition and cooperation are important aspects of biological systems.

Learning Objective
Explain how invasive species affect ecosystem dynamics.

Essential Knowledge
The intentional or unintentional introduction of an invasive species can allow the species to exploit a new niche free of predators or competitors or to outcompete other organisms for resources.
The availability of resources can result in uncontrolled population growth and ecological changes.

Learning Objective
Describe human activities that lead to changes in ecosystem structure and/ or dynamics.

Essential Knowledge
The distribution of local and global ecosystems changes over time.
Human impact accelerates change at local and global levels—

a. The introduction of new diseases can devastate native species.
b. Habitat change can occur because of human activity.

Learning Objective
Explain how geological and meteorological activity leads to changes in ecosystem structure and/or dynamics.

Essential Knowledge
Geological and meteorological events affect habitat change and ecosystem distribution. Biogeographical studies illustrate these changes.