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<th>Chapter 1. Introduction to Biological Concepts and Research</th>
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<th>Content not required for the AP Course</th>
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<tr>
<td>1.1 What Is Life? Characteristics of Living Organisms</td>
<td>This section provides a nice introduction to many essential knowledge points, providing a quick overview of all four big ideas.</td>
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<td>p.2-6</td>
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<td>1.2 Biological Evolution</td>
<td>This section further develops the essential knowledge points of Big Idea 1: Evolution.</td>
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<td>p.6-8</td>
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<td>1.3 Biodiversity and the Tree of Life</td>
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<td>p.8-12 (Taxonomy and the three domains of life)</td>
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<td>1.4 Biological Research</td>
<td></td>
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<td>p.12-18* (Scientific process and experimental design)</td>
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<p>| Chapter 2. Life, Chemistry, and Water                    |                                                                           |                                   |                                                                     |                                      |
| 2.0 Why It Matters                                       |                                                                           |                                   |                                                                     |                                      |
| 2.1 The Organization of Matter: Elements and Atoms       |                                                                           |                                   |                                                                     |                                      |</p>
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<th>2.2 Atomic Structure</th>
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<th>p.24-28* (Atomic properties, electron orbitals)</th>
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<td>2.3 Chemical Bonds and Chemical Reactions</td>
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<td>p.28-32* (Forms of bonding and relative strengths, chemical equations)</td>
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<tr>
<td>2.4 Hydrogen Bonds and the Properties of Water</td>
<td>2.A.3 Organisms must exchange matter with the environment to grow, reproduce and maintain organization. [2.A.3.a.3 Living systems depend on properties of water that result from its polarity and hydrogen bonding.]</td>
<td></td>
<td>p.32-33</td>
<td>The following are illustrative examples of 2.A.3.a.3: - Universal solvent, p.33, 35 - Density of ice versus liquid water, p.33 - Specific heat and heat of vaporization, p.33-34 - Cohesion, adhesion, and surface tension, p.34</td>
</tr>
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<td>2.5 Water Ionization and Acids, Bases, and Buffers</td>
<td></td>
<td></td>
<td></td>
<td>p.36-38* (Definitions of acids, bases, and the carbonic acid-bicarbonate buffer system)</td>
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Chapter 3. Biological Molecules: The Carbon Compounds of Life
| 3.0 Why It Matters | 2.A.3 Organisms must exchange matter with the environment to grow, reproduce and maintain organization. [2.A.3.a.1 Carbon moves from the environment to organisms where it is used to build carbohydrates, proteins, lipids or nucleic acids. Carbon is used in storage compounds and cell formation in all organisms.] | p.42-43 |
| 3.1 Formation and Modification of Biological Molecules | 4.A.1 The subcomponents of biological molecules and their sequence determine the properties of that molecule. [4.a.1.a Structure and function of polymers are derived from the way their monomers are assembled.] | p.46 | p.43-45 (Functional groups and isomers) |
| 3.2 Carbohydrates | 2.A.3 Organisms must exchange matter with the environment to grow, reproduce and maintain organization. [2.A.3.a.1 Carbon moves from the environment to organisms where it is used to build carbohydrates, proteins, lipids or nucleic acids. Carbon is used in storage compounds and cell formation in all organisms.] | p.47-50 |
| 4.A.1 | The subcomponents of biological molecules and their sequence determine the properties of that molecule. [4.a.1.a.4 Carbohydrates are composed of sugar monomers whose structures and bonding with each other by dehydration synthesis determine the properties and functions of the molecules.] [4.A.1.b.3 The nature of the bonding between carbohydrate subunits determines their relative orientation in the carbohydrate, which then determines the secondary structure of the carbohydrate.] p.47-50 | The following is an illustrative example of 4.A.1.a.4: - Cellulose, glycogen, amylose and chitin, p.48-50 | X. The molecular structure of specific carbohydrate polymers is beyond the scope of the course and the AP exam. |
| 3.3 Lipids | 4.A.1 The subcomponents of biological molecules and their sequence determine the properties of that molecule. [4.a.1.a.3 In general, lipids are nonpolar; however, phospholipids exhibit structural properties with polar regions that interact with other polar molecules such as water, and with nonpolar regions where differences in saturation determine the structure and function of lipids.] p.50-54 | | X. The molecular structure of specific lipids is beyond the scope of the course and the AP exam. |
Proteins

4.A.1 The subcomponents of biological molecules and their sequence determine the properties of that molecule. [4.a.1.a.2 In proteins, the specific order of amino acids in a polypeptide (primary structure) interacts with the environment to determine the overall shape of the protein, which also involves secondary, tertiary and quaternary structure and, thus, its function. The R group of an amino acid can be categorized by chemical properties (hydrophobic, hydrophilic and ionic), and the interactions of these R groups determine structure and function of that region of the protein.]

4.A.1.b.2 Proteins have an amino (NH2) and a carboxyl (COOH) end, and consist of a linear sequence of amino acids connected by the formation of peptide bonds by dehydration synthesis between the amino and carboxyl groups of adjacent monomers.

Though not required, note that the Experimental Research box on p.61 describes the classic RNase denaturation/refolding experiment (aligns with LO 4.1, 4.2, and 4.17).

3.A.1 DNA and, in some cases, RNA is the primary source of heritable information. [3.A.1.d Phenotypes are determined through protein activities.]

The following is an illustrative example of 3.A.1.d:
- Examples of specific proteins and their functions, p.55

X. The molecular structure of specific amino acids is beyond the scope of the course and the AP exam.
### 3.5 Nucleotides and Nucleic Acids

#### 3.A.1 DNA and, in some cases, RNA is the primary source of heritable information. [3.A.1.b DNA and RNA molecules have structural similarities and differences that define function.]

*Page 63-66*

### 4.A.1 The subcomponents of biological molecules and their sequence determine the properties of that molecule. [4.a.1.a.1 In nucleic acids, biological information is encoded in sequences of nucleotide monomers. Each nucleotide has structural components: a 5-carbon sugar (deoxyribose or ribose), a phosphate, and a nitrogen base (adenine, thymine, guanine, cytosine, or uracil). DNA and RNA differ in function and differ slightly in structure, and these structural differences account for their differing functions.]

*Page 63-66*

### Chapter 4. Energy, Enzymes, and Biological Reactions

#### 4.0 Why It Matters

*Page 70-71*

*Function of catalysts*
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<td>4.1 Energy, Life, and the Laws of Thermodynamics</td>
<td>2.A.1</td>
<td>All living systems require constant input of free energy. [2.A.1.a Life requires a highly ordered system.] [2.A.1.b Living systems do not violate the second law of thermodynamics, which states that entropy increases over time.]</td>
<td>p.71-72</td>
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<td>4.2 Free Energy and Spontaneous Reactions</td>
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<td>(Free energy calculations)</td>
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<td></td>
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<td>(Dynamic equilibrium and reversibility)</td>
<td>p.74*</td>
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<td>(Anabolic vs catabolic, exergonic vs endergonic reactions)</td>
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<tr>
<td>4.3 Adenosine Triphosphate (ATP): The Energy Currency of the Cell</td>
<td>2.A.1</td>
<td>All living systems require constant input of free energy. [2.A.1.b Living systems do not violate the second law of thermodynamics, which states that entropy increases over time.]</td>
<td>p.74-76</td>
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<td>2.A.2</td>
<td>Organisms capture and store free energy for use in biological processes. [2.A.2.h Free energy becomes available for metabolism by the conversion of ATP-&gt;ADP, which is coupled to many steps in metabolic pathways.]</td>
<td>p.74-76</td>
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<tr>
<td>4.4 Role of Enzymes in Biological Reactions</td>
<td>4.B.1 Interactions between molecules affect their structure and function. [4.B.1.b The shape of enzymes, active sites and interaction with specific molecules are essential for basic functioning of the enzyme.]</td>
<td>p.78-79</td>
<td>p.77-78* (Catalysis and activation energy) X. No specific cofactors or coenzymes are within the scope of the course and the AP exam.</td>
</tr>
<tr>
<td>4.5 Conditions and Factors that Affect Enzyme Activity</td>
<td>4.B.1 Interactions between molecules affect their structure and function. [4.B.1.c Other molecules and the environment in which the enzyme acts can enhance or inhibit enzyme activity. Molecules can bind reversibly or irreversibly to the active or allosteric sites, changing the activity of the enzyme.]</td>
<td>p.79-83</td>
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### Chapter 5. The Cell: An Overview

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<td>5.0 Why It Matters</td>
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<td>p.88-89* (Cell theory)</td>
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<tr>
<td>5.1 Basic Features of Cell Structure and Function</td>
<td>1.B.1 Structural and functional evidence supports the relatedness of all domains. [1.B.1.a.2 Major features of the genetic code are shared by all modern living systems.]</td>
<td>p.92</td>
<td></td>
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<tr>
<td>2.A.3</td>
<td>Organisms must exchange matter with the environment to grow, reproduce and maintain organization. [2.A.3.b Surface area-to-volume ratios affect a biological system’s ability to obtain necessary resources or eliminate waste products.]</td>
<td>p.90</td>
<td>p.89-90* (Basic properties of all cells) p.92* (Prokaryotes vs eukaryotes)</td>
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<tr>
<td>5.2 Prokaryotic Cells</td>
<td>2.B.3 Eukaryotic cells maintain internal membranes that partition the cell into specialized regions. [2.B.3.c Archaea and Bacteria generally lack internal membranes and organelles and have a cell wall.]</td>
<td>p.93</td>
<td>p.93-94 (Glycocalyx, flagellum)</td>
<td></td>
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<td></td>
<td>2.B.1 Cell membranes are selectively permeable due to their structure. [2.B.1.c.2 Other examples are cell walls of prokaryotes and fungi.]</td>
<td>p.93</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5.3 Eukaryotic Cells</td>
<td>4.B.2 Cooperative interactions within organisms promote efficiency in the use of energy and matter. [4.B.2.a Organisms have areas or compartments that perform a subset of functions related to energy and matter, and these parts contribute to the whole.]</td>
<td>p.94-104</td>
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<td>2.B.3</td>
<td>Eukaryotic cells maintain internal membranes that partition the cell into specialized regions. [2.B.3.a Internal membranes facilitate cellular processes by minimizing competing interactions and by increasing surface area where reactions can occur.] [2.B.3.b Membranes and membrane-bound organelles in eukaryotic cells localize (compartmentalize) intracellular metabolic processes and specific enzymatic reactions.]</td>
<td>p.94-104</td>
<td>The following are illustrative examples of 2.B.3.b: - Endoplasmic reticulum, p.99-100 - Mitochondria, p.102-103 - Golgi, p.100-101 - Nuclear envelope, p.95-96</td>
<td>p.104-107 (Cytoskeletal elements, flagella and cilia)</td>
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X. Specific functions of smooth ER in specialized cells are beyond the scope of the course and the AP Exam.

X. The role of the Golgi in specific phospholipid synthesis and the packaging of enzymatic contents of lysosomes, peroxisomes, and secretory vesicles are beyond the scope of the course and the AP Exam.

X. Specific examples of how lysosomes carry out intracellular digestion are beyond the scope of the course and the AP Exam.
| 1.B.1 Organisms share many conserved core processes and features that evolved and are widely distributed among organisms today. [1.B.1.b Structural evidence supports the relatedness of all eukaryotes.] | The following are illustrative examples of 1.B.1.b:  
- Cytoskeleton, p.104-106  
- Flagella and cilia, p.106-107  
- Mitochondria, p.102-103  
- Endomembrane systems, p.99-102 |
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<tr>
<td>5.4 Specialized Structures of Plant Cells</td>
<td>4.B.2 Cooperative interactions within organisms promote efficiency in the use of energy and matter. [4.B.2.a Organisms have areas or compartments that perform a subset of functions related to energy and matter, and these parts contribute to the whole.] p.108</td>
</tr>
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</table>
| 2.B.3 Eukaryotic cells maintain internal membranes that partition the cell into specialized regions. [2.B.3.a Internal membranes facilitate cellular processes by minimizing competing interactions and by increasing surface area where reactions can occur.] [2.B.3.b Membranes and membrane-bound organelles in eukaryotic cells localize (compartmentalize) intracellular metabolic processes and specific enzymatic reactions.] p.108 | The following is an illustrative example of 2.B.3.b:  
- Chloroplasts, p.108 |
<table>
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<tr>
<th>4.A.2</th>
<th>The structure and function of subcellular components, and their interactions, provide essential cellular processes. [4.A.2.f] A vacuole is a membrane-bound sac that plays roles in intracellular digestion and the release of cellular waste products. In plants, a large vacuole serves many functions, from storage of pigments or poisonous substances to a role in cell growth.] [4.A.2.g] Chloroplasts are specialized organelles found in algae and higher plants that capture energy through photosynthesis.</th>
<th>p.108</th>
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<td>2.B.1</td>
<td>Cell membranes are selectively permeable due to their structure. [2.B.1.c.1] Plant cell walls are made of cellulose and are external to the cell membrane.</td>
<td>p.109</td>
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<td>3.D.2</td>
<td>Cells communicate with each other through direct contact with other cells or from a distance via chemical signaling. [3.D.2.a] Cells communicate by cell-to-cell contact.</td>
<td>The following is an illustrative example of 3.D.2.a: - Plasmodesmata, p.109</td>
</tr>
<tr>
<td>5.5 The Animal Cell Surface</td>
<td>3.D.2</td>
<td>Cells communicate with each other through direct contact with other cells or from a distance via chemical signaling. [3.D.2.a] Cells communicate by cell-to-cell contact.</td>
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p.110 (Cell junctions)
p.110-111 (Composition of extracellular matrix)
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| 3.A.3 The chromosomal basis of inheritance provides an understanding of the pattern of passage (transmission) of genes from parent to offspring. [3.A.3.c Certain human genetic disorders can be attributed to the inheritance of single gene traits or specific chromosomal changes, such as nondisjunction.]
| The following is an illustrative example of 3.A.3.c:
- Cystic fibrosis, p.116-117 |
| 3.A.1 DNA, and in some cases RNA, is the primary source of heritable information. [3.A.1.d Phenotypes are determined through protein activities.]
| The following is an illustrative example of 3.A.1.d:
- Transport by proteins, p.124-125 |
| **6.1 Membrane Structure and Function** |
| 2.B.1 Cell membranes are selectively permeable due to their structure. [2.B.1.a Cell membranes separate the internal environment of the cell from the external environment.]
[2.B.1.b Selective permeability is a direct consequence of membrane structure, as described by the fluid mosaic model.]
| p.117-122 |
| 4.C.1 Variation in molecular units provides cells with a wider range of functions. [4.C.1.a Variations within molecular classes provide cells and organisms with a wider range of functions.]
| The following is an illustrative example of 4.C.1.a:
- Different types of phospholipids in cell membranes, p.117, 120 |
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<th>Illustrative Examples</th>
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<td>6.2 Functions of Membranes in Transport: Passive Transport</td>
<td>2.B.2 Growth and dynamic homeostasis are maintained by the constant movement of molecules across membranes. [2.B.2.a Passive transport does not require the input of metabolic energy; the net movement of molecules is from high concentration to low concentration.]</td>
<td>p.122-124</td>
<td>The following are illustrative examples of 2.B.2.a: - Glucose transport, p.125 - Na+/K+ transport, p.125 - Cl- transport by CFTR, p.124 X. There is no particular membrane protein that is required for teaching this concept.</td>
</tr>
<tr>
<td>6.3 Passive Water Transport and Osmosis</td>
<td>2.B.2 Growth and dynamic homeostasis are maintained by the constant movement of molecules across membranes. [2.B.2.a Passive transport does not require the input of metabolic energy; the net movement of molecules is from high concentration to low concentration.]</td>
<td>p.124-127</td>
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<tr>
<td>6.4 Active Transport</td>
<td>2.B.2 Growth and dynamic homeostasis are maintained by the constant movement of molecules across membranes. [2.B.2.b Active transport requires free energy to move molecules from regions of low concentration to regions of high concentration.]</td>
<td>p.127-128</td>
<td>p.129-130 (Symport and antiport)</td>
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<td>6.5 Exocytosis and Endocytosis</td>
<td>2.B.2 Growth and dynamic homeostasis are maintained by the constant movement of molecules across membranes. [2.B.2.c The processes of endocytosis and exocytosis move large molecules from the external environment to the internal environment and vice versa, respectively.]</td>
<td>p.130-133</td>
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<td><strong>Chapter 7. Cell Communication</strong></td>
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<td><strong>p.137-138</strong> (Importance of cell signaling)</td>
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<tr>
<td><strong>7.0 Why It Matters</strong></td>
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</table>
| **7.1 Cell Communication: An Overview** | **3.D.1** Cell communication processes share common features that reflect a shared evolutionary history. [3.D.1.a Communication involves transduction of stimulatory or inhibitory signals from other cells, organisms, or the environment.] [3.D.1.d In multicellular organisms, signal transduction pathways coordinate the activities within individual cells that support the function of the organism as a whole.] | p.139-140 | The following is an illustrative example of 3.D.1.d:  
- Epinephrine stimulation of glycogen breakdown in animals, p.138-139  
Though not required, the Experimental Research box on p.139 describes a classic experiment demonstrating the role of second messengers in epinephrine signal transduction (aligns with LO 3.36 and 3.37). |
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<th></th>
<th><strong>3.D.2</strong> Cells communicate with each other through direct contact with other cells or from a distance via chemical signaling. [3.D.2.a Cells communicate by cell-to-cell contact.] [3.D.2.b Cells communicate over short distances by using local regulators that target cells in the vicinity of the emitting cell.] [3.D.2.c Signals released by one cell type can travel long distances to target cells of another cell type.]</th>
<th>p.138</th>
<th>X. No specific system, with the exception of the endocrine system, is required for teaching the concepts in 3.D.2. Teachers are free to choose a system that best fosters student understanding.</th>
</tr>
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<tr>
<td></td>
<td>3.D.2 Cells communicate with each other through direct contact with other cells or from a distance via chemical signaling. [3.D.2.c Signals released by one cell type can travel long distances to target cells of another cell type.]</td>
<td></td>
<td>The following is an illustrative example of 3.D.2.c.1: - Insulin, p.144</td>
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<td>3.D.4 Changes in signal transduction pathways can alter cellular response. [3.D.4.a Conditions where signal transduction is blocked or defective can be deleterious, preventative or prophylactic.]</td>
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<td>The following is an illustrative example of 3.D.3.b.2: - Diabetes, p.144</td>
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<tr>
<td>7.5 Pathways Triggered by Internal Receptors: Steroid Hormone Receptors</td>
<td>3.B.2 A variety of intercellular and intracellular signal transmissions mediate gene expression. [3.B.2.a Signal transmission within and between cells mediates gene expression.]</td>
<td>p.150-151</td>
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<td>7.6 Integration of Cell Communication Pathways</td>
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<td>p.151 (Cross-talk)</td>
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Chapter 8. Harvesting Chemical Energy: Cellular Respiration

8.0 Why It Matters

2.A.2 Organisms capture and store free energy for use in biological processes. [2.A.2.b Heterotrophs capture free energy present in carbon compounds produced by other organisms.] | p.156 | p.155-156 (Consequences of mitochondrial defects) |

