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

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UNIT AT A GLANCE *(cont'd)*

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

SAMPLE INSTRUCTIONAL ACTIVITIES

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

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

TOPIC 2.1
Cell Structure and Function

Required Course Content

BIG IDEA 4

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

LEARNING OBJECTIVE

2.1.A

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

ESSENTIAL KNOWLEDGE

2.1.A.1

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

2.1.A.2

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

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SUGGESTED SKILLS

Concept Explanation

1.A

Describe biological concepts and processes.

Argumentation

6.A

Make a scientific claim.

ILLUSTRATIVE EXAMPLE

EK 2.1.A.4

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

LEARNING OBJECTIVE

2.1.A

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

ESSENTIAL KNOWLEDGE

2.1.A.3

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

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

TOPIC 2.4
Membrane Permeability

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. i. In endocytosis, the cell takes in large molecules and particulate matter by folding the plasma membrane in on itself and forming new (small) vesicles that engulf material from the external environment. ii. In exocytosis, internal vesicles release material from cells by fusing with the plasma membrane and secreting large molecules from the cell.

TOPIC 2.6
Facilitated Diffusion

SUGGESTED SKILL

Argumentation

6.E

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

Required Course Content

BIG IDEA 2

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

LEARNING OBJECTIVE

2.6.A

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

ESSENTIAL KNOWLEDGE

2.6.A.1

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

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. **RELEVANT EQUATION** Water Potential: $\Psi = \Psi_p + \Psi_s$ where: Ψ_p = pressure potential Ψ_s = solute potential
2.7.B Explain how osmoregulatory mechanisms contribute to the health and survival of organisms.	**2.7.B.1** Growth and homeostasis are maintained by the constant movement of molecules across membranes.

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LEARNING OBJECTIVE

2.7.B

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

ESSENTIAL KNOWLEDGE

2.7.B.2

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

RELEVANT EQUATION

Solute Potential of a Solution:

$\psi_s = -iCRT$ 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.