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<tr>
<th>8.1 Overview of Cellular Energy Metabolism</th>
<th>2.A.2 Organisms capture and store free energy for use in biological processes. [2.A.2.c Different energy-capturing processes use different types of electron acceptors.]</th>
<th>p.158-159</th>
<th>The following is an illustrative example of 2.A.2.c: - Oxygen as final electron acceptor of cellular respiration, p.157</th>
<th>p.156-157* (Role of electron flow, oxidation, and reduction in energy metabolism)</th>
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<td>8.2 Glycolysis: Splitting the Sugar in Half</td>
<td>2.A.2 Organisms capture and store free energy for use in biological processes. [2.A.2.f Cellular respiration in eukaryotes involves a series of coordinated enzyme-catalyzed reactions that harvest free energy from simple carbohydrates.]</td>
<td>p.159-161</td>
<td>X. Memorization of the steps in glycolysis and the Krebs cycle, or of the structures of the molecules and the names of the enzymes involved, are beyond the scope of the course and the AP Exam.</td>
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<tr>
<td>8.3 Pyruvate Oxidation and the Citric Acid Cycle</td>
<td>2.A.2 Organisms capture and store free energy for use in biological processes. [2.A.2.b.f Heterotrophs may metabolize carbohydrates, lipids and proteins by hydrolysis as sources of free energy.] [2.A.2.f Cellular respiration in eukaryotes involves a series of coordinated enzyme-catalyzed reactions that harvest free energy from simple carbohydrates.]</td>
<td>p.162-165</td>
<td>X. Memorization of the steps in glycolysis and the Krebs cycle, or of the structures of the molecules and the names of the enzymes involved, are beyond the scope of the course and the AP Exam.</td>
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<td><strong>2.A.1</strong> All living systems require constant input of free energy. [2.A.1.c Energy-related pathways in biological systems are sequential and may be entered at multiple points in the pathway.]</td>
<td>The following is an illustrative example of 2.A.1.c: - Krebs cycle, p.163</td>
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<td><strong>8.4 Oxidative Phosphorylation: the Electron Transfer System and Chemiosmosis</strong></td>
<td><strong>2.A.2</strong> Organisms capture and store free energy for use in biological processes. [2.A.2.g The electron transport chain captures free energy from electrons in a series of coupled reactions that establish an electrochemical gradient across membranes.]</td>
<td>p.165-170</td>
<td>Though not required, the Experimental Research box on p.168 describes a classic experiment demonstrating that ATP synthase is powered by a proton gradient (aligns with LO 2.4). Also not required but an interesting evolutionary connection nonetheless, the Molecular Revolution box on p.171 describes the detection of decoupled oxidative phosphorylation in plants as a mechanism of thermoregulation. X. The names of the specific electron carriers in the ETC are beyond the scope of the course and the AP Exam.</td>
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<tr>
<td><strong>8.5 Fermentation</strong></td>
<td><strong>2.A.2</strong> Organisms capture and store free energy for use in biological processes. [2.A.2.b.2 Fermentation produces organic molecules, including alcohol and lactic acid, and it occurs in the absence of oxygen.]</td>
<td>p.170-172</td>
<td>X. Specific steps, names of enzymes and intermediates of the pathways for alcohol and lactic acid fermentation are beyond the scope of the course and the AP Exam.</td>
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**Chapter 9. Photosynthesis**
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<th>9.1 Photosynthesis: An Overview</th>
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<tbody>
<tr>
<td>2.A.2 Organisms capture and store free energy for use in biological processes. [2.A.2.a Autotrophs capture free energy from physical sources in the environment.] [2.A.2.d The light-dependent reactions of photosynthesis in eukaryotes involve a series of coordinated reaction pathways that capture free energy present in light to yield ATP and NADPH, which power the production of organic molecules.] [2.A.2.e Photosynthesis first evolved in prokaryotic organisms; scientific evidence supports that prokaryotic (bacterial) photosynthesis was responsible for the production of an oxygenated atmosphere; prokaryotic photosynthetic pathways were the foundation of eukaryotic photosynthesis.]</td>
<td></td>
</tr>
<tr>
<td>4.C.1 Variation in molecular units provides cells with a wider range of functions. [4.C.1.a Variations within molecular classes provide cells and organisms with a wider range of functions.]</td>
<td></td>
</tr>
<tr>
<td>The following is an illustrative example of 4.C.1.a: - Chlorophylls, p.181-182</td>
<td></td>
</tr>
<tr>
<td>4.A.2 The structure and function of subcellular components, and their interactions, provide essential cellular processes. [4.A.2.g Chloroplasts are specialized organelles found in algae and higher plants that capture energy through photosynthesis.]</td>
<td>p.178</td>
</tr>
<tr>
<td>9.2 The Light-Dependent Reactions of Photosynthesis</td>
<td>2.A.2 Organisms capture and store free energy for use in biological processes. [2.A.2.c Different energy-capturing processes use different types of electron acceptors.] [2.A.2.d.1 Chlorophylls absorb free energy from light, boosting electrons to a higher energy level in Photosystems I and II.] [2.A.2.d.2 Photosystems I and II are embedded in the internal membranes of chloroplasts (thylakoids) and are connected by the transfer of higher free energy electrons through an electron transport chain (ETC).] [2.A.2.d.3 When electrons are transferred between molecules in a sequence of reactions as they pass through the ETC, an electrochemical gradient of protons across the thylakoid membrane is established.] [2.A.2.d.4 The formation of the proton gradient is a separate process, but it is linked to the synthesis of ATP from ADP and inorganic phosphate via ATP synthase.]</td>
</tr>
</tbody>
</table>
### 9.3 The Light-Independent Reactions of Photosynthesis

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<tr>
<td>2.A.2</td>
<td>Organisms capture and store free energy for use in biological processes. [2.A.2.d.5 The energy captured in the light reactions as ATP and NADPH powers the production of carbohydrates from carbon dioxide in the Calvin cycle, which occurs in the stroma of the chloroplast.]</td>
<td>p.186-190</td>
<td>Though not required, the Basic Research box on p.188 describes the method of paper chromatography, a method used both in the classroom and by Calvin and Benson to identify the intermediates of the Calvin cycle.</td>
</tr>
<tr>
<td>2.A.1</td>
<td>All living systems require constant input of free energy. [2.A.1.c Energy-related pathways in biological systems are sequential and may be entered at multiple points in the pathway.]</td>
<td></td>
<td>The following is an illustrative example of 2.A.1.c: - Calvin cycle, p.187-190</td>
</tr>
<tr>
<td>4.B.1</td>
<td>Interactions between molecules affect their structure and function. [4.B.1.c Other molecules and the environment in which the enzyme acts can enhance or inhibit enzyme activity. Molecules can bind reversibly or irreversibly to the active or allosteric sites, changing the activity of the enzyme.]</td>
<td></td>
<td>The following is an illustrative example of 4.B.1.c: - Rubisco and effect of ATP and NADPH availability, p.187-190 Though not required, the Molecular Revolution box on p.190 describes a mutagenesis experiment demonstrating the effect of the small regulatory subunit of rubisco on enzyme activity (aligns with LO 4.2, 4.3, and 4.17).</td>
</tr>
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<td>9.4 Photorespiration and Alternative Processes of Carbon Fixation</td>
<td>4.A.6</td>
<td>Interactions among living systems and with their environment result in the movement of matter and energy. [4.A.6.g Many adaptations of organisms are related to obtaining and using energy and matter in a particular environment.]</td>
<td>p.191-192 (Photorespiration)</td>
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<td>9.5 Photosynthesis and Cellular Respiration Compared</td>
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<td>p.195</td>
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<td>Chapter 10. Cell Division and Mitosis</td>
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<td>p.199 (Mitosis in tissue regeneration)</td>
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<td>10.0 Why It Matters</td>
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<tr>
<td>10.1 The Cycle of Cell Growth and Division: An Overview</td>
<td>3.A.2</td>
<td>In eukaryotes, heritable information is passed to the next generation via processes that include the cell cycle and mitosis or meiosis plus fertilization. [3.A.2.a Mitosis passes a complete genome from the parent cell to daughter cells.]</td>
<td>p.200-201</td>
</tr>
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<tr>
<td>10.2</td>
<td>The Mitotic Cell Cycle</td>
<td>In eukaryotes, heritable information is passed to the next generation via processes that include the cell cycle and mitosis or meiosis plus fertilization. [3.A.2.a The cell cycle is a complex set of stages that is highly regulated with checkpoints, which determine the ultimate fate of the cell.]</td>
<td>p.201-205</td>
</tr>
<tr>
<td>10.3</td>
<td>Formation and Action of the Mitotic Spindle</td>
<td>Though not required, the Experimental Research box on p.209 describes a photobleaching experiment that demonstrated how chromosomes move during anaphase (aligns with LO 3.7 ad 3.8).</td>
<td>p.206-208</td>
</tr>
<tr>
<td>10.4</td>
<td>Cell Cycle Regulation</td>
<td>The following are illustrative examples of 3.A.2.a.2: - MPF, p.212 - Growth factors, p.212-213 - Contact inhibition, p.213 - Cancer results from disruptions in cell cycle control, p.213-214</td>
<td>p.208-213</td>
</tr>
<tr>
<td>4.B.1</td>
<td>Interactions between molecules affect their structure and function. [4.B.1.a Change in the structure of a molecular system may result in a change of the function of the system.]</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3.D.4</td>
<td>Changes in signal transduction pathways can alter cellular response. [3.D.4.a Conditions where signal transduction is blocked or defective can be deleterious, preventative or prophylactic.]</td>
<td></td>
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</tr>
</tbody>
</table>

The following is an illustrative example of both 4.B.1.a and 3.D.4.a:
- Herpesvirus-induced cancer due to viral override of cell cycle checkpoint, p.214

### 10.5 Cell Division in Prokaryotes

| 10.5 Cell Division in Prokaryotes | p.214-215* |

| Chapter 11. Meiosis: The Cellular Basis of Sexual Reproduction |
| 11.0 Why It Matters | 3.A.2 In eukaryotes, heritable information is passed to the next generation via processes that include the cell cycle and mitosis or meiosis plus fertilization. |
| 11.1 The Mechanisms of Meiosis | 3.A.2 In eukaryotes, heritable information is passed to the next generation via processes that include the cell cycle and mitosis or meiosis plus fertilization. |
### 11.2 Mechanisms That Generate Genetic Variability

<table>
<thead>
<tr>
<th>3.A.2</th>
<th>In eukaryotes, heritable information is passed to the next generation via processes that include the cell cycle and mitosis or meiosis plus fertilization. [3.A.2.a.4 During meiosis, homologous chromatids exchange genetic material via a process called “crossing over,” which increases genetic variation in the resultant gametes.] [3.A.2.a.5 Fertilization involves the fusion of two gametes, increases genetic variation in populations by providing for new combinations of genetic information in the zygote, and restores the diploid number of chromosomes.]</th>
<th>p.225-228</th>
</tr>
</thead>
<tbody>
<tr>
<td>3.C.2</td>
<td>Biological systems have multiple processes that increase genetic variation. [3.C.2.c Sexual reproduction eukaryotes involving gamete formation, including crossing-over during meiosis and the random assortment of chromosomes during meiosis, and fertilization serve to increase variation. Reproduction processes that increase genetic variation are evolutionarily conserved and are shared by various organisms.]</td>
<td>p.225-228</td>
</tr>
</tbody>
</table>
### 11.4 The Time and Place of Meiosis in Organismal Life Cycles

X. The details of sexual reproduction cycles in various plants and animals are beyond the scope of the course and the AP Exam. However, the similarities of the processes that provide for genetic variation are relevant and should be the focus of instruction.

### Chapter 12. Mendel, Genes, and Inheritance

12.0 Why It Matters

p.234-235

(Discovery of sickle cell disease)
| 12.1 The Beginnings of Genetics: Mendel's Garden Peas | 3.A.3 The chromosomal basis of inheritance provides an understanding of the pattern of passage (transmission) of genes from parent to offspring. [3.A.3.a Rules of probability can be applied to analyze passage of single gene traits from parent to offspring.] [3.A.3.b Segregation and independent assortment of chromosomes result in genetic variation.] [3.A.3.c Certain human genetic disorders can be attributed to the inheritance of single gene traits or specific chromosomal changes, such as nondisjunction.] | p.235-247 | The following are illustrative examples of 3.A.3.c: - Cystic fibrosis, p.246 - Albinism, p.246 - Short-limb dwarfism, p.246 |
| 2.E.1 Timing and coordination of specific events are necessary for the normal development of an organism, and these events are regulated by a variety of mechanisms. [2.E.1.b.4 Genetic mutations can result in abnormal development.] | 3.C.1 Changes in genotype can result in changes in phenotype. [3.C.1.a Alterations in a DNA sequence can lead to changes in the type or amount of the protein produced and the consequent phenotype.] | The following is an illustrative example of both 2.E.1.b.4 and 3.C.1.a: - Molecular basis of tall/short pea plant phenotype, p.246 |
### 12.2 Later Modifications and Additions to Mendel's Hypotheses

| 3.A.4 | The inheritance pattern of many traits cannot be explained by simple Mendelian genetics. [3.A.4.a Many traits are the product of multiple genes and/or physiological processes.] | p.246-249, 251 | p.250 (Epistasis) p.252 (Pleiotropy) X. Epistasis and pleiotropy are beyond the scope of the course and the AP Exam. |

| 4.C.2 | Environmental factors influence the expression of the genotype in an organism. [4.C.2.a Environmental factors influence many traits both directly and indirectly.] | p.251 | The following is an illustrative example of 4.C.2.a: - Height in humans, p.251 |

### Chapter 13. Genes, Chromosomes, and Human

#### 13.0 Why It Matters

| 3.A.3 | The chromosomal basis of inheritance provides an understanding of the pattern of passage (transmission) of genes from parent to offspring. [3.A.3.c Certain human genetic disorders can be attributed to the inheritance of single gene traits or specific chromosomal changes, such as nondisjunction.] |  | The following is an illustrative example of 3.A.3.c: - Progeria, p.256 |

#### 13.1 Genetic Linkage and Recombination

<p>| 3.A.3 | The chromosomal basis of inheritance provides an understanding of the pattern of passage (transmission) of genes from parent to offspring. [3.A.3.b Segregation and independent assortment of chromosomes result in genetic variation.] | p.256-261 |  |
|----------------------|-------------------------------------------------------------------------------------------------------------------------------------------------|-----------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------|
| 13.3 Chromosomal Mutations That Affect Inheritance | 3.A.3 The chromosomal basis of inheritance provides an understanding of the pattern of passage (transmission) of genes from parent to offspring. [3.A.3.c Certain human genetic disorders can be attributed to the inheritance of single gene traits or specific chromosomal changes, such as nondisjunction.] | p.267-271 | The following are illustrative examples of 3.A.3.c: - Cri-du-chat syndrome, p.267 - Philadelphia chromosome and chronic myelogenous leukemia (CML), p.267-268 - Down syndrome/Trisomy 21, p.268-269 - Patau syndrome/Trisomy 13, p.269-270 - Edwards syndrome/Trisomy 18, p.270 - Turner syndrome, Klinefelter syndrome, XXY syndrome, and Triple-X syndrome, p.270 |</p>
<table>
<thead>
<tr>
<th>3.C.1</th>
<th>Changes in genotype can result in changes in phenotype. [3.C.1.c.1 Changes in chromosome number often result in new phenotypes, including sterility caused by triploidy and increased vigor of other polyploids.] [3.C.1.c.2 Changes in chromosome number often result in human disorders with developmental limitations, including Trisomy 21 (Down syndrome) and XO (Turner syndrome).]</th>
<th>p.267-271</th>
</tr>
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<tr>
<th>13.4 Human Genetics and Genetic Counseling</th>
<th>3.A.3 The chromosomal basis of inheritance provides an understanding of the pattern of passage (transmission) of genes from parent to offspring. [3.A.3.c Certain human genetic disorders can be attributed to the inheritance of single gene traits or specific chromosomal changes, such as nondisjunction.] [3.A.3.d Many ethical, social and medical issues surround human genetic disorders.]</th>
<th>p.271-274</th>
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<tr>
<td>3.A.3 The following are illustrative examples of 3.A.3.d:</td>
<td>- Prenatal genetic counseling, p.274</td>
<td>- Prenatal genetic counseling, p.274</td>
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<tr>
<td>2.E.1</td>
<td>Timing and coordination of specific events are necessary for the normal development of an organism, and these events are regulated by a variety of mechanisms. [2.E.1.b.4 Genetic mutations can result in abnormal development.]</td>
<td></td>
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<tr>
<td>3.C.1</td>
<td>Changes in genotype can result in changes in phenotype. [3.C.1.a Alterations in a DNA sequence can lead to changes in the type or amount of the protein produced and the consequent phenotype.]</td>
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<tr>
<td>13.5</td>
<td>Non-Mendelian Patterns of Inheritance</td>
<td></td>
</tr>
<tr>
<td>3.A.4</td>
<td>The inheritance pattern of many traits cannot be explained by simple Mendelian genetics. [3.A.4.c Some traits result from nonnuclear inheritance.]</td>
<td></td>
</tr>
<tr>
<td>p.275-276</td>
<td>The following is an illustrative example of both 2.E.1.b.4 and 3.C.1.a: - Molecular basis of achondroplasia, p.273</td>
<td></td>
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<th>DNA Structure, Replication, and Organization</th>
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<tr>
<td>14.0</td>
<td>Why It Matters</td>
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<tr>
<td>p.281-282</td>
<td>(Discovery of &quot;nuclein&quot; in 1868)</td>
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<tr>
<td>14.1 Establishing DNA as the Hereditary Molecule</td>
<td>3.A.1 DNA, and in some cases RNA, is the primary source of heritable information. [3.A.1.a.1 Genetic information is stored in and passed to subsequent generations through DNA molecules and, in some cases, RNA molecules.] [3.A.1.a.4 The proof that DNA is the carrier of genetic information involved a number of important historical experiments. These include: (i) Contributions of Watson, Crick, Wilkins, and Franklin on the structure of DNA, (ii) Avery-MacLeod-McCarty experiments, (iii) Hershey-Chase experiment.]</td>
</tr>
<tr>
<td>14.2 DNA Structure</td>
<td>3.A.1 DNA, and in some cases RNA, is the primary source of heritable information. [3.A.1.a.4 The proof that DNA is the carrier of genetic information involved a number of important historical experiments. These include: (i) Contributions of Watson, Crick, Wilkins, and Franklin on the structure of DNA, (ii) Avery-MacLeod-McCarty experiments, (iii) Hershey-Chase experiment.] [3.A.1.b DNA and RNA molecules have structural similarities and differences that define function.]</td>
</tr>
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### 14.3 DNA Replication

| 3.A.1 DNA, and in some cases RNA, is the primary source of heritable information. [3.A.1.a.5 DNA replication ensure continuity of hereditary information.] | p.287-294 | Though not required, the Experimental Research box on p.289 describes the classic Meselson-Stahl experiment demonstrating that DNA replication is semiconservative (aligns with LO 3.2 and 3.3). | p.296 (Telomerase and the end replication problem) |

#### 3.A.3 The chromosomal basis of inheritance provides an understanding of the pattern of passage (transmission) of genes from parent to offspring. [3.A.3.c Certain human genetic disorders can be attributed to the inheritance of single gene traits or specific chromosomal changes, such as nondisjunction.] |

The following is an illustrative example of 3.A.3.c: - Fragile X syndrome, p.295 |

### 14.4 Mechanisms That Correct Replication Errors

<p>| 1.A.1 Natural selection is a major mechanism of evolution. [1.A.1.c Genetic variation and mutation play roles in natural selection.] | p.298 |  |  |</p>
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<tr>
<td>3.C.1</td>
<td>Changes in genotype can result in changes in phenotype. [3.C.1.b Errors in DNA replication or DNA repair mechanisms, and external factors, including radiation and reactive chemicals, can cause random changes, e.g., mutations in the DNA.]</td>
</tr>
</tbody>
</table>
| 3.D.1   | Cell communication processes share common features that reflect a shared evolutionary history. [3.D.1.d In multicellular organisms, signal transduction pathways coordinate the activities within individual cells that support the function of the organism as a whole.]
| 3.A.1   | DNA, and in some cases RNA, is the primary source of heritable information. [3.A.1.a.2 Noneukaryotic organisms have circular chromosomes, while eukaryotic organisms have multiple linear chromosomes, although in biology there are exceptions to this rule.] [3.A.1.a.3 Prokaryotes, viruses and eukaryotes can contain plasmids, which are small extra-chromosomal, double-stranded circular DNA molecules.] |

**Chapter 15. From DNA to Protein**
<table>
<thead>
<tr>
<th>15.0 Why It Matters</th>
<th>3.A.1 DNA, and in some cases RNA, is the primary source of heritable information. [3.A.1.f Genetic engineering techniques can manipulate the heritable information of DNA and, in special cases, RNA.]</th>
<th>The following is an illustrative example of 3.A.1.f: - Producing recombinant mussel protein for use as glue, p.305</th>
</tr>
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<tbody>
<tr>
<td>15.1 The Connection between DNA, RNA, and Protein</td>
<td>1.B.1 Organisms share many conserved core processes and features that evolved and are widely distributed among organisms today. [1.B.1.a.1 DNA and RNA are carriers of genetic information through transcription, translation and replication.] [1.B.1.a.2 Major features of the genetic code are shared by all modern living systems.]</td>
<td>p.308-309</td>
</tr>
<tr>
<td></td>
<td>3.A.1 DNA, and in some cases RNA, is the primary source of heritable information. [3.A.1.c Genetic information flows from a sequence of nucleotides in a gene to a sequence of amino acids in a protein.]</td>
<td>p.306-310</td>
</tr>
<tr>
<td></td>
<td>15.2 Transcription: DNA-Directed RNA Synthesis</td>
<td>3.A.1 DNA, and in some cases RNA, is the primary source of heritable information. [3.A.1.c.1 The enzyme RNA polymerase reads the DNA molecule in the 3' to 5' direction and synthesizes complementary mRNA molecules that determine the order of amino acids in the polypeptide.]</td>
</tr>
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### 15.3 Production of mRNAs in Eukaryotes

**3.A.1** DNA, and in some cases RNA, is the primary source of heritable information. [3.A.1.c.2 In eukaryotic cells the mRNA transcript undergoes a series of enzyme-regulated modifications.]

The following are illustrative examples of 3.A.1.c.2:
- Addition of a poly-A tail, p.313
- Addition of a 5' GTP cap, p.313
- Excision of introns, p.313-315

**4.C.1** Variation in molecular units provides cells with a wider range of functions. [4.C.1.a Variations within molecular classes provide cells and organisms with a wider range of functions.]

The following is an illustrative example of 4.C.1.a:
- Alternative splice variants of tropomyosin, p.314-315

### 15.4 Translation: mRNA-Directed Polypeptide Synthesis

**3.A.1** DNA, and in some cases RNA, is the primary source of heritable information. [3.A.1.c.4 In prokaryotic organisms, transcription is coupled to translation of the message. Translation involves energy and many steps, including initiation, elongation, and termination.]

The following is a table with additional information on protein synthesis and chaperones:
- p.315-322
- p.322-323 (Chaperones)
- p.323-325 (Protein sorting)
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<tr>
<th>15.5 Genetic Changes That Affect Protein Structure and Function</th>
<th>3.C.2: Biological systems have multiple processes that increase genetic variation. [3.C.2.b 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) and transposition (movement of DNA segments within and between DNA molecules) increase variation.]</th>
<th>p.324-327</th>
<th>p.327-329 (Retrotransposons in eukaryotes) X. Details and specifics about the various processes are beyond the scope of the course and the AP Exam.</th>
</tr>
</thead>
<tbody>
<tr>
<td>3.C.1 Changes in genotype can result in changes in phenotype. [3.C.1.a.1 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.]</td>
<td>The following is an illustrative example of 3.C.1.a.1: - Effect of a missense mutation on hemoglobin folding and sickle cell disease, p.326</td>
<td></td>
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**Chapter 16. Regulation of Gene Expression**

| 16.0 Why It Matters | 2.E.1 Timing and coordination of specific events are necessary for the normal development of an organism, and these events are regulated by a variety of mechanisms. [2.E.1.a Observable cell differentiation results from the expression of genes for tissue-specific proteins.] | p.333-334 |

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| 16.1 Regulation of Gene Expression in Prokaryotes | **3.B.1** Gene regulation results in differential gene expression, leading to cell specialization. [*3.B.1.a* Both DNA regulatory sequences, regulatory genes, and small regulatory RNAs are involved in gene expression.][3.B.1.b* Both positive and negative control mechanisms regulate gene expression in bacteria and viruses.][ ]

The following are illustrative examples of **3.B.1.a**:
- The *lac* operon in gene regulation, p.335-336
- The *trp* operon in gene regulation, p.336-338

| 2.C.1 Organisms use feedback mechanisms to maintain their internal environments and respond to external environmental changes. [*2.C.1.a* Negative feedback mechanisms maintain dynamic homeostasis for a particular condition (variable) by regulating physiological processes, returning the changing condition back to its target set point.] |

The following are illustrative examples of **2.C.1.a**:
- Effect of adding lactose to a Lac + bacterial culture, p.335-336

| 4.C.2 Environmental factors influence the expression of the genotype in an organism. [*4.C.2.a* Environmental factors influence many traits both directly and indirectly.] |

The following is an illustrative example of **4.C.2.a**:
- Effect of adding lactose to a Lac + bacterial culture, p.335-336

| 3.B.2 A variety of intercellular and intracellular signal transmissions mediate gene expression. [*3.B.2.a* Signal transmission within and between cells mediates gene expression.] |

The following is an illustrative example of **3.B.2.a**:
- Levels of cAMP regulate metabolic gene expression in bacteria, p.336
### 16.2 Regulation of Transcription in Eukaryotes

| **3.B.1** | Gene regulation results in differential gene expression, leading to cell specialization. [3.B.1.c In eukaryotes, gene expression is complex and control involves regulatory genes, regulatory elements and transcription factors that act in concert.] | p.339-345 | p.344 (DNA methylation and imprinting) |

### 16.3 Posttranscriptional, Translational, and Posttranslational Regulation

| **2.E.1** | Timing and coordination of specific events are necessary for the normal development of an organism, and these events are regulated by a variety of mechanisms. [2.E.1.b.6 Genetic regulation by microRNAs plays an important role in the development of organisms and the control of cellular functions.] | p.346-347 | p.345-346 (mRNA processing and stability) p.348 (Translational and posttranslational regulation) |

| **3.A.1** | DNA, and in some cases RNA, is the primary source of heritable information. [3.A.1.b.4.iv The role of RNAi includes regulation of gene expression at the level of mRNA transcription.] | p.346-348 | |

### 16.4 Genetic and Molecular Regulation of Development

<p>| <strong>2.E.1</strong> | Timing and coordination of specific events are necessary for the normal development of an organism, and these events are regulated by a variety of mechanisms. | p.348-354 | |</p>
<table>
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<tr>
<th>16.5 The Genetics of Cancer</th>
<th>3.B.2 A variety of intercellular and intracellular signal transmissions mediate gene expression. [3.B.2.b Signal transmission within and between cells mediates cell function.]</th>
<th>The following is an illustrative example of 3.B.2.b: - Changes in p53 activity can result in cancer, p.356</th>
</tr>
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<tbody>
<tr>
<td>Chapter 17. Bacterial and Viral Genetics</td>
<td>3.A.2 In eukaryotes, heritable information is passed to the next generation via processes that include the cell cycle and mitosis or meiosis plus fertilization. [3.A.2.a.2 The cell cycle is directed by internal controls or checkpoints. Internal and external signals provide stop-and-go signs at the checkpoints.]</td>
<td>The following is an illustrative example of 3.B.1.a.2: - Cancer results from disruptions in cell cycle control, p.355-356</td>
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</tbody>
</table>
### 17.0 Why It Matters

### 17.1 Gene Transfer and Genetic Recombination in Bacteria

<table>
<thead>
<tr>
<th>3.C.2</th>
<th>Biological systems have multiple processes that increase genetic variation. [3.C.2.b 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) and transposition (movement of DNA segments within and between DNA molecules) increase variation.]</th>
</tr>
</thead>
<tbody>
<tr>
<td>p.363-365, 367-370</td>
<td>p.365-367 (Detailed mechanism of bacterial conjugation) X. Details and specifics about prokaryotic horizontal gene transfer mechanisms are beyond the scope of the course and the AP Exam.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>3.A.1</th>
<th>DNA, and in some cases RNA, is the primary source of heritable information. [3.A.1.a.3 Prokaryotes, viruses, and eukaryotes can contain plasmids, which are small extrachromosomal, double-stranded circular DNA molecules.]</th>
</tr>
</thead>
<tbody>
<tr>
<td>p.365</td>
<td>Not required, the Molecular Revolution box on p.377 describes the actual experiment that confirmed the existence of a RNA-dependent DNA polymerase.</td>
</tr>
</tbody>
</table>

### 17.2 Viruses and Viral Genetics

<table>
<thead>
<tr>
<th>3.A.3</th>
<th>Viral replication results in genetic variation, and viral infection can introduce genetic variation into the hosts.</th>
</tr>
</thead>
<tbody>
<tr>
<td>p.370-379</td>
<td>p.371 (Viral structural forms)</td>
</tr>
</tbody>
</table>

### 17.3 Viroids and Prions, Infectious Agents Lacking Protein Coats

Chapter 18. DNA Technologies and Genomics

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<table>
<thead>
<tr>
<th>18.0 Why It Matters</th>
<th>18.1 DNA Cloning</th>
<th>18.2 Application of DNA Technologies</th>
</tr>
</thead>
</table>
| 3.A.1 DNA, and in some cases RNA, is the primary source of heritable information. [3.A.1.e Genetic engineering techniques can manipulate the heritable information of DNA and, in special cases, RNA.] | p.384-389 | The following are illustrative examples of 3.A.1.e:  
- Cloning a gene of interest, p.384-385  
- Electrophoresis, p.389, 391  
- Polymerase chain reaction (PCR), p.389-390  

Note that LO 3.5 requires students to justify the claim that humans can manipulate heritable information by identifying at least two commonly used technologies.  

The following are illustrative examples for 3.A.1.f:  
- Bacterial recombinant proteins used in pharmaceuticals, p.395  
- Transgenic animals, p.396-397  
- Human gene therapy, p.397-398  
- Recombinant proteins produced in domestic animals, p.398  
- Cloned animals, p.398-399  
- Transgenic plants (and genetically modified foods), p.398, 400-402  

The following provide illustrative examples for 3.A.1.f:  
- Restriction enzyme analysis of DNA, p.392  
- Microsatellite analysis of DNA by PCR and Southern blot analysis, p.392-394 |
| 18.3 Genome Analysis | 3.A.3 The chromosomal basis of inheritance provides an understanding of the pattern of passage (transmission) of genes from parent to offspring. [3.A.3.d Many ethical, social and medical issues surround human genetic disorders.] | The following is an illustrative example of 3.A.3.d:
- Human gene therapy, p.397-398 |  |

| 3.B.2 A variety of intercellular and intracellular signal transmissions mediate gene expression. [3.B.2.a Signal transmission within and between cells mediates gene expression.] | The following is an illustrative example of 3.B.2.a:
- Using DNA microarrays to measure differential gene expression, p.407-409 |  | p.403, 405-406 (Genomics)
p.404 (Sanger method of DNA sequencing)
p.407 (RNAi and genetic knockouts)
p.407-408 (DNA microarrays)
p.409 (Comparative genomics)
p.410 (Proteomics) |
### Chapter 19. Development of Evolutionary Thought

#### 19.0 Why It Matters

- Biological evolution is supported by scientific evidence from many disciplines, including mathematics. [1.A.4.b.3 Biochemical and genetic similarities, in particular DNA nucleotide and protein sequences, provide evidence for evolution and ancestry.]

#### 19.1 Recognition of Evolutionary Change

- Biological evolution is supported by scientific evidence from many disciplines, including mathematics. [1.A.4.a Scientific evidence of biological evolution uses information from geographical, geological, physical, chemical and mathematical applications.] [1.A.4.b Molecular, morphological and genetic information of existing and extinct organisms add to our understanding of evolution.]

**p.407**

**p.414-417**

**p.414 (Pre-Darwinian thinking)**

**p.414-415 (Darwin, Wallace, and publication priority)**
<table>
<thead>
<tr>
<th>19.2 Darwin's Journeys</th>
<th>1.A.1 Natural selection is a major mechanism of evolution. [1.A.1.a 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.] [1.A.1.b Evolutionary fitness is measured by reproductive success.] [1.A.1.e 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.]</th>
<th>p.419-422</th>
<th>p.417-419 (Voyage of the HMS Beagle)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1.A.2 Natural selection acts on phenotypic variations in populations. [1.A.2.a Environments change and act as selective mechanism on populations.] [1.A.2.b Phenotypic variations are not directed by the environment but occur through random changes in the DNA and through new gene combinations.] [1.A.2.c Some phenotypic variations significantly increase or decrease fitness of the organism and the population.] [1.A.2.d Humans impact variation in other species.]</td>
<td>p.419-422</td>
<td></td>
</tr>
<tr>
<td>19.3 Evolutionary Biology since Darwin</td>
<td>1.A.2 Natural selection acts on phenotypic variations in populations. [1.A.2.c Some phenotypic variations significantly increase or decrease fitness of the organism and the population.]</td>
<td>The following is an illustrative example of 1.A.2.c: - DDT resistance in insects, p.424</td>
<td></td>
</tr>
<tr>
<td>p.422-428</td>
<td>Though not required, the Molecular Revolution box on p.427 describes the use of molecular data to estimate the closest extant relative of the woolly mammoth (aligns with LO 1.10 and 1.12).</td>
<td></td>
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</tr>
<tr>
<td>1.A.4 Biological evolution is supported by scientific evidence from many disciplines, including mathematics. [1.A.4.b Molecular, morphological, and genetic information of existing and extinct organisms add to our understanding of evolution.]</td>
<td>p.422-428</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1.C.3 Populations of organisms continue to evolve. [1.C.3.b Scientific evidence supports the idea that evolution continues to occur.]</td>
<td>p.422-428</td>
<td></td>
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</tr>
</tbody>
</table>

### Chapter 20. Microevolution: Genetic Changes within Populations

#### 20.0 Why It Matters

| 1.A.2 Natural selection acts on phenotypic variations in populations. [1.A.2.c Some phenotypic variations significantly increase or decrease fitness of the organism and the population.] | The following is an illustrative example of 1.A.2.c: - Penicillin resistance in *Staphylococcus* bacteria, p.431-432 |
| 20.1 Variation in Natural Populations | 1.A.2 Natural selection acts on phenotypic variations in populations. [1.A.2.b Phenotypic variations are not directed by the environment but occur through random changes in the DNA and through new gene combinations.] [1.A.2.d Humans impact variation in other species.] | p.432-435 | The following is an illustrative example of 1.A.2.d:  
- Artificial selection of activity level in lab mice, p.434 |

| 4.C.2 Environmental factors influence the expression of the genotype in an organism. [4.C.2.a Environmental factors influence many traits both directly and indirectly.] | | | The following is an illustrative example of 4.C.2.a:  
- Effect of soil acidity on flower color of Hydrangea, p.433 |

| 20.2 Population Genetics | 1.A.1 Natural selection is a major mechanism of evolution. [1.A.1.g 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.] [1.A.1.h Mathematical approaches are used to calculate changes in allele frequency, providing evidence for the occurrence of evolution in a population.] | | The following are illustrative examples of 1.A.1.h:  
- Application of the Hardy-Weinberg equilibrium equation, p.438-439  
- Graphical analysis of allele frequencies in a population, p.434 |
<table>
<thead>
<tr>
<th>Cell</th>
<th>Text</th>
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</thead>
<tbody>
<tr>
<td>4.C.3</td>
<td>The level of variation in a population affects population dynamics. [4.C.3.c Allelic variation within a population can be modeled by the Hardy-Weinberg equation(s).] [4.C.3.d Mathematical approaches are used to calculate changes in allele frequency, providing evidence for the occurrence of evolution in a population.]</td>
</tr>
<tr>
<td>20.3</td>
<td>The Agents of Microevolution</td>
</tr>
<tr>
<td>1.A.1</td>
<td>Natural selection is a major mechanism of evolution. [1.A.1.c Genetic variation and mutation play roles in natural selection. A diverse gene pool is important for the survival of a species in a changing environment.] [1.A.1.d Environments can be more or less stable or fluctuating, and this affects evolutionary rate and direction; different genetic variations can be selected in each generation.] [1.A.1.f In addition to natural selection, chance and random events can influence the evolutionary process, especially for small populations.]</td>
</tr>
<tr>
<td>1.A.3</td>
<td>Evolutionary change is also driven by random processes.</td>
</tr>
<tr>
<td>p.436-448</td>
<td></td>
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<tr>
<td>p.439-440</td>
<td></td>
</tr>
<tr>
<td>1.A.4</td>
<td>Biological evolution is supported by scientific evidence from many disciplines, including mathematics. [1.A.4.b Molecular, morphological, and genetic information of existing and extinct organisms add to our understanding of evolution.]</td>
</tr>
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</tbody>
</table>
| 1.A.4.b | The following are illustrative examples of 1.A.4.b:  
- Genetic analysis of humpback whale population after bottleneck, p.441  
- Evidence of stabilizing selection in human population, p.443  
- Cause of stabilizing selection in gallmaking flies, p.443-444 |
| 4.C.3 | The level of variation in a population affects population dynamics. [4.C.3.a Population ability to respond to changes in the environment is affected by genetic diversity. Species and populations with little genetic diversity are at risk for extinction.] [4.C.3.b Genetic diversity allows individuals in a population to respond differently to the same changes in environmental conditions.] |
| 4.C.3.a | p.436-448 |

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<table>
<thead>
<tr>
<th>3.C.1</th>
<th>Changes in genotype can result in changes in phenotype. [3.C.1.d Changes in genotype may affect phenotypes that are subject to natural selection. Genetic changes that enhance survival and reproduction can be selected by environmental conditions.] [3.C.1.b.1 Whether or not a mutation is detrimental, beneficial or neutral depends on the environmental context. Mutations are the primary source of genetic variation.]</th>
<th>p.437, 440-444</th>
</tr>
</thead>
<tbody>
<tr>
<td>4.C.4</td>
<td>The diversity of species within an ecosystem may influence the stability of the ecosystem. [4.C.4.a Natural and artificial ecosystems with fewer component parts and with little diversity among the parts are often less resilient to changes in the environment.]</td>
<td>p.440</td>
</tr>
</tbody>
</table>
1.C.3 Populations of organisms continue to evolve. [1.C.3.b Scientific evidence supports the idea that evolution continues to occur.]

- Evidence of stabilizing selection in human population, p.443
- Cause of stabilizing selection in gallmaking flies, p.443-444
- Evidence of sexual selection in long-tailed widowbirds, p.445
- Observed directional phenotypic change in a population (Grant's observations of Darwin's finches in the Galapagos), p.453

20.4 Maintaining Genetic and Phenotypic Variation

1.A.2 Natural selection acts on phenotypic variations in populations. [1.A.2.a Environments change and act as selective mechanism on populations. [Some phenotypic variations significantly increase or decrease fitness of the organism and the population.]

- Stripping patterns of European garden snails in different habitats, p.448

4.C.1 Variation in molecular units provides cells with a wider range of functions. [4.C.1.b.1 A heterozygote may be a more advantageous genotype than a homozygote under particular conditions, since with two different alleles, the organism has two forms of proteins that may provide functional resilience in response to environmental stresses.]
<p>| 20.5 Adaptation and Evolutionary Constraints | Natural selection acts on phenotypic variations in populations. [1.A.2.b Phenotypic variations are not directed by the environment but occur through random changes in the DNA and through new gene combinations.] | p.450 | p.449 (A cautionary note on interpreting results) |
| Chapter 21. Speciation | p.454-455 (Species as a fundamental unit) | | |
| 21.0 Why It Matters | | | |
| 21.1 What Is a Species? | p.455-456* (Species concepts) | p.456-457 (Ring species) | p.457 (Clinal variation) |</p>
<table>
<thead>
<tr>
<th>21.2 Maintaining Reproductive Isolation</th>
<th>1.C.2 Speciation may occur when two populations become reproductively isolated from each other. [1.C.2.a Speciation results in diversity of life forms. Species can be physically separated by a geographic barrier such as an ocean or a mountain range, or various pre-and post-zygotic mechanisms can maintain reproductive isolation and prevent gene flow.]</th>
<th>p.457-459</th>
</tr>
</thead>
</table>
| 21.3 The Geography of Speciation | 1.C.2 Speciation may occur when two populations become reproductively isolated from each other. [1.C.2.a Speciation results in diversity of life forms. Species can be physically separated by a geographic barrier such as an ocean or a mountain range, or various pre-and post-zygotic mechanisms can maintain reproductive isolation and prevent gene flow.] | p.460-464 | Though not required, the Basic Research box on p.462 describes evidence of adaptive radiation among fruit fly species in the Hawaiian islands (aligns with LO 1.23 and 1.24).

Also not required, the Observational Research box on p.464 describes evidence of reproductive isolation among parapatric populations of bent grass (aligns with LO 1.22 and 1.23). |
### 21.4 Genetic Mechanisms of Speciation

1. **C.2** Speciation may occur when two populations become reproductively isolated from each other. [1.C.2.b New species arise from reproductive isolation over time, which can involve scales of hundreds of thousands or even millions of years, or speciation can occur rapidly through mechanisms such as polyploidy in plants.]

Though not required, the Molecular Revolution box on p.466 describes genetic analysis of closely related Mimulus species, identifying key flurally expressed genes responsible for their reproductive isolation (aligns with LO 1.20).

Also not required, the Observational Research box on p.469 describes evidence of chromosomal inversion, breakage, and translocation among the primate lineage (aligns with LO 1.20).

3. **C.1** Changes in genotype can result in changes in phenotype. [3.C.1.c.1 Changes in chromosome number often result in new phenotypes, including sterility caused by triploidy and increased vigor of other polyploids.]

### Chapter 22. Paleobiology and Macroevolution

22. **0 Why It Matters**

- p.473-474
  - (Key dinosaur fossil discoveries)
### 22.1 The Fossil Record

1. **A.4 Biological evolution is supported by scientific evidence from many disciplines, including mathematics.**
   - Fossils can be dated by a variety of methods that provide evidence for evolution. These include the age of the rocks where a fossil is found, the rate of decay of isotopes including carbon-14, the relationships within phylogenetic trees, and the mathematical calculations that take into account information from chemical properties and/or geographical data.

### 22.2 Earth History

4. **B.4 Distribution of local and global ecosystems changes over time.**
   - Geological and meteorological events impact ecosystem distribution.

### 22.3 Historical Biogeography and Convergent Biotas

1. **A.4 Biological evolution is supported by scientific evidence from many disciplines, including mathematics.**
   - Scientific evidence of biological evolution uses information from geographical, geological, physical, chemical and mathematical applications.
   - Morphological homologies represent features shared by common ancestry.
<table>
<thead>
<tr>
<th>22.4 The History of Biodiversity</th>
<th>1.C.1 Speciation and extinction have occurred throughout the Earth’s history. [1.C.1.a Speciation rates can vary, especially when adaptive radiation occurs when new habitats become available.] [1.C.1.b Species extinction rates are rapid at times of ecological stress.]</th>
<th>p.485-488</th>
<th>X. The names and dates of these five major extinctions are beyond the scope of this course and the AP Exam.</th>
</tr>
</thead>
<tbody>
<tr>
<td>22.5 Interpreting Evolutionary Lineages</td>
<td>1.C.1 Speciation and extinction have occurred throughout the Earth’s history. [1.C.1.a Speciation rates can vary, especially when adaptive radiation occurs when new habitats become available.] [1.C.1.b Species extinction rates are rapid at times of ecological stress.]</td>
<td>p.489-492</td>
<td>Though not required, the Observational Research boxes on p.490 and 491 describe fossil evidence in favor of gradualism and the punctuated equilibrium hypothesis, respectively (aligns with LO 1.20).</td>
</tr>
<tr>
<td>22.6 The Evolution of Morphological Novelties</td>
<td>2.E.1 Timing and coordination of specific events are necessary for the normal development of an organism, and these events are regulated by a variety of mechanisms. [2.E.1.b.1 Homeotic genes are involved in developmental patterns and sequences.] [2.E.1.b.4 Genetic mutations can result in abnormal development.]</td>
<td>p.495</td>
<td>The following are illustrative examples of 2.E.1.b.4: - Pax-6 in eye development, p.495 - Pitx1 in stickleback fish, p.497-498</td>
</tr>
<tr>
<td>Chapter 23. Systematics and Phylogenetics: Revealing the Tree of Life</td>
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<tr>
<td>23.0 Why It Matters</td>
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<tr>
<td>23.1 Nomenclature and Classification</td>
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<tr>
<td>23.2 Phylogenetic Trees</td>
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### 1.A.4 Biological evolution is supported by scientific evidence from many disciplines, including mathematics. [1.A.4.b.3 Biochemical and genetic similarities, in particular DNA nucleotide and protein sequences, provide evidence for evolution and ancestry.]

The following is an illustrative example of 1.A.4.b.3:
- Master toolkit genes in vertebrates, p.494

### Chapter 23. Systematics and Phylogenetics: Revealing the Tree of Life

<table>
<thead>
<tr>
<th>23.0 Why It Matters</th>
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<td>23.1 Nomenclature and Classification</td>
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<td>23.2 Phylogenetic Trees</td>
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| 1.B.2 Phylogenetic trees and cladograms are graphical representations (models) of evolutionary history that can be tested. [1.B.2.b Phylogenetic trees and cladograms illustrate speciation that has occurred, in that relatedness of any two groups on the tree is shown by how recently two groups had a common ancestor.] |

| p.503-506 |

### Chapter 23. Systematics and Phylogenetics: Revealing the Tree of Life

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<tr>
<td>23.2 Phylogenetic Trees</td>
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</table>

| p.501-502 (Differences in mosquito species as malarial hosts) |

| p.502-503* (Linnaeus and binomial nomenclature) |

### 1.B.2 Phylogenetic trees and cladograms are graphical representations (models) of evolutionary history that can be tested. [1.B.2.b Phylogenetic trees and cladograms illustrate speciation that has occurred, in that relatedness of any two groups on the tree is shown by how recently two groups had a common ancestor.]

| p.503-506 |

### Chapter 23. Systematics and Phylogenetics: Revealing the Tree of Life

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| p.501-502 (Differences in mosquito species as malarial hosts) |

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### 1.B.2 Phylogenetic trees and cladograms are graphical representations (models) of evolutionary history that can be tested. [1.B.2.b Phylogenetic trees and cladograms illustrate speciation that has occurred, in that relatedness of any two groups on the tree is shown by how recently two groups had a common ancestor.]

| p.503-506 |

### Chapter 23. Systematics and Phylogenetics: Revealing the Tree of Life

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</tbody>
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| p.501-502 (Differences in mosquito species as malarial hosts) |

| p.502-503* (Linnaeus and binomial nomenclature) |

### 1.B.2 Phylogenetic trees and cladograms are graphical representations (models) of evolutionary history that can be tested. [1.B.2.b Phylogenetic trees and cladograms illustrate speciation that has occurred, in that relatedness of any two groups on the tree is shown by how recently two groups had a common ancestor.]

| p.503-506 |
| Section | 1.A.4 Biological evolution is supported by scientific evidence from many disciplines, including mathematics. [1.A.4.b.4 Mathematical models and simulations can be used to illustrate and support evolutionary concepts.] | The following is an illustrative example of 1.A.4.b.4:
- Analysis of phylogenetic trees, p.504-506 |
<table>
<thead>
<tr>
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<th></th>
<th></th>
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</thead>
<tbody>
<tr>
<td>23.3 Sources of Data for Phylogenetic Analyses</td>
<td>1.A.4 Biological evolution is supported by scientific evidence from many disciplines, including mathematics. [1.A.4.b Molecular, morphological and genetic information of existing and extinct organisms add to our understanding of evolution.]</td>
<td>p.507-510</td>
</tr>
<tr>
<td>23.4 Traditional Classification and Paraphyletic Groups</td>
<td></td>
<td>p.510-511 (Comparison of traditional systematics and cladistics)</td>
</tr>
</tbody>
</table>
| 23.5 The Cladistic Revolution | 1.B.2 Phylogenetic trees and cladograms are graphical representations (models) of evolutionary history that can be tested. | The following are illustrative examples of 1.B.2.a:
- Number of legs on insects, p.513
- Defining characters of vertebrate clades (used to construct a cladogram), p.514-515
- Defining characters of vascular plant clades, p.516 |
<table>
<thead>
<tr>
<th>Section</th>
<th>Subsection</th>
<th>Text</th>
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</tr>
</thead>
<tbody>
<tr>
<td>23.6 Phylogenetic Trees as Research Tools</td>
<td>1.B.2</td>
<td>Phylogenetic trees and cladograms are graphical representations (models) of evolutionary history that can be tested.</td>
<td>p.517</td>
</tr>
<tr>
<td>23.7 Molecular Phylogenetic Analyses</td>
<td>1.B.1</td>
<td>Organisms share many conserved core processes and features that evolved and are widely distributed among organisms today.</td>
<td>p.520-521</td>
</tr>
<tr>
<td>2.B.3</td>
<td>Eukaryotic cells maintain internal membranes that partition the cell into specialized regions.</td>
<td>p.520-521</td>
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</table>

Chapter 24. The Origin of Life

24.0 Why It Matters

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1. There are several hypotheses about the natural origin of life on Earth, each with supporting scientific evidence. [1.D.1.a.1 Primitive Earth provided inorganic precursors from which organic molecules could have been synthesized due to the presence of available free energy and the absence of a significant quantity of oxygen.]

2. Scientific evidence from many different disciplines supports models of the origin of life. [1.D.2.a.2 Chemical experiments have shown that it is possible to form complex organic molecules from inorganic molecules in the absence of life.]
### 24.2 The Origin of Cells

1. D. 1 There are several hypotheses about the natural origin of life on Earth, each with supporting scientific evidence. [1.D.1.a.2 In turn, these molecules served as monomers or building blocks for the formation of more complex molecules, including amino acids and nucleotides.] [1.D.1.a.3 The joining of these monomers produced polymers with the ability to replicate, store and transfer information.] [1.D.1.a.4 These complex reaction sets could have occurred in solution (organic soup model) or as reactions on solid reactive surfaces.] [1.D.1.a.5 The RNA World hypothesis proposes that RNA could have been the earliest genetic material.]

p.529-532

Though not required, the Molecular Revolution box on p.84 of Chapter 4 describes how science practices were applied in the discovery of ribozymes in support of the RNA World hypothesis (aligns with LO 1.28 and 1.30).

### 24.3 The Origins of Eukaryotic Cells

1. B. 1 Organisms share many conserved core processes and features that evolved and are widely distributed among organisms today. [1.B.1.b Structural evidence supports the relatedness of all eukaryotes.]

p.533-535
<table>
<thead>
<tr>
<th>2.A.2</th>
<th>Organisms capture and store free energy for use in biological processes. [2.A.2.e Photosynthesis first evolved in prokaryotic organisms; scientific evidence supports that prokaryotic (bacterial) photosynthesis was responsible for the production of an oxygenated atmosphere; prokaryotic photosynthetic pathways were the foundation of eukaryotic photosynthesis.]</th>
<th>p.533-535</th>
</tr>
</thead>
</table>

### Chapter 25. Prokaryotes: Bacteria and Archaea

#### 25.0 Why It Matters

(Wide prokaryotic diversity)

#### 25.1 Prokaryotic Structure and Function

| 2.B.3 | Eukaryotic cells maintain internal membranes that partition the cell into specialized regions. [2.B.3.c Archaea and Bacteria generally lack internal membranes and organelles and have a cell wall.] | p.541 |

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<table>
<thead>
<tr>
<th>3.A.1.a.2 Noneukaryotic organisms have circular chromosomes, while eukaryotic organisms have multiple linear chromosomes, although in biology there are exceptions to this rule. [3.A.1.a.3 Prokaryotes, viruses and eukaryotes can contain plasmids, which are small extrachromosomal, double-stranded circular DNA molecules.]</th>
<th>p.541-542</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.B.1 Cell membranes are selectively permeable due to their structure. [2.B.1.c.2 Cell walls provide a structural boundary, as well as a permeability barrier for some substances to the internal environments.]</td>
<td>p.542-543</td>
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<tr>
<td>2.A.2 Organisms capture and store free energy for use in biological processes. [2.A.2.a Autotrophs capture free energy from physical sources in the environment.] [2.A.2.b Heterotrophs capture free energy present in carbon compounds produced by other organisms.]</td>
<td>p.544-545</td>
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<tr>
<td>2.A.3 Organisms must exchange matter with the environment to grow, reproduce and maintain organization. [2.A.3.a.2 Nitrogen moves from the environment to organisms where it is used in building proteins and nucleic acids.]</td>
<td>p.545-546</td>
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<tr>
<td>3.C.2 Biological systems have multiple processes that increase genetic variation. [3.C.2.b 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) and transposition (movement of DNA segments within and between DNA molecules) increase variation.]</td>
<td>p.546</td>
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| 2.D.3 Biological systems are affected by disruptions to their dynamic homeostasis [2.D.3.a Disruptions at the molecular and cellular levels affect the health of the organism.] | The following is an illustrative example of 2.D.3.a:
- Dehydration and toxic substances, p.546 |
| 2.D.1 All biological systems from cells and organisms to populations, communities and ecosystems are affected by complex biotic and abiotic interactions involving exchange of matter and free energy. [2.D.1.a Cell activities are affected by interactions with biotic and abiotic factors.] | The following is an illustrative example of 2.D.1.a:
- Biofilms, p.546-547 |
### 25.2 The Domain Bacteria

#### 1.A.4 Biological evolution is supported by scientific evidence from many disciplines, including mathematics. [1.A.4.b.4 Mathematical models and simulations can be used to illustrate and support evolutionary concepts.]

The following is an illustrative example of 1.A.4.b.4:
- Construction of phylogenetic trees based on sequence data, p.547-548

#### 3.C.1 Changes in genotype can result in changes in phenotype. [3.C.1.d Changes in genotype may affect phenotypes that are subject to natural selection. Genetic changes that enhance survival and reproduction can be selected by environmental conditions.]

The following is an illustrative example of 3.C.1.d:
- Antibiotic resistance mutations, p.552

#### 1.A.2 Natural selection acts on phenotypic variations in populations. [1.A.2.d Humans impact variation in other species.]

The following is an illustrative example of 1.A.2.d:
- Overuse of antibiotics, p.552

#### 1.C.3 Populations of organisms continue to evolve. [1.C.3.b Scientific evidence supports the idea that evolution continues to occur.]

The following is an illustrative example of 1.C.3.b:
- Chemical resistance (mutations for resistance to antibiotics occur in the absence of the chemicals), p.552

#### 2.E.3 Timing and coordination of behavior are regulated by various mechanisms and are important in natural selection. [2.E.3.b.4 Cooperative behavior within or between populations contributes to the survival of the populations.]

The following is an illustrative example of 2.E.3.b.4:
- Availability of resources leading to fruiting body formation in fungi and certain types of bacteria, p.548-549
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<th>2.E.1</th>
<th>Timing and coordination of specific events are necessary for the normal development of an organism, and these events are regulated by a variety of mechanisms. [2.E.1.c In fungi, protists and bacteria, internal and external signals regulate a variety of physiological responses that synchronize with environmental cycles and cues.]</th>
<th>The following is an illustrative example of 2.E.1.c: - Fruiting body formation in fungi, slime molds and certain types of bacteria, p.548-549</th>
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<td>Though not required, the Molecular Revolution boxes on p.94 of Chapter 5 and p.553 of this chapter describe how science practices were applied in the first comprehensive genetic analysis of Archaea (aligns with LO 1.11 and 1.19). p.552-555 (Survey of archaeal lineages)</td>
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<td>2.D.2</td>
<td>Homeostatic mechanisms reflect both common ancestry and divergence due to adaptation in different environments. [2.D.2.b Organisms have various mechanisms for obtaining nutrients and eliminating wastes.]</td>
<td>The following is an illustrative example of 2.D.2.b: - Food vacuoles in protists, p.562</td>
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<td>26.2 The Protist Groups</td>
<td>2.E.3</td>
<td>Timing and coordination of behavior are regulated by various mechanisms and are important in natural selection. [2.E.3.b.4 Cooperative behavior within or between populations contributes to the survival of the populations.]</td>
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<td>Timing and coordination of specific events are necessary for the normal development of an organism, and these events are regulated by a variety of mechanisms. [2.E.1.c In fungi, protists and bacteria, internal and external signals regulate a variety of physiological responses that synchronize with environmental cycles and cues.]</td>
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<td></td>
<td>2.C.2</td>
<td>Organisms respond to changes in their external environments. [2.C.2.a Organisms respond to changes in their environment through behavioral and physiological mechanisms.]</td>
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<td>3.D.1</td>
<td>Cell communication processes share common features that reflect a shared evolutionary history. Communication involves transduction of stimulatory or inhibitory signals from other cells, organisms or the environment.</td>
<td>The following is an illustrative example of 3.D.1.a: - Role of cAMP in fruiting body formation in slime molds, p.578</td>
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<td>2.A.1</td>
<td>All living systems require constant input of free energy. Reproduction and rearing of offspring require free energy beyond that used for maintenance and growth. Different organisms use various reproductive strategies in response to energy availability.</td>
<td>The following is an illustrative example of 2.A.1.d.2: - Life-history strategy of cellular slime molds, p.576-577</td>
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<td>1.B.1</td>
<td>Organisms share many conserved core processes and features that evolved and are widely distributed among organisms today. Structural evidence supports the relatedness of all eukaryotes.</td>
<td>The following is an illustrative example of 1.B.1.b: - Membrane-bound organelles (chloroplasts), p.579-580</td>
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Chapter 27. Plants

27.0 Why It Matters

p.585-586 (Origin of plants)
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<th>27.1 The Transition to Life on Land</th>
<th>2.A.1 All living systems require constant input of free energy. [2.A.1.d.2 Reproduction and rearing of offspring require free energy beyond that used for maintenance and growth. Different organisms use various reproductive strategies in response to energy availability.]</th>
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<td>4.A.6 Interactions among living systems and with their environment result in the movement of matter and energy. [4.A.6.g Many adaptations of organisms are related to obtaining and using energy and matter in a particular environment.]</td>
<td>The following is an illustrative example of 4.A.6.g: - Plant adaptations for living on land, p.586-589</td>
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<td>1.B.2 Phylogenetic trees and cladograms are graphical representations (models) of evolutionary history that can be tested. [1.B.2.a Phylogenetic trees and cladograms can represent traits that are either derived or lost due to evolution.]</td>
<td>The following is an illustrative example of 1.B.2.a: - Phylogenetic tree of major plant groups and their defining characters, p. 590-591</td>
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<td>2.E.3 Timing and coordination of behavior are regulated by various mechanisms and are important in natural selection. [2.E.3.b.4 Cooperative behavior within or between populations contributes to the survival of the populations.]</td>
<td>The following is an illustrative example of 2.E.3.b.4: - Coevolution of flowers and pollinators, p.611</td>
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<td>2.E.1 Many biological processes involved in growth, reproduction and dynamic homeostasis include temporal regulation and coordination. [2.E.1.a Observable cell differentiation results from the expression of genes for tissue-specific proteins.]</td>
<td>The following is an illustrative example of 2.E.1.a: - Role of transcription factor LEAFY in plant development, p.612</td>
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<td>4.C.1 Variation in molecular units provides cells with a wider range of functions. [4.C.1.b.2 Gene duplication creates a situation in which one copy of the gene maintains its original function, while the duplicate may evolve a new function.]</td>
<td>The following is an illustrative example of 4.C.1.b.2: - Duplication and subsequent specialization of phytochrome genes in angiosperms, p.608</td>
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### 28.1 General Characteristics of Fungi

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<th>2.D.2</th>
<th>Homeostatic mechanisms reflect both common ancestry and divergence due to adaptation in different environments. [2.D.2.b Organisms have various mechanisms for obtaining nutrients and eliminating wastes.]</th>
<th>The following is an illustrative example of 2.D.2.b: - Hyphae in fungi, p.618-620</th>
<th>p.618-622 (Defining traits of fungi)</th>
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<td>4.A.6</td>
<td>Interactions among living systems and with their environment result in the movement of matter and energy. [4.A.6.g Many adaptations of organisms are related to obtaining and using energy and matter in a particular environment.]</td>
<td>The following is an illustrative example of 4.A.6.g: - Adaptations for saprobes, p.619-620</td>
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<td>2.C.2</td>
<td>Organisms respond to changes in their external environments. [2.C.2.a Organisms respond to changes in their environment through behavioral and physiological mechanisms.]</td>
<td>The following is an illustrative example of 2.C.2.a: - Sexual reproduction in fungi, p.620-622</td>
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<td>2.A.1</td>
<td>All living systems require constant input of free energy. [2.A.1.d.2 Reproduction and rearing of offspring require free energy beyond that used for maintenance and growth. Different organisms use various reproductive strategies in response to energy availability.]</td>
<td>The following is an illustrative example of 2.A.1.d.2: - Life-history strategy of fungi, p.620-622</td>
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### 28.2 Major Groups of Fungi

| 4.C.2 | Environmental factors influence the expression of the genotype in an organism. [4.C.2.a Environmental factors influence many traits both directly and indirectly.] | The following is an illustrative example of 4.C.2.a:
- Presence of the opposite mating type on pheromone production in yeast and other fungi, p.625-626 | p.622-631 (Survey of major fungi groups) |
| 3.B.2 | A variety of intercellular and intracellular signal transmissions mediate gene expression. [3.B.2.a Signal transmission within and between cells mediates gene expression.] | The following is an illustrative example of 3.B.2.a:
- Mating pheromones in yeast trigger mating gene expression, p.625-626 | |
| 2.C.2 | Organisms respond to changes in their external environments. [2.C.2.a Organisms respond to changes in their environment through behavioral and physiological mechanisms.] | The following are illustrative examples of 2.C.2.a:
- Sexual reproduction in zygomycetes p.625-626
- Sexual reproduction in ascomycetes, p.628-629
- Sexual reproduction in basidiomycetes, p.630-631 | |

### 28.3 Fungal Associations

| 4.B.3 | Interactions between and within populations influence patterns of species distribution and abundance. [4.B.3.a.3 Many complex symbiotic relationships exist in an ecosystem, and feedback control systems play a role in the functioning of these ecosystems.] | The following are illustrative examples of 4.B.3.a.3:
- Lichen, p.632-633
- Mycorrhizae, p.633-635 | |
| 2.E.3 | Timing and coordination of behavior are regulated by various mechanisms and are important in natural selection. [2.E.3.b.4 Cooperative behavior within or between populations contributes to the survival of the populations.] | The following are illustrative examples of 2.E.3.b.4:
- Lichen, p.632-633
- Mycorrhizae, p.633-635 | X. Specific symbiotic interactions are beyond the scope of the course and the AP Exam. |
2.D.1 All biological systems from cells and organisms to populations, communities and ecosystems are affected by complex biotic and abiotic interactions involving exchange of matter and free energy. [2.D.1.b Organism activities are affected by interactions with biotic and abiotic factors.]

The following is an illustrative example of 2.D.1.b:
- Symbiosis (mutualism), p.632-635

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| 29.3 An Overview of Animal Phylogeny and Classification    | The following is an illustrative example of 1.B.2.a:
- Phylogenetic tree of major animal groups and their defining characters, p. 644-646 |
| 29.4 Animals without Tissues: Parazoa                      | p.646 (Overview of sponges) |

1.B.2 Phylogenetic trees and cladograms are graphical representations (models) of evolutionary history that can be tested. [1.B.2.a Phylogenetic trees and cladograms can represent traits that are either derived or lost due to evolution.]
| 29.5 Eumetazoans with Radial Symmetry | 2.D.2 Homeostatic mechanisms reflect both common ancestry and divergence due to adaptation in different environments. [2.D.2.b Organisms have various mechanisms for obtaining nutrients and eliminating wastes.] | The following are illustrative examples of 2.D.2.b: - Gastrovascular cavity of cnidarians, p.547-648 - Tentacles and cilia of comb jellies, p.651 | p.647-651 (Survey of Cnidaria and Ctenophora) |
| 4.B.3 Interactions between and within populations influence patterns of species distribution and abundance. [4.B.3.a.3 Many complex symbiotic relationships exist in an ecosystem, and feedback control systems play a role in the functioning of these ecosystems.] | The following is an illustrative example of 4.B.3.a.3: - Coral, p.649 | X. Specific symbiotic interactions are beyond the scope of the course and the AP Exam. |
| 29.6 Lophotrochozoan Protostomes | 2.D.2 Homeostatic mechanisms reflect both common ancestry and divergence due to adaptation in different environments. [2.D.2.b Organisms have various mechanisms for obtaining nutrients and eliminating wastes.] | The following are illustrative examples of 2.D.2.b: - Digestive system of flatworms, p.652-653 | p.651-661 (Survey of molluscs, annelids, flatworms, and rotifers) |
| 2.D.1 All biological systems from cells and organisms to populations, communities and ecosystems are affected by complex biotic and abiotic interactions involving exchange of matter and free energy. [2.D.1.b Organism activities are affected by interactions with biotic and abiotic factors.] | The following is an illustrative example of 2.D.1.b: - Symbiosis (parasitism), p.632-635 | |
| 29.7 Ecdysozoan Protostomes | 4.A.6 Interactions among living systems and with their environment result in the movement of matter and energy. \[4.A.6.g Many adaptations of organisms are related to obtaining and using energy and matter in a particular environment.\] | The following are illustrative examples of 4.A.6.g:  - Suckers and hooks of parasitic worms, p.653, 661  - Cilia of rotifers, p.655  - Proboscis of ribbon worms, p.656  - Adhesive tentacles of cephalopods, p.659 |  | 2.E.1 Timing and coordination of specific events are necessary for the normal development of an organism, and these events are regulated by a variety of mechanisms. \[2.E.1.b.1 Homeotic genes are involved in developmental patterns and sequences.\] \[2.E.1.b.4 Genetic mutations can result in abnormal development.\] | The following is an illustrative example of 2.E.1.b.1 and 2.E.1.b.4:  - Mutation in the homeotic gene \(Ubx\) leading to legs on thorax, not abdomen, p.668 |  | }
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<th>2.A.1 All living systems require constant input of free energy. [2.A.1.d.2 Reproduction and rearing of offspring require free energy beyond that used for maintenance and growth. Different organisms use various reproductive strategies in response to energy availability.]</th>
<th>The following is an illustrative example of 2.A.1.d.2: - Postembryonic developmental stages in insects, p.670-671</th>
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### Chapter 30. Deuterostomes: Vertebrates and Their Closest Relatives

#### 30.0 Why It Matters

- p.675-676 (Oddity of duck-billed platypus)

#### 30.1 Invertebrate Deuterostomes

- p.676-677 (Survey of echinoderms and hemichordates)

#### 30.2 Overview of the Phylum Chordata

- p.679-681 (Defining traits of chordates)

#### 30.3 The Origin and Diversification of Vertebrates

1. B. 2 Phylogenetic trees and cladograms are graphical representations (models) of evolutionary history that can be tested. [1.B.2.a Phylogenetic trees and cladograms can represent traits that are either derived or lost due to evolution.]

- The following is an illustrative example of 1.B.2.a: - Phylogenetic tree of major vertebrate groups and their defining characters, p. 681-683

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<td><strong>1.A.4</strong> Biological evolution is supported by scientific evidence from many disciplines, including mathematics. [1.A.4.b.4 Mathematical models and simulations can be used to illustrate and support evolutionary concepts.]</td>
<td>The following is an illustrative example of 1.A.4.b.4: - Phylogenetic analysis of chordates using Hox gene cluster, p.681-682</td>
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<td><strong>30.4</strong> &quot;Agnathans&quot;: Hagfishes and Lampreys, Conodonts and Ostracoderms</td>
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<td><strong>30.5</strong> Gnathostomata: The Evolution of Jaws</td>
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<td>The following is an illustrative example of 2.D.2.b: - Jaws, p.685</td>
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<td>4.A.6 Interactions among living systems and with their environment result in the movement of matter and energy. [4.A.6.g Many adaptations of organisms are related to obtaining and using energy and matter in a particular environment.]</td>
<td>The following is an illustrative example of 4.A.6.g: - Early animal adaptations for living on land, p.690</td>
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<td>4.B.3 Interactions between and within populations influence patterns of species distribution and abundance. [4.B.3.a Interactions between populations affect the distributions and abundance of populations.] The following is an illustrative example of 4.B.3.a: - Physiological differences enforces ecological separation of Anolis lizard species in Caribbean, p.697</td>
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<td>p.701-703</td>
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<td>1.A.4 Biological evolution is supported by scientific evidence from many disciplines, including mathematics. [1.A.4.b.4 Mathematical models and simulations can be used to illustrate and support evolutionary concepts.] The following is an illustrative example of 1.A.4.b.4: - Phylogenetic classification of the guinea pig based on sequence data, p.704</td>
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### 30.13 The Evolution of Humans

| 1.C.3 Populations of organisms continue to evolve. [1.C.3.a Scientific evidence supports the idea that evolution has occurred in all species.] [1.C.3.b Scientific evidence supports the idea that evolution continues to occur.] | The following is an illustrative example of 1.C.3.a: - The divergence of the hominin lineage, p.707-712. The following is an illustrative example of 1.C.3.b: - The evolution of modern humans, p.711-712. | p.707-712 (Hominin evolution) |

### Chapter 31. The Plant Body

#### 31.0 Why It Matters

##### 31.1 Plant Structure and Growth: An Overview

| 2.A.1 All living systems require constant input of free energy. [2.A.1.d.2 Reproduction and rearing of offspring require free energy beyond that used for maintenance and growth. Different organisms use various reproductive strategies in response to energy availability.] | The following is an illustrative example of 2.A.1.d.2: - Life-history strategy (biennial plants), p.720. | p.717-718 (Importance of plants), p.718-719 (Plant body organization), p.720 (Monocots and dicots) |

<p>| 4.A.4 Organisms exhibit complex properties due to interactions between their constituent parts. [4.A.4.a Interactions and coordination between organs provide essential biological activities.] | The following is an illustrative example of 4.A.4.a: - Root, stem and leaf, p.718. |</p>
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<th>The following is an illustrative example of 4.B.2.a.2: - Specialization of ground, dermal, and vascular tissues in plants, p.720-726</th>
<th>p.720-726 (Plant primary tissues and cell types)</th>
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<td>31.3 Primary Shoot Systems</td>
<td>2.C.1 Organisms use feedback mechanisms to maintain their internal environments and respond to external environmental changes. ([2.C.1.c) Alteration in the mechanisms of feedback often results in deleterious consequences.]</td>
<td>The following is an illustrative example of 2.C.1.c: - Trimming and release of apical dominance, p.727</td>
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<td>2.E.1 Timing and coordination of specific events are necessary for the normal development of an organism, and these events are regulated by a variety of mechanisms. ([2.E.1.b.1) Homeotic genes are involved in developmental patterns and sequences.]</td>
<td>The following is an illustrative example of 2.E.1.b.1: - knotted-1, a homeotic gene in corn, p.728</td>
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<td>2.D.2 Homeostatic mechanisms reflect both common ancestry and divergence due to adaptation in different environments. ([2.D.2.b) Organisms have various mechanisms for obtaining nutrients and eliminating wastes.]</td>
<td>The following is an illustrative example of 2.D.2.b: - Gas exchange in leaves, p.730-732</td>
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<td>4.A.4</td>
<td>Organisms exhibit complex properties due to interactions between their constituent parts. [4.A.4.b] Interactions and coordination between systems provide essential biological activities.</td>
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<td>The following is an illustrative example of 4.A.4.b: - Plant vascular and leaf, p.732</td>
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<th>2.D.1</th>
<th>All biological systems from cells and organisms to populations, communities and ecosystems are affected by complex biotic and abiotic interactions involving exchange of matter and free energy. [2.D.1.b] Organism activities are affected by interactions with biotic and abiotic factors.</th>
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<td>The following is an illustrative example of 2.D.1.b: - Seasonal shedding of leaves, p.732</td>
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<th>4.A.3</th>
<th>Interactions between external stimuli and regulated gene expression result in specialization of cells, tissues and organs. [4.A.3.a] Differentiation in development is due to external and internal cues that trigger gene regulation by proteins that bind to DNA.</th>
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<td>The following is an illustrative example of 4.A.3.a: - Juvenile versus adult leaf forms, p.732-733</td>
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<th>31.4</th>
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<td>2.D.2 Homeostatic mechanisms reflect both common ancestry and divergence due to adaptation in different environments. [2.D.2.b] Organisms have various mechanisms for obtaining nutrients and eliminating wastes.</td>
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<td>The following is an illustrative example of 2.D.2.b: - Specialization of roots, p.732-734</td>
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*AP® is a registered trademark of the College Board which was not involved in the development of, and does not endorse this product.*
| 2.A.3 Organisms must exchange matter with the environment to grow, reproduce and maintain organization. [2.A.3.b Surface area-to-volume ratios affect a biological system’s ability to obtain necessary resources or eliminate waste products.] | The following is an illustrative example of 2.A.3.b:
- Root hairs, p.735 |

| 31.5 Secondary Growth | |

| Chapter 32. Transport in Plants | |

| 32.0 Why It Matters | p.743 (Height limitations of plants) |

| 32.1 Principles of Water and Solute Movement in Plants | 2.B.2 Growth and dynamic homeostasis are maintained by the constant movement of molecules across membranes. p.744-748 The following is an illustrative example of 2.B.2.a.2:
- Rapid water transport through aquaporins, p.746-747 |
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<td>4.A.2</td>
<td>The structure and function of subcellular components, and their interactions, provide essential cellular processes. [4.A.2.f A vacuole is a membrane-bound sac that plays roles in intracellular digestion and the release of cellular waste products. In plants, a large vacuole serves many functions, from storage of pigments or poisonous substances to a role in cell growth. In addition, a large central vacuole allows for a large surface area to volume ratio.] p.746, 748</td>
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<td>32.2</td>
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<td>2.B.2</td>
<td>Growth and dynamic homeostasis are maintained by the constant movement of molecules across membranes.</td>
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<td>2.D.2</td>
<td>Homeostatic mechanisms reflect both common ancestry and divergence due to adaptation in different environments. [2.D.2.b Organisms have various mechanisms for obtaining nutrients and eliminating wastes.]</td>
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<td>The following is an illustrative example of 2.B.2: - Water and mineral uptake by the roots, p.747-749</td>
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<td>The following is an illustrative example of 2.D.2.b: - Water and mineral uptake by roots, p.747-749</td>
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p.747-749 (Mechanisms of water and mineral uptake)
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<td>Organisms must exchange matter with the environment to grow, reproduce and maintain organization. [2.A.3.a.3 Living systems depend on properties of water that result from its polarity and hydrogen bonding.]</td>
<td>The following is an illustrative example of 2.A.3.a.3: - Cohesion-tension mechanism of water transport, p.750-751 (Water movement through plants)</td>
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<td>2.C.1</td>
<td>Organisms use feedback mechanisms to maintain their internal environments and respond to external environmental changes. [2.C.1.a Negative feedback mechanisms maintain dynamic homeostasis for a particular condition (variable) by regulating physiological processes, returning the changing condition back to its target set point.]</td>
<td>The following is an illustrative example of 2.C.1.a : - Plant responses to water limitations, p.752-753, 754-755 (Water movement through plants)</td>
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<td>2.C.2</td>
<td>Organisms respond to changes in their external environments. [2.C.2.a Organisms respond to changes in their environment through behavioral and physiological mechanisms.]</td>
<td>The following is an illustrative example of 2.C.2.a : - Nocturnal and diurnal activity: circadian rhythms, p.753-754</td>
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<td>2.D.1</td>
<td>All biological systems from cells and organisms to populations, communities and ecosystems are affected by complex biotic and abiotic interactions involving exchange of matter and free energy. [2.D.1.b Organism activities are affected by interactions with biotic and abiotic factors.]</td>
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<td>The following is an illustrative example of 2.D.1.b: - Water availability, p.752-755</td>
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<td>3.B.2</td>
<td>A variety of intercellular and intracellular signal transmissions mediate gene expression. [3.B.2.b Signal transmission within and between cells mediates cell function.]</td>
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<td>The following is an illustrative example of 3.B.2.b: - ABA signaling in response to water stress, p.753</td>
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<td>The following is an illustrative example of 2.B.2: - Sugar loading and unloading at source and sink, respectively, p.756-757</td>
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<td>4.B.2</td>
<td>Cooperative interactions within organisms promote efficiency in the use of energy and matter. [4.B.2.a.2 Within multicellular organisms, specialization of organs contributes to the overall functioning of the organism.]</td>
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<td>The following is an illustrative example of 4.B.2.a.2: - Sinks for excess sugar, p.756</td>
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<td>33.1 Plant Nutritional Requirements</td>
<td>2.A.3 Organisms must exchange matter with the environment to grow, reproduce and maintain organization. [2.A.3.a.2 Nitrogen moves from the environment to organisms where it is used in building proteins and nucleic acids. Phosphorus moves from the environment to organisms where it is used in nucleic acids and certain lipids.]</td>
<td>p.762-763</td>
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<td>2.D.3 Biological systems are affected by disruptions to their dynamic homeostasis. [2.D.3.a Disruptions at the molecular and cellular levels affect the health of the organism.]</td>
<td>The following is an illustrative example of 2.D.3.a: - Nutritional deficiencies, p.764-765</td>
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<td>33.2 Soil</td>
<td>2.D.2 Homeostatic mechanisms reflect both common ancestry and divergence due to adaptation in different environments. [2.D.2.b Organisms have various mechanisms for obtaining nutrients and eliminating wastes.]</td>
<td>The following is an illustrative example of 2.D.2.b: - Cation exchange, p.768</td>
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<td>2.D.1 All biological systems from cells and organisms to populations, communities and ecosystems are affected by complex biotic and abiotic interactions involving exchange of matter and free energy. [2.D.1.b Organism activities are affected by interactions with biotic and abiotic factors.]</td>
<td>The following is an illustrative example of 2.D.1.b: - Soil salinity and pH, p.768-769</td>
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### 33.3 Obtaining and Absorbing Nutrients

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<td><strong>2.A.3</strong></td>
<td>Organisms must exchange matter with the environment to grow, reproduce and maintain organization. [2.A.3.a.2 Nitrogen moves from the environment to organisms where it is used in building proteins and nucleic acids. Phosphorus moves from the environment to organisms where it is used in nucleic acids and certain lipids.]</td>
<td>p.771-772</td>
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<td><strong>2.E.3</strong></td>
<td>Timing and coordination of behavior are regulated by various mechanisms and are important in natural selection. [2.E.3.b.4 Cooperative behavior within or between populations contributes to the survival of the populations.]</td>
<td>The following are illustrative examples of 2.E.3.b.4: - Mycorrhizae, p.770-771 - Associations between plants and nitrogen-fixing bacteria, p.772-773</td>
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<td><strong>4.B.3</strong></td>
<td>Interactions between and within populations influence patterns of species distribution and abundance. [4.B.3.a.3 Many complex symbiotic relationships exist in an ecosystem, and feedback control systems play a role in the functioning of these ecosystems.]</td>
<td>The following is an illustrative example of 4.B.3.a.3: - Plants and nitrogen-fixing bacteria, p.771-773</td>
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<td><strong>2.D.2</strong></td>
<td>Homeostatic mechanisms reflect both common ancestry and divergence due to adaptation in different environments. [2.D.2.b Organisms have various mechanisms for obtaining nutrients and eliminating wastes.]</td>
<td>The following is an illustrative example of 2.D.2.b: - Plants that trap and digest animals, p.774</td>
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<th>Chapter 34. Reproduction and Development in Flowering Plants</th>
<th>34.0 Why It Matters</th>
<th>p.779-780  (Reproduction of the cacao plant)</th>
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<td>34.1 Overview of Flowering Plant Reproduction</td>
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<td>p.780-781  (Life cycle of a flowering plant)</td>
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<td>34.2 The Formation of Flowers and Gametes</td>
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<td>p.781-783  (Flower anatomy) p.783-784  (Gamete development)</td>
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<td>34.3 Pollination, Fertilization, and Germination</td>
<td>4.C.1 Variation in molecular units provides cells with a wider range of functions. [4.C.1.a Variations within molecular classes provide cells and organisms with a wider range of functions.]</td>
<td>The following is an illustrative example of 4.C.1.a: - Diversity of self genes in plants to prevent self-fertilization, p.784-785 p.784-785  (Events of fertilization) p.785-788  (Seed development before germination) p.789-790  (Seed development after germination)</td>
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<td>2.E.1 Timing and coordination of specific events are necessary for the normal development of an organism, and these events are regulated by a variety of mechanisms. [2.E.1.b.3 Temperature and the availability of water determine seed germination in most plants.]</td>
<td>p.788-789</td>
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| 2.D.1 All biological systems from cells and organisms to populations, communities and ecosystems are affected by complex biotic and abiotic interactions involving exchange of matter and free energy. [2.D.1.b Organism activities are affected by interactions with biotic and abiotic factors.] | The following is an illustrative example of 2.D.1.b:  
- Germination conditions for seeds, p.788-789
| 34.4 Asexual Reproduction of Flowering Plants | 2.A.1 All living systems require constant input of free energy.  
[2.A.1.d.2 Reproduction and rearing of offspring require free energy beyond that used for maintenance and growth. Different organisms use various reproductive strategies in response to energy availability.] | The following is an illustrative example of 2.A.1.d.2:  
- Sexual vs asexual modes of reproduction in plants, p.790
| 1.A.2 Natural selection acts on phenotypic variations in populations.  
[1.A.2.d Humans impact variation in other species.] | The following is an illustrative example of 1.A.2.d:  
- Loss of genetic diversity in bananas, p.792
| 34.5 Early Development of Plant Form and Function | 4.A.3 Interactions between external stimuli and regulated gene expression result in specialization of cells, tissues and organs. | The following are illustrative examples of 4.A.3:  
- Asymmetrical cytoplasmic determinants in zygote leads to root-shoot axis specification, p.793-794  
- Expression of GL2 gene results in epidermal differentiation into root hair, p.795  
- Loss of genetic diversity in bananas, p.792

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<th>3.D.2</th>
<th>Cells communicate with each other through direct contact with other cells or from a distance via chemical signaling. [3.D.2.a Cells communicate by cell-to-cell contact.]</th>
<th>The following is an illustrative example of 3.D.2.a: - Positional information from root cortical cells to root epidermal cells, p.795</th>
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<td>3.C.1</td>
<td>Changes in genotype can result in changes in phenotype. [3.C.1.d Changes in genotype may affect phenotypes that are subject to natural selection. Genetic changes that enhance survival and reproduction can be selected by environmental conditions.]</td>
<td>The following is an illustrative example of 3.C.1.d: - Mutation of TRY affects trichome development, p.796</td>
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<td>2.E.1</td>
<td>Timing and coordination of specific events are necessary for the normal development of an organism, and these events are regulated by a variety of mechanisms. [2.E.1.b.1 Homeotic genes are involved in developmental patterns and sequences.]</td>
<td>The following is an illustrative example of 3.C.1.d and 2.E.1.b.1: - Homeotic genes in flower development, p.798-799</td>
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<td>Though not required, the Experimental Research box on p.799 describes a seminal experiment identifying the role of homeotic genes in floral organ specification (aligns with LO 2.31 and 2.33).</td>
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**Chapter 35. Plant Responses to the Environment**

35.0 Why It Matters

p.805-806 (Role of gibberellin in beer)
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<th>35.1 Plant Hormones</th>
<th>2.E.2 Timing and coordination of physiological events are regulated by multiple mechanisms. [2.E.2.a In plants, physiological events involve interactions between environmental stimuli and internal molecular signals.]</th>
<th>p.806-815</th>
<th>X. Memorization of the names, molecular structures and specific effects of all plant hormones are beyond the scope of the course and the AP Exam.</th>
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<td>2.D.1 All biological systems from cells and organisms to populations, communities and ecosystems are affected by complex biotic and abiotic interactions involving exchange of matter and free energy. [2.D.1.b Organism activities are affected by interactions with biotic and abiotic factors.]</td>
<td>The following are illustrative examples of 2.D.1.b: - Phototropism, p.806 - Water stress response, p.814-815 - Infections and herbivory, p.815</td>
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<td>2.C.1 Organisms use feedback mechanisms to maintain their internal environments and respond to external environmental changes. [2.D.1.b Positive feedback mechanisms amplify responses and processes in biological organisms.]</td>
<td>The following is an illustrative example of 2.D.1.b: - The ripening of fruit, p.813-814</td>
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### 2.D.4 Plants and animals have a variety of chemical defenses against infections that affect dynamic homeostasis. [2.D.4.a Plants, invertebrates and vertebrates have multiple, nonspecific immune responses.]

#### 3.D.3 Signal transduction pathways link signal reception with cellular response. [3.D.3.b Signal transduction is the process by which a signal is converted to a cellular response.]

The following are illustrative examples of 3.D.3.b:
- Systemin-mediated response to wounding, p.818
- Activation of plant defenses based on gene-for-gene recognition of pathogens, p.819-820

#### 2.E.3 Timing and coordination of behavior are regulated by various mechanisms and are important in natural selection. [2.E.3.b.4 Cooperative behavior within or between populations contributes to the survival of the populations.]

#### 3.E.1 Individuals can act on information and communicate it to others. [3.E.1.a Organisms exchange information with each other in response to internal changes and external cues, which can change behavior.]

The following is an illustrative example of 2.E.3.b.4 and 3.E.1.a:
- Diffusion of volatile protective compounds from wounded plant to neighbors, p.818-819
| 3.D.1 | Cell communication processes share common features that reflect a shared evolutionary history. [3.D.1.a Communication involves transduction of stimulatory or inhibitory signals from other cells, organisms or the environment.] [3.D.1.d In multicellular organisms, signal transduction pathways coordinate the activities within individual cells that support the function of the organism as a whole.] | The following are illustrative examples of 3.D.1.d: - Hypersensitive response in plants, p.818 - Systemic acquired resistance, p.820 |
| 3.D.2 | Cells communicate with each other through direct contact with other cells or from a distance via chemical signaling. [3.D.2.b Cells communicate over short distances by using local regulators that target cells in the vicinity of the emitting cell.] | The following are illustrative examples of 3.D.2.b: - Salicylic acid, p.818 - Systemin (in tomato), p.818 |
| 4.A.3 | Interactions between external stimuli and regulated gene expression result in specialization of cells, tissues and organs. [4.A.3.c Environmental stimuli can affect gene expression in a mature cell.] | The following is an illustrative example of 4.A.3.c: - Expression induced by exposure to extreme heat or cold |

| 35.3 Plant Movements | 2.E.2 Timing and coordination of physiological events are regulated by multiple mechanisms. [2.E.2.a.1 Phototropism, or the response to the presence of light.] | p.820 |
| 4.A.3 | Interactions between external stimuli and regulated gene expression result in specialization of cells, tissues and organs. [4.A.3.c Environmental stimuli can affect gene expression in a mature cell.] | The following is an illustrative example of 4.A.3.c: 
- Thigmomorphogenesis, p.822-823 |

| 2.C.2 | Organisms respond to changes in their external environments. [2.C.2.a Organisms respond to changes in their environment through behavioral and physiological mechanisms.] | The following are illustrative examples of 2.C.2.a: 
- Phototropism, p.821 
- Nastic sleep movements, p.823 |

| 35.4 Plant Biological Clocks | 2.E.2 Timing and coordination of physiological events are regulated by multiple mechanisms. [2.E.2.a.2 Photoperiodism, or the response to change in length of the night, that results in flowering in long-day and short-day plants.] | p.824-826 |

| 2.C.2 | Organisms respond to changes in their external environments. [2.C.2.a Organisms respond to changes in their environment through behavioral and physiological mechanisms.] | The following is an illustrative example of 2.C.2.a: 
- Circadian rhythms, p.824 
- Photoperiodism, p.824-825 |

| 3.D.3 | Signal transduction pathways link signal reception with cellular response. [3.D.3.b Signal transduction is the process by which a signal is converted to a cellular response.] | The following is an illustrative examples of 3.D.3.b: 
- How floral identity genes are activated by sensors of day/night length, p.826-827 |
| 3.A.1 DNA, and in some cases RNA, is the primary source of heritable information. [3.A.1.e Genetic engineering techniques can manipulate the heritable information of DNA and, in special cases, RNA.] | The following is an illustrative example of 3.A.1.e:
- Identification and mutational analysis of the putative florigen-encoding gene, p.828 |

| 35.5 Signal Responses at the Cellular Level | 3.D.3 Signal transduction pathways link signal reception with cellular response. | The following are illustrative examples of 3.D.3:
- Auxin receptor TIR, p.829
- ABA-sensitive G-protein-coupled receptors and IP3 as second messenger, p.829 |

| Chapter 36. Introduction to Animal Organization and Physiology | | p.828 (Some details on specific plant signal transduction pathways) |

| 36.0 Why It Matters | | p.835 (Hypothermia and the Titanic) p.835-836* (Defining homeostasis) |

| 36.1 Organization of the Animal Body | | p.836* (Defining tissue, organ, organ system) |

| 36.2 Animal Tissues | 4.A.3 Interactions between external stimuli and regulated gene expression result in specialization of cells, tissues and organs. [4.A.3.b Structural and functional divergence of cells in development is due to expression of genes specific to a particular tissue or organ type.] | The following are illustrative examples of 4.A.3.b:
- Keratin in epithelial tissue, p.837
- Collagen and fibronectin in connective tissue, p.840
- Hemoglobin in erythrocytes, p.841
- Actin and myosin in muscle tissue, p.841 |

<p>| | | p.836-843 (Overview of tissue types and functions) |</p>
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<th>4.A.4 Organisms exhibit complex properties due to interactions between their constituent parts.</th>
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<tr>
<td>36.4 Homeostasis</td>
<td>4.A.4 Organisms exhibit complex properties due to interactions between their constituent parts. [4.A.4.b Interactions and coordination between systems provide essential biological activities.]</td>
<td>p.843-844</td>
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<td>2.D.2 Homeostatic mechanisms reflect both common ancestry and divergence due to adaptation in different environments. [2.D.2.b Organisms have various mechanisms for obtaining nutrients and eliminating wastes.]</td>
<td>p.843-845</td>
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</table>
2.C.1 Organisms use feedback mechanisms to maintain their internal environments and respond to external environmental changes. 

- **Negative feedback**
  - Negative feedback mechanisms maintain dynamic homeostasis for a particular condition (variable) by regulating physiological processes, returning the changing condition back to its target set point.

- **Positive feedback**
  - 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.

The following is an illustrative example of 2.C.1.a:
- Temperature regulation in animals, p.846-847

The following is an illustrative example of 2.C.1.b:
- Onset of birth in animals, p.848

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<th>2.C.2 Organisms respond to changes in their external environments</th>
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### Chapter 37. Information Flow and the Neuron

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<td>(Simple example of neural signaling and processing)</td>
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<td>37.1 Neurons and Their Organization in Nervous Systems</td>
<td>3.E.2 Animals have nervous systems that detect external and internal signals, transmit and integrate information, and produce responses. [3.E.2.a The neuron is the basic structure of the nervous system that reflects function.]</td>
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<td>3.D.2 Cells communicate with each other through direct contact with other cells or from a distance via chemical signaling. [3.D.2.a Cells communicate by cell-to-cell contact.]</td>
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<td>37.2 Signaling by Neurons</td>
<td>3.E.2 Animals have nervous systems that detect external and internal signals, transmit and integrate information, and produce responses. [3.E.2.b Action potentials propagate impulses along neurons.]</td>
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<tr>
<td>3.A.1 DNA, and in some cases RNA, is the primary source of heritable information. [3.A.1.d Phenotypes are determined through protein activities.]</td>
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<td>37.3 Transmission across Chemical Synapses</td>
<td>3.E.2 Animals have nervous systems that detect external and internal signals, transmit and integrate information, and produce responses. [3.E.2.c Transmission of information between neurons occurs across synapses.]</td>
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<tr>
<td>3.D.2 Cells communicate with each other through direct contact with other cells or from a distance via chemical signaling. [3.D.2.b Cells communicate over short distances by using local regulators that target cells in the vicinity of the emitting cell.]</td>
<td>The following is an illustrative example of 3.D.2.b: - Neurotransmitters, p.863-866</td>
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<td>3.D.4 Changes in signal transduction pathways can alter cellular response. [3.D.4.a Conditions where signal transduction is blocked or defective can be deleterious, preventative or prophylactic.]</td>
<td>The following is an illustrative example of 3.D.4.a: - Drugs that affect neurotransmission, p.864-865</td>
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### Chapter 38. Nervous Systems

#### 38.0 Why It Matters

- **Nutrient-seeking behavior in flies**

#### 38.1 Invertebrate and Vertebrate Nervous Systems Compared

- **Populations of organisms continue to evolve.** [1.C.3.b Scientific evidence supports the idea that evolution continues to occur.]

#### 38.2 The Peripheral Nervous System

- **Autonomic and somatic nervous system**

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### 38.3 The Central Nervous System and Its Functions

**3.E.2** Animals have nervous systems that detect external and internal signals, transmit and integrate information, and produce responses. [3.E.2.d Different regions of the vertebrate brain have different functions.]

<table>
<thead>
<tr>
<th>p.878-884</th>
<th>The following are illustrative examples of 3.E.2.d:</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>- Hearing and vision (sensory regions of the cerebral cortex), p.883</td>
</tr>
<tr>
<td></td>
<td>- Muscle movement (motor regions of the cerebral cortex), p.883-884</td>
</tr>
<tr>
<td></td>
<td>- Abstract thought and emotions (cerebral cortex), p.884</td>
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<td></td>
<td>- Neurohormone production (hypothalamus), p.881</td>
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<td></td>
<td>- Forebrain, midbrain and hindbrain, p.879</td>
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<tr>
<td></td>
<td>- Right and left cerebral hemispheres in humans, p.884-885</td>
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<tr>
<td></td>
<td>Though not required, the Experimental Research box on p.885 describes the discovery of differences in function between the two cerebral hemispheres using split-brain patients (aligns with LO 3.43 and 3.44).</td>
</tr>
</tbody>
</table>

### 38.4 Memory, Learning, and Consciousness

**3.A.1** DNA, and in some cases RNA, is the primary source of heritable information. [3.A.1.d Phenotypes are determined through protein activities.]

<table>
<thead>
<tr>
<th>p.886-888</th>
<th>The following is an illustrative example of 3.A.1.d:</th>
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<tr>
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<td>- NMDA receptor and memory, p.887</td>
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<td></td>
<td>p.886 (Long-term vs short-term memory)</td>
</tr>
<tr>
<td></td>
<td>p.886 (Molecular basis of learning)</td>
</tr>
<tr>
<td></td>
<td>p.886-888 (Sleep and EEGs)</td>
</tr>
</tbody>
</table>
### 2.E.2 Timing and coordination of physiological events are regulated by multiple mechanisms. [2.E.2.b In animals, internal and external signals regulate a variety of physiological responses that synchronize with environmental cycles and cues.]

The following is an illustrative example of 2.E.2.b:
- Reticular activating system and sleep/awake cycles, p.887-888

---

### Chapter 39. Sensory Systems

#### 39.0 Why It Matters

3.E.1 Individuals can act on information and communicate it to others. [3.E.1.a Organisms exchange information with each other in response to internal changes and external cues, which can change behavior.]

The following is an illustrative example of 3.E.1.a:
- Avoidance behavior of moth in response to bat echolocation, p.891

#### 39.1 Overview of Sensory Receptors and Pathways

4.B.2 Cooperative interactions within organisms promote efficiency in the use of energy and matter. [4.B.2.a.2 Within multicellular organisms, specialization of organs contributes to the overall functioning of the organism.]

The following is an illustrative example of 4.B.2.a.2:
- Overview of sensory receptor specializations, p.892-893

#### 39.2 Mechanoreceptors and the Tactile and Spatial Senses

1.A.4 Biological evolution is supported by scientific evidence from many disciplines, including mathematics. [1.A.4.2 Morphological homologies represent features shared by common ancestry.]

The following is an illustrative example of 1.A.4.2:
- Structure of sensory hair cells in lateral line system and inner ear, p.895-896
<table>
<thead>
<tr>
<th>39.3 Mechanoreceptors and Hearing</th>
<th></th>
<th></th>
<th>p.897 (Invertebrate hearing mechanisms) p.897-899 (Vertebrate hearing and the human ear)</th>
</tr>
</thead>
<tbody>
<tr>
<td>39.4 Photoreceptors and Vision</td>
<td>1.C.3 Populations of organisms continue to evolve. [1.C.3.b Scientific evidence supports the idea that evolution continues to occur.]</td>
<td>The following is an illustrative example of 1.C.3.b: - Evolution of the eye, p.899-901</td>
<td>p.899-900 (Non-vertebrate vision) p.900-902 (Vertebrate vision and the human eye) p.902-904 (Molecular basis of vision)</td>
</tr>
<tr>
<td></td>
<td>3.E.2 Animals have nervous systems that detect external and internal signals, transmit and integrate information, and produce responses. [3.E.2.d Different regions of the vertebrate brain have different functions.]</td>
<td>The following is an illustrative example of 3.E.2.d: - Visual cortex and vision, p.904</td>
<td></td>
</tr>
<tr>
<td></td>
<td>4.C.1 Variation in molecular units provides cells with a wider range of functions. [4.C.1.a Variations within molecular classes provide cells and organisms with a wider range of functions.]</td>
<td>The following is an illustrative example of 4.C.1.a: - Photopsin genes and color vision, p.903</td>
<td></td>
</tr>
</tbody>
</table>
### 39.5 Chemoreceptors

*3.E.2* Animals have nervous systems that detect external and internal signals, transmit and integrate information, and produce responses. [3.E.2.d Different regions of the vertebrate brain have different functions.]

The following is an illustrative example of 3.E.2.d:
- Olfactory center of cerebral cortex, p.906

- Invertebrate taste and smell, p.905
- Taste buds, p.906
- Olfactory bulb, p.906

### 39.6 Thermoreceptors and Nociceptors

- Thermoreceptors, p.906-907
- Nociceptors, p.907

### 39.7 Magnetoreceptors and Electroreceptors

- Magnetoreceptors, p.907, 909
- Electroreceptors, p.910

### Chapter 40. The Endocrine System

#### 40.0 Why It Matters

*2.A.1* All living systems require constant input of free energy. [2.A.1.d.2 Reproduction and rearing of offspring require free energy beyond that used for maintenance and growth. Different organisms use various reproductive strategies in response to energy availability.]

The following is an illustrative example of 2.A.1.d.2:
- Seasonal mating in animals, p.914-915

- Seasonal changes in hormones, p.914-915
### 40.1 Hormones and Their Secretion

| 3.D.2 | Cells communicate with each other through direct contact with other cells or from a distance via chemical signaling. [3.D.2.b] Cells communicate over short distances by using local regulators that target cells in the vicinity of the emitting cell. [3.D.2.c] Signals released by one cell type can travel long distances to target cells of another cell type. | p.915-917 | X. No specific system, with the exception of the endocrine system, is required for teaching the concepts in 3.D.2. |

### 40.2 Mechanisms of Hormone Action

| 3.B.2 | A variety of intercellular and intracellular signal transmissions mediate gene expression. [3.B.2.a] Signal transmission within and between cells mediates gene expression. | p.917-920 | The following is an illustrative example of 3.B.2.a: - Effect of steroid hormone aldosterone on sodium channel synthesis, p.918-99
Though not required, the Experimental Research box on p.920 describes an experiment demonstrating the ability of ectopic epinephrine receptors to initiate cAMP synthesis (aligns with LO 3.26). |

| 3.D.1 | Cell communication processes share common features that reflect a shared evolutionary history. [3.D.1.d] In multicellular organisms, signal transduction pathways coordinate the activities within individual cells that support the function of the organism as a whole. | The following is an illustrative example of 3.D.1.d: - Aldosterone stimulation of sodium reuptake, p.918-919
- Epinephrine stimulation of glycogen breakdown in mammals, p.919 |
| 40.3 The Hypothalamus and Pituitary | 3.D.2 Cells communicate with each other through direct contact with other cells or from a distance via chemical signaling. [3.D.2.c Signals released by one cell type can travel long distances to target cells of another cell type.] | p.920-925 | The following are illustrative examples of 3.D.2.c:  
- Human growth hormone (GH), p.922  
- Prolactin, p.922  
- Melanocyte-stimulating hormone (MSH), p.923  
- Endorphins, p.924  
- Antidiuretic hormone (ADH), p.925  
- Oxytocin, p.925 |
|  | 4.A.4 Organisms exhibit complex properties due to interactions between their constituent parts. [4.A.4.b Interactions and coordination between systems provide essential biological activities.] |  | The following is an illustrative example of 4.A.4.a:  
- Nervous system and endocrine system, p.921 |
|  | 2.C.1 Organisms use feedback mechanisms to maintain their internal environments and respond to external environmental changes. [2.C.1.b 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.] |  | The following is an illustrative example of 2.C.1.b:  
- Prolactin and lactation in mammals, p.922 |
| 3.A.1 | DNA, and in some cases RNA, is the primary source of heritable information. [3.A.1.d Phenotypes are determined through protein activities.] | The following is an illustrative example of 3.A.1.d: - Diverse effects of peptide hormones, p.921-925 |
| 40.4 | Other Major Endocrine Glands in Vertebrates | |
| 3.D.2 | Cells communicate with each other through direct contact with other cells or from a distance via chemical signaling. [3.D.2.c Signals released by one cell type can travel long distances to target cells of another cell type.] | p.925-932 |
| 4.A.4 | Organisms exhibit complex properties due to interactions between their constituent parts. [4.A.4.a Interactions and coordination between organs provide essential biological activities.] | The tropic hormones and their targets are illustrative examples of 4.A.4.a: - TSH and thyroid hormones, p.925 - ACTH and glucocorticoids, p.929 - GnRH (i.e. LH and FSH) and sex hormones, p.930 |
| 2.C.2 | Organisms respond to changes in their external environments. [2.C.2.a Organisms respond to changes in their environment through behavioral and physiological mechanisms.] | The following are illustrative examples of 2.C.2.a: - Epinephrine and norepinephrine release in response to stress, p.928 - Glucocorticoid release in response to fasting, p.929 - Insulin release in response to eating, p.931 |
| 2.C.1 Organisms use feedback mechanisms to maintain their internal environments and respond to external environmental changes. [2.C.1.a Negative feedback mechanisms maintain dynamic homeostasis for a particular condition (variable) by regulating physiological processes, returning the changing condition back to its target set point.] [2.C.1.c Alteration in the mechanisms of feedback often results in deleterious consequences.]

| The following are illustrative examples of 2.C.1.a: |
| - Falling calcium levels inhibit calcitonin secretion, p.927-928 |
| - Rising calcium levels inhibit PTH secretion, p.927-928 |
| - Glucocorticoids inhibit CRH and ACTH secretion, p.929 |
| - High blood glucose inhibits glucagon secretion, p.931 |
| - Low blood glucose inhibits insulin secretion, p.931 |

| The following are illustrative examples of 2.C.1.c: |
| - Hyperthyroidism (including Graves' disease) and hypothyroidism, p.926-927 |
| - PTH underproduction and overproduction, p.928 |
| - Epinephrine overproduction, p.929 |
| - Glucocorticoid underproduction and overproduction, p.929 |
| - Aldosterone underproduction and overproduction, p.929 |
| - Consequences of anabolic steroid doping, p.930 |
| - Diabetes mellitus, p.930-931 |
| 3.D.4 | Changes in signal transduction pathways can alter cellular response. [3.D.4.a Conditions where signal transduction is blocked or defective can be deleterious, preventative or prophylactic.] | The following are illustrative examples of 3.D.4.a:  
- Breast cancer inhibitor and antiestrogen tamoxifen, p.926-927  
- Hyperthyroidism (including Graves' disease) and hypothyroidism, p.926-927  
- Diabetes mellitus, p.930-931 |
| 4.C.1 | Variation in molecular units provides cells with a wider range of functions. [4.C.1.a Variations within molecular classes provide cells and organisms with a wider range of functions.] | The following is an illustrative example of 4.C.1.a:  
- Variety in sex hormones (both synthetic and natural), p.930; see also p.54 |
| 2.B.2 | Growth and dynamic homeostasis are maintained by the constant movement of molecules across membranes. | The following is an illustrative example of 2.B.2:  
- Effect of mineralocorticoids on degree of active and passive transport, p.929 |
| 2.A.1 | All living systems require constant input of free energy. [2.A.1.d.1 Organisms use various strategies to regulate body temperature and metabolism.] [2.A.1.d.4 Excess acquired free energy versus required free energy expenditure results in energy storage or growth.] | The following is an illustrative example of 2.A.1.d.1:  
- Thyroid hormones maintain metabolic rate, p.925-927  
- Excess fuel substances in body leads to insulin release and storage, p.931 |
### 2.E.2 Timing and coordination of physiological events are regulated by multiple mechanisms.

2.E.2.b In animals, internal and external signals regulate a variety of physiological responses that synchronize with environmental cycles and cues.

The following is an illustrative example of 2.E.2.b:
- Pineal gland and role of melatonin in biological clock maintenance, p.932

### 40.5 Endocrine System in Invertebrates

2.D.2 Homeostatic mechanisms reflect both common ancestry and divergence due to adaptation in different environments.

The following is an illustrative example of 2.D.2.c:
- Peptide neurohormones in invertebrates, p.932-933

### Chapter 41. Muscles, Bones, and Body Movements

#### 41.0 Why It Matters

- p.937-938 (Speed of frog jump)

#### 41.1 Vertebrate Skeletal Muscle: Structure and Function

- p.938-939 (Muscle structure)
- p.939-942 (Sliding filament model)
- p.943-944 (Slow and fast fibers)
- p.945 (Invertebrate muscles)

#### 41.2 Skeletal Systems

4.A.4 Organisms exhibit complex properties due to interactions between their constituent parts.

The following is an illustrative example of 4.A.4:
- Bones consist of interactions between many tissue types, p.927
- p.945-947 (Types of skeletons)
- p.948 (Human bones)
<table>
<thead>
<tr>
<th>41.3 Vertebrate Movement: The Interactions between Muscles and Bones</th>
<th>4.A.4 Organisms exhibit complex properties due to interactions between their constituent parts.</th>
<th>The following is an illustrative example of 4.A.4: - Joints and ligaments allow interactions between muscles and bones, p.947-949</th>
<th>p.947-949 (Joints and ligaments)</th>
</tr>
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<tbody>
<tr>
<td><strong>Chapter 42. The Circulatory System</strong></td>
<td>42.0 Why It Matters</td>
<td></td>
<td></td>
</tr>
<tr>
<td>42.1 Animal Circulatory Systems: An Introduction</td>
<td>1.C.3 Populations of organisms continue to evolve. [1.C.3.b Scientific evidence supports the idea that evolution continues to occur.] The following is an illustrative example of 1.C.3.b: - Evolution of blood circuits and number of chambers of the heart, p.955-957</td>
<td></td>
<td>p.954-955 (Invertebrate circulatory systems) p.955-957 (Vertebrate circulatory systems)</td>
</tr>
<tr>
<td></td>
<td>2.D.2 Homeostatic mechanisms reflect both common ancestry and divergence due to adaptation in different environments. [2.D.2.c Homeostatic control systems in species of microbes, plants and animals support common ancestry.] The following is an illustrative example of 2.D.2.c: - Circulatory systems in fish, amphibians and mammals, p.955-957</td>
<td></td>
<td></td>
</tr>
<tr>
<td>42.2 Blood and Its Components</td>
<td>2.C.1 Organisms use feedback mechanisms to maintain their internal environments and respond to external environmental changes. [2.C.1.a Negative feedback mechanisms maintain dynamic homeostasis for a particular condition (variable) by regulating physiological processes, returning the changing condition back to its target set point.] The following is an illustrative example of 2.C.1.c: - Oxygen levels and erythropoietin (EPO) secretion, p.958-959</td>
<td></td>
<td>p.957-960 (Composition of blood and function of components)</td>
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<tr>
<th>Section</th>
<th>Concept</th>
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</thead>
<tbody>
<tr>
<td>3.C.1</td>
<td>Changes in genotype can result in changes in phenotype. [3.C.1.a Alterations in a DNA sequence can lead to changes in the type or amount of the protein produced and the consequent phenotype.]</td>
<td>The following is an illustrative example of 3.C.1.a: - Factor VIII and hemophilia, p.959-960</td>
</tr>
<tr>
<td>42.3 The Heart</td>
<td>Organisms exhibit complex properties due to interactions between their constituent parts. [4.A.4.b Interactions and coordination between systems provide essential biological activities.]</td>
<td>The following is an illustrative example of 4.A.4.b: - Respiratory system and circulatory system, p.960-961</td>
</tr>
<tr>
<td>4.B.2</td>
<td>Cooperative interactions within organisms promote efficiency in the use of energy and matter. [4.B.2.a.2 Within multicellular organisms, specialization of organs contributes to the overall functioning of the organism.]</td>
<td>The following is an illustrative example of 4.B.2.a.2: - Circulation of fluids, p.960-961</td>
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<td>42.4 Blood Vessels of the Circulatory System</td>
<td>Growth and dynamic homeostasis are maintained by the constant movement of molecules across membranes.</td>
<td>The following is an illustrative example of 2.B.2: - Blood-brain barrier permeability, p.964-965</td>
</tr>
<tr>
<td>42.5 Maintaining Blood Flow and Pressure</td>
<td>2.C.1 Organisms use feedback mechanisms to maintain their internal environments and respond to external environmental changes. [2.C.1.a Negative feedback mechanisms maintain dynamic homeostasis for a particular condition (variable) by regulating physiological processes, returning the changing condition back to its target set point.]</td>
<td>The following is an illustrative example of 2.C.1.c: - Regulation of blood pressure through control of cardiac output, arteriole diameter, and blood volume, p.966-968</td>
</tr>
<tr>
<td>42.6 The Lymphatic System</td>
<td>4.A.4 Organisms exhibit complex properties due to interactions between their constituent parts. [4.A.4.b Interactions and coordination between systems provide essential biological activities.]</td>
<td>The following is an illustrative example of 4.A.4.b: - Circulatory system, immune system, and lymphatic system, p.968-969</td>
</tr>
<tr>
<td>42. Unanswered Questions</td>
<td>1.B.2 Phylogenetic trees and cladograms are graphical representations (models) of evolutionary history that can be tested. [1.B.2.d Phylogenetic trees and cladograms are dynamic (i.e., phylogenetic trees and cladograms are constantly being revised), based on the biological data used, new mathematical and computational ideas, and current and emerging knowledge.]</td>
<td>The following is an illustrative example of 1.B.2.d: - Evolution of blood clotting factors, p.969-970</td>
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Chapter 43. Defenses against Disease

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<th>43.0 Why It Matters</th>
<th>43.1 Three Lines of Defense against Pathogens</th>
<th>43.2 Innate Immunity: Nonspecific Defenses</th>
<th>p.974-975 (Discovery of vaccination)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>2.D.4</strong> Plants and animals have a variety of chemical defenses against infections that affect dynamic homeostasis.</td>
<td><strong>2.D.4</strong> Plants and animals have a variety of chemical defenses against infections that affect dynamic homeostasis. [2.D.4.a Plants, invertebrates and vertebrates have multiple, nonspecific immune responses.]</td>
<td><strong>2.D.4</strong> Plants and animals have a variety of chemical defenses against infections that affect dynamic homeostasis. [2.D.4.a Plants, invertebrates and vertebrates have multiple, nonspecific immune responses.]</td>
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<tr>
<td>p.975-976</td>
<td>p.975-976</td>
<td>The following is an illustrative example of 2.D.4.a: - Vertebrate immune systems have nonspecific and nonheritable defense mechanisms against pathogens, p.976-979</td>
<td></td>
</tr>
<tr>
<td><strong>2.C.1</strong> Organisms use feedback mechanisms to maintain their internal environments and respond to external environmental changes. [2.C.1.c Alteration in the mechanisms of feedback often results in deleterious consequences.]</td>
<td><strong>2.C.1</strong> Organisms use feedback mechanisms to maintain their internal environments and respond to external environmental changes. [2.C.1.c Alteration in the mechanisms of feedback often results in deleterious consequences.]</td>
<td>The following is an illustrative example of 2.C.1.c: - Fever (change in set point, maintenance of homeostasis), p.978 -- versus hyperthermia (no change in set point, disruption of homeostasis), p.1061 of Chapter 46</td>
<td></td>
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<tr>
<td>p.976-979</td>
<td>The following is an illustrative example of 2.C.1.c: - Fever (change in set point, maintenance of homeostasis), p.978 -- versus hyperthermia (no change in set point, disruption of homeostasis), p.1061 of Chapter 46</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>3.D.2</strong> Cells communicate with each other through direct contact with other cells or from a distance via chemical signaling. [3.D.2.b Cells communicate over short distances by using local regulators that target cells in the vicinity of the emitting cell.]</td>
<td><strong>3.D.2</strong> Cells communicate with each other through direct contact with other cells or from a distance via chemical signaling. [3.D.2.b Cells communicate over short distances by using local regulators that target cells in the vicinity of the emitting cell.]</td>
<td>The following are illustrative examples of 3.D.2.b: - Histamine, p.977 - Chemokines, p.978 - Prostaglandins, p.978 - Interferons, p.978</td>
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</table>
### 3.B.2

A variety of intercellular and intracellular signal transmissions mediate gene expression. 

**3.B.2.a** Signal transmission within and between cells mediates gene expression. 

**3.B.2.b** Signal transmission within and between cells mediates cell function.

The following is an illustrative example of **3.B.2.a**: 
- Interferon effect on gene expression patterns, p.978

The following are illustrative examples of **3.B.2.b**: 
- Histamine effect on capillary endothelial cells, p.977
- Chemokine effect on leukocyte migration, p.978
- Interferon effect on protein synthesis rate, p.978

### 43.3 Adaptive Immunity: Specific Defenses

**2.D.4** Plants and animals have a variety of chemical defenses against infections that affect dynamic homeostasis. 

**2.D.4.b** Mammals use specific immune responses triggered by natural or artificial agents that disrupt dynamic homeostasis.

p.979-989

X. Memorization of the structures of specific immunoglobulin classes is beyond the scope of the course and the AP Exam.

### 3.D.2

Cells communicate with each other through direct contact with other cells or from a distance via chemical signaling. 

**3.D.2.a** Cells communicate by cell-to-cell contact. 

**3.D.2.b** Cells communicate over short distances by using local regulators that target cells in the vicinity of the emitting cell.

The following is an illustrative example of **3.D.2.a**: 
- Interaction of antigen-presenting cells (APCs) with helper T-cells and killer T-cells, p.983-984, 987-989

The following is an illustrative example of **3.D.2.b**: 
- Interleukins and other cytokines activate T cells, p.983-984, 987-989
<table>
<thead>
<tr>
<th>3.B.2</th>
<th>A variety of intercellular and intracellular signal transmissions mediate gene expression. [3.B.2.b Signal transmission within and between cells mediates cell function.]</th>
<th>The following is an illustrative example of 3.B.2.b: - Interactions between APCs and T-cells, p.983-984, 987-989</th>
</tr>
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<tr>
<td>43.4 Malfunctions and Failures of the Immune System</td>
<td>2.E.1 Timing and coordination of specific events are necessary for the normal development of an organism, and these events are regulated by a variety of mechanisms. [2.E.1.c Programmed cell death (apoptosis) plays a role in the normal development and differentiation.]</td>
<td>The following is an illustrative example of 2.E.1.c: - Immunological tolerance, p.989</td>
</tr>
<tr>
<td></td>
<td>2.D.3 Biological systems are affected by disruptions to their dynamic homeostasis. [2.D.3.a Disruptions at the molecular and cellular levels affect the health of the organism.]</td>
<td>The following are illustrative examples of 2.D.3.a: - Pathogen avoidance of immune system, p.991 - Allergies, p.991-992</td>
</tr>
<tr>
<td></td>
<td>4.C.1 Variation in molecular units provides cells with a wider range of functions. [4.C.1.a Variations within molecular classes provide cells and organisms with a wider range of functions.]</td>
<td>The following are illustrative examples of 4.C.1.a: - Antibodies, p.980-982 - MHC proteins, 982-983</td>
</tr>
<tr>
<td></td>
<td>4.C.3 The level of variation in a population affects population dynamics. [4.C.3.b Genetic diversity allows individuals in a population to respond differently to the same changes in environmental conditions.]</td>
<td>The following is an illustrative example of 4.C.3.b: - MHC diversity in human population, 982-983</td>
</tr>
</tbody>
</table>
### 3.C.3 Viral replication results in genetic variation, and viral infection can introduce genetic variation into the hosts. [3.C.3.a Viral replication differs from other reproductive strategies and generates genetic variation via various mechanisms.]

The following is an illustrative example of 3.C.3.a:
- HIV, p.991-992

### 3.D.4 Changes in signal transduction pathways can alter cellular response. [3.D.4.a Conditions where signal transduction is blocked or defective can be deleterious, preventative or prophylactic.]

The following is an illustrative example of 3.D.4.a:
- Autoimmune disease, p.989-990

### 43.5 Defenses in Other Animals

2.D.4 Plants and animals have a variety of chemical defenses against infections that affect dynamic homeostasis. [2.D.4.a Plants, invertebrates and vertebrates have multiple, nonspecific immune responses.]

The following is an illustrative example of 2.D.4.a:
- Invertebrate immune systems have nonspecific response mechanisms, but they lack pathogen-specific defense responses, p.993
| 44.2 Adaptations for Respiration | 2.D.2 Homeostatic mechanisms reflect both common ancestry and divergence due to adaptation in different environments. [2.D.2.b Organisms have various mechanisms for obtaining nutrients and eliminating wastes.] | The following are illustrative examples of 2.D.2.b: - Respiratory systems of aquatic animals, p.1000-1001 - Respiratory system of terrestrial insects, p.1001-1002 - Respiratory system of amphibians, p.1002 - Respiratory system of birds, p.1002 | p.1000-1001 (Gills) p.1001 (Countercurrent exchange) |
| 44.3 The Mammalian Respiratory System | 4.B.2 Cooperative interactions within organisms promote efficiency in the use of energy and matter. [4.B.2.a.2 Within multicellular organisms, specialization of organs contributes to the overall functioning of the organism.] | The following is an illustrative example of 4.B.2.a.2: - Exchange of gases in humans, p.1003-1005 | p.1003-1005 (Human respiratory system) p.1005-1007 (Regulation of breathing) |
| | 2.A.3 Organisms must exchange matter with the environment to grow, reproduce and maintain organization. [2.A.3.b Surface area-to-volume ratios affect a biological system’s ability to obtain necessary resources or eliminate waste products.] | The following is an illustrative example of 2.A.3.b.1: - Cells of the alveoli, p.1003 |
| 2.C.1 | Organisms use feedback mechanisms to maintain their internal environments and respond to external environmental changes. [2.C.1.a Negative feedback mechanisms maintain dynamic homeostasis for a particular condition (variable) by regulating physiological processes, returning the changing condition back to its target set point.] | The following is an illustrative example of 2.C.1.a: 
- Effect of oxygen and carbon dioxide levels on breathing rate, p.1006-1007 |
| 2.B.2 | Growth and dynamic homeostasis are maintained by the constant movement of molecules across membranes. [2.B.2.a Passive transport does not require the input of metabolic energy; the net movement of molecules is from high concentration to low concentration.] | The following is an illustrative example of 2.B.2.a: 
- Diffusion of oxygen and carbon dioxide at lungs and body tissues, p.1007-009 |
| 2.D.3 | Biological systems are affected by disruptions to their dynamic homeostasis. [2.D.3.a Disruptions at the molecular and cellular levels affect the health of the organism.] | The following is an illustrative example of 2.D.3.a: 
- Effect of carbon monoxide on gas exchange, p.1009 |
| 44.5 Respiration at High Altitudes and in Ocean Depths | 2.C.2 Organisms respond to changes in their external environments. [2.C.2.a Organisms respond to changes in their environment through behavioral and physiological mechanisms.] | The following are illustrative examples of 2.C.2.a:  
- Adaptations to high altitude, p.1010-1011  
- Adaptations to deep ocean dives, p.1011-1012 | X. No specific behavioral or physiological mechanism is required for teaching the above concept. Teachers are free to choose the mechanism that best fosters student understanding. |
| --- | --- | --- | --- |
| 4.C.1 Variation in molecular units provides cells with a wider range of functions. [4.C.1.a Variations within molecular classes provide cells and organisms with a wider range of functions.] | The following is an illustrative example of 4.C.1.a:  
- Globin genes (alpha, beta, and gamma), p.1011 | 45.0 Why It Matters | p.1016-1017  
(The anglerfish's lure) |
| 4.C.2 Environmental factors influence the expression of the genotype in an organism. [4.C.2.b An organism's adaptation to the local environment reflects a flexible response of its genome.] | The following is an illustrative example of 4.C.2.b:  
- High altitude adaptations of deer mice, p.1011 | 45.1 Feeding and Nutrition | p.1017  
(Basic nutritional requirements)  
p.1018-1019  
(Feeding strategies) |
| 2.A.2 Organisms capture and store free energy for use in biological processes. [2.A.2.b Heterotrophs capture free energy present in carbon compounds produced by other organisms.] | The following is an illustrative example of 2.A.2.b:  
- Herbivores, carnivores, and omnivores, p.1017 |  |  |
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<tr>
<td>2.A.1</td>
<td>All living systems require constant input of free energy.</td>
<td>[2.A.1.d.5 Insufficient acquired free energy versus required free energy expenditure results in loss of mass and, ultimately, the death of an organism.]</td>
<td>The following is an illustrative example of 2.A.1.d.5: - Effects of undernutrition, p.1017</td>
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<td>45.2</td>
<td>Digestive Processes</td>
<td>2.D.2 Homeostatic mechanisms reflect both common ancestry and divergence due to adaptation in different environments. [2.D.2.b Organisms have various mechanisms for obtaining nutrients and eliminating wastes.]</td>
<td>The following is an illustrative example of 2.D.2.b: - Digestive mechanisms in animals such as food vacuoles, gastrovascular cavities, one-way digestive systems, p.1019-1021</td>
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<td>45.3</td>
<td>Digestion in Humans and Other Mammals</td>
<td>4.B.2 Cooperative interactions within organisms promote efficiency in the use of energy and matter. [4.B.2.a.2 Within multicellular organisms, specialization of organs contributes to the overall functioning of the organism.]</td>
<td>The following is an illustrative example of 4.B.2.a.2: - Digestion of food, p.1025-1032</td>
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<td>2.A.3 Organisms must exchange matter with the environment to grow, reproduce and maintain organization. [2.A.3.b Surface area-to-volume ratios affect a biological system’s ability to obtain necessary resources or eliminate waste products.]</td>
<td>The following is an illustrative example of 2.A.3.b.1: - Cells of the villi and microvilli, p.1028</td>
</tr>
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</table>
| 2.B.2 | Growth and dynamic homeostasis are maintained by the constant movement of molecules across membranes. [2.B.2.a Passive transport does not require the input of metabolic energy; the net movement of molecules is from high concentration to low concentration.] | The following are illustrative examples of 2.B.2.a:  
- Absorption of water-soluble and water-insoluble nutrients at brush border of small intestine, p.1029-1031  
- Absorption of water and mineral ions in large intestine, p.1030-1032 |
|---|---|---|
| 45.4 Regulation of the Digestive Process | 4.A.4 Organisms exhibit complex properties due to interactions between their constituent parts. [4.A.4.a Interactions and coordination between organs provide essential biological activities.] | The following is an illustrative example of 4.A.4.a:  
- Stomach and small intestine, p.1032-1033 |
| | 3.D.2 Cells communicate with each other through direct contact with other cells or from a distance via chemical signaling. [3.D.2.c Signals released by one cell type can travel long distances to target cells of another cell type.] | The following are illustrative examples of 3.D.2.c:  
- Gastrin, p.1033  
- Secretin, p.1033  
- CCK, p.1033  
- GIP, p.1033 |
| | 2.C.1 Organisms use feedback mechanisms to maintain their internal environments and respond to external environmental changes. [2.C.1.a Negative feedback mechanisms maintain dynamic homeostasis for a particular condition (variable) by regulating physiological processes, returning the changing condition back to its target set point.] | The following is an illustrative example of 2.C.1.a:  
- Appetite regulation by hormones, p.1033 |
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<td>2.D.2</td>
<td>Homeostatic mechanisms reflect both common ancestry and divergence due to adaptation in different environments. [2.D.2.b Organisms have various mechanisms for obtaining nutrients and eliminating wastes.]</td>
<td>The following are illustrative examples of 2.D.2.b: - Specializations of teeth depending on diet, p.1034, 1035 - Specializations of digestive tract depending on diet, p.1035-1036</td>
<td>p.1033-1035 (Teeth) p.1035-1038 (Digestive tract elaborations, length)</td>
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<tr>
<td>2.D.1</td>
<td>All biological systems from cells and organisms to populations, communities and ecosystems are affected by complex biotic and abiotic interactions involving exchange of matter and free energy. [2.D.1.b Organism activities are affected by interactions with biotic and abiotic factors.]</td>
<td>The following is an illustrative example of 2.D.1.b: - Symbiosis between gut bacteria and ruminant, p.1036</td>
<td></td>
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<tr>
<td>2.E.3</td>
<td>Timing and coordination of behavior are regulated by various mechanisms and are important in natural selection. [2.E.3.b.4 Cooperative behavior within or between populations contributes to the survival of the populations.]</td>
<td>The following is an illustrative example of 2.E.3.b.4: - Mutualistic relationships (bacteria in digestive tracts of animals), p.1036</td>
<td></td>
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<td>4.B.2</td>
<td>Cooperative interactions within organisms promote efficiency in the use of energy and matter. [4.B.2.a.3 Interactions among cells of a population of unicellular organisms can be similar to those of multicellular organisms, and these interactions lead to increased efficiency and utilization of energy and matter.]</td>
<td>The following is an illustrative example of 4.B.2.a.3: - Differences in intestinal bacterial communities of obese and normal humans, p.1037</td>
<td></td>
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</table>
### 3.D.4 Changes in signal transduction pathways can alter cellular response. [3.D.4.a Conditions where signal transduction is blocked or defective can be deleterious, preventative or prophylactic.]

Though not required, the Molecular Revolution box on p.1034 discusses an interesting observation that shows how drugs intended to manipulate a specific signal transduction pathway -- in this case, appetite stimulation by neuropeptide Y) may not produce the intended effect or any effect at all.

### Chapter 46. Regulating the Internal Environment

#### 46.0 Why It Matters

p.1041-1042
(Effects of being stranded in the desert)

#### 46.1 Introduction to Osmoregulation and Excretion

2.D.2 Homeostatic mechanisms reflect both common ancestry and divergence due to adaptation in different environments. [2.D.2.b Organisms have various mechanisms for obtaining nutrients and eliminating wastes.]

The following is an illustrative example of 2.D.2.b: - Nitrogenous waste production and elimination in aquatic and terrestrial animals, p.1043-1044

p.1042
(Review of osmolarity)

p.1042-1043
(General features of osmoregulatory systems)

p.1044
(Types of nitrogenous waste)

#### 46.2 Osmoregulation and Excretion in Invertebrates

2.D.2 Homeostatic mechanisms reflect both common ancestry and divergence due to adaptation in different environments. [2.D.2.a Continuity of homeostatic mechanisms reflects common ancestry, while changes may occur in response to different environmental conditions.]

The following is an illustrative example of 2.D.2.a: - Osmoregulation in freshwater flatworms, annelids, and insects, p.1045-1046

p.1044-1046
(Invertebrate osmoregulation)
| 46.3 Osmoregulation and Excretion in Mammals | 4.B.2 Cooperative interactions within organisms promote efficiency in the use of energy and matter. [4.B.2.a.2 Within multicellular organisms, specialization of organs contributes to the overall functioning of the organism.] | The following is an illustrative example of 4.B.2.a.2:
- Excretion of wastes, p.1046-1052
Though not required, the Molecular Revolution box on p.1050-1051 describes how a luciferase reporter was used to identify regulatory elements involved in the osmotic stress response (aligns with LO 3.20 and 3.22). | p.1046-1052 (Mammalian excretory system) |
| 2.B.2 Growth and dynamic homeostasis are maintained by the constant movement of molecules across membranes. | The following are illustrative examples of 2.B.2.a.2:
- Glucose reabsorption, p.1048
- Na+ secretion and reabsorption, p.1048-1051
- K+ reabsorption, p.1048-1051 | |
| 4.A.4 Organisms exhibit complex properties due to interactions between their constituent parts. [4.A.4.a Interactions and coordination between organs provide essential biological activities.] | The following is an illustrative example of 4.A.4.a:
- Kidney and bladder, p.1047 | |
| 46.4 Regulation of Mammalian Kidney Function | 2.D.3 Biological systems are affected by disruptions to their dynamic homeostasis. [2.D.3.a Disruptions at the molecular and cellular levels affect the health of the organism.] | The following is an illustrative example of 2.D.3.a:
- Dehydration, p.1053-1054 | p.1052-1053 (RAAS)
p.1053-1055 (ADH)|
| 3.D.2 | Cells communicate with each other through direct contact with other cells or from a distance via chemical signaling. [3.D.2.c Signals released by one cell type can travel long distances to target cells of another cell type.] | The following are illustrative examples of 3.D.2.c:  
- Renin-angiotensin-aldosterone system, p.1053  
- Atrial natriuretic factor (ANF), p.1053  
- Antidiuretic hormone (ADH), p.1053-1055 |
| 2.C.1 | Organisms use feedback mechanisms to maintain their internal environments and respond to external environmental changes. [2.C.1.a Negative feedback mechanisms maintain dynamic homeostasis for a particular condition (variable) by regulating physiological processes, returning the changing condition back to its target set point.] | The following are illustrative examples of 2.C.1.a:  
- Blood sodium concentration, p.1052  
- Blood osmolarity, p.1053-1054  
Though not required, the Experimental Research box on p.1054-1055 describes the current model for how activation of the ADH receptor, a G-protein-coupled receptor, increases the rate of water reuptake in collecting duct epithelial cells (aligns with LO 3.33 and 3.36).|
| 2.D.2 | Homeostatic mechanisms reflect both common ancestry and divergence due to adaptation in different environments. [2.D.2.a Continuity of homeostatic mechanisms reflects common ancestry, while changes may occur in response to different environmental conditions.] | The following is an illustrative example of 2.D.2.a:  
- Osmoregulation in freshwater teleosts, marine teleosts, and elasmobranchs, p.1055-1056  
- Osmoregulation in birds and reptiles, p.1056-1057 |
| 46.6 Introduction to Thermoregulation | 2.D.1 All biological systems from cells and organisms to populations, communities and ecosystems are affected by complex biotic and abiotic interactions involving exchange of matter and free energy. [2.D.1.b Organism activities are affected by interactions with biotic and abiotic factors.] | The following is an illustrative example of 2.D.1.b: - Temperature and thermoregulatory responses, p.1057-1059 | p.1057-1058 (Modes of heat exchange) p.1058-1059 (Endothermy and ectothermy) |
|  | 2.A.1 All living systems require constant input of free energy. [2.A.1.d.1 Organisms use various strategies to regulate body temperature and metabolism.] | The following are illustrative examples of 2.A.1.d.1: - Endothermy (the use of thermal energy generated by metabolism to maintain homeostatic body temperatures), p.1058-1059 - Ectothermy (the use of external thermal energy to help regulate and maintain body temperature), p.1058-1059 | |
|  | 2.C.2 Organisms respond to changes in their external environments. [2.C.2.a Organisms respond to changes in their environment through behavioral and physiological mechanisms.] | The following is an illustrative example of 2.C.2.a: - Thermal acclimatization, p.1060 | p.1059-1060 (Thermoregulatory mechanisms of ectotherms) |
|  | 4.C.2 Environmental factors influence the expression of the genotype in an organism. | The following is an illustrative example of 4.C.2: - Antifreeze protein synthesis induced when temperatures fall below freezing, p.1060 | |
46.8 Endothermy

2.E.3 Timing and coordination of behavior are regulated by various mechanisms and are important in natural selection. [2.E.3.b.3 Behaviors in animals are triggered by environmental cues and are vital to reproduction, natural selection and survival.]

The following are illustrative examples of 2.E.3.b.3:
- Hibernation, p.1062-1063
- Estivation, p.1062-1063

p.1060-1063 (Thermoregulatory mechanisms of endotherms)

2.E.2 Timing and coordination of physiological events are regulated by multiple mechanisms. [2.E.2.b In animals, internal and external signals regulate a variety of physiological responses that synchronize with environmental cycles and cues.]

The following are illustrative examples of 2.E.2.b:
- Diurnal/nocturnal cycles, p.1062
- Seasonal responses, such as hibernation and estivation, p.1062-1063

2.D.2 Homeostatic mechanisms reflect both common ancestry and divergence due to adaptation in different environments. [2.D.2.c Homeostatic control systems in species of microbes, plants and animals support common ancestry.]

The following is an illustrative example of 2.D.2.c:
- Thermoregulation in aquatic and terrestrial animals (countercurrent exchange mechanisms), p.1063
| 2.C.1 Organisms use feedback mechanisms to maintain their internal environments and respond to external environmental changes. [2.C.1.a Negative feedback mechanisms maintain dynamic homeostasis for a particular condition (variable) by regulating physiological processes, returning the changing condition back to its target set point.] | The following is an illustrative example of 2.C.1.a: - Temperature regulation in endotherms, p.1061 |
| 2.C.2 Organisms respond to changes in their external environments. [2.C.2.a Organisms respond to changes in their environment through behavioral and physiological mechanisms.] | The following is an illustrative example of 2.C.2.a: - Nocturnal and diurnal activity: circadian rhythms, p.1062 - Shivering and sweating in humans, p.1061 |

**Chapter 47. Animal Reproduction**

47.0 Why It Matters

47.1 Animal Reproductive Modes: Asexual and Sexual Reproduction

2.A.1 All living systems require constant input of free energy. [2.A.1.d.2 Reproduction and rearing of offspring require free energy beyond that used for maintenance and growth. Different organisms use various reproductive strategies in response to energy availability.] The following is an illustrative example of 2.A.1.d.2: - Energy required for sexual and asexual reproduction strategies, p.1068-1069

p.1068 (Modes and characteristics of asexual reproduction) p.1069 (Benefits of sexual reproduction)
3.C.2 Biological systems have multiple processes that increase genetic variation. [3.C.2.c Sexual reproduction in eukaryotes involving gamete formation, including crossing-over during meiosis and the random assortment of chromosomes during meiosis, and fertilization serve to increase variation. Reproduction processes that increase genetic variation are evolutionarily conserved and are shared by various organisms.]

The following is an illustrative example of 3.C.2.c:
- p.1068-1069

X. The details of sexual reproduction cycles in various plants and animals are beyond the scope of the course and the AP Exam. However, the similarities of the processes that provide for genetic variation are relevant and should be the focus of instruction.

47.2 Cellular Mechanisms of Sexual Reproduction

- p.1069-1071 (Gametogenesis)
- p.1071-1074 (Events of fertilization)
- p.1074-1075 (Different sexual reproductive systems)
| 47.3 Sexual Reproduction in Humans | 2.C.1 Organisms use feedback mechanisms to maintain their internal environments and respond to external environmental changes. [2.C.1.a Negative feedback mechanisms maintain dynamic homeostasis for a particular condition (variable) by regulating physiological processes, returning the changing condition back to its target set point.] [2.C.1.b 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.] | p.844-848 | The following are illustrative examples of 2.C.1.a: - Inhibitory effect of low estrogen levels on GnRH secretion, p.1077 - Inhibitory effect of testosterone on GnRH and LH secretion, p.1080 - Inhibitory effect of inhibin on FSH secretion, p.1080 The following is an illustrative example of 2.C.1.b: - Stimulatory effect of high estrogen levels on GnRH secretion, p.1077 | p.1075-1078 (Human female anatomy and hormonal regulation) p.1078-1081 (Human male anatomy and hormonal regulation) p.1081-1083 (Copulation and fertilization) p.1083 (Sources of infertility) |
| 3.D.1 Cell communication processes share common features that reflect a shared evolutionary history. [3.D.1.d In multicellular organisms, signal transduction pathways coordinate the activities within individual cells that support the function of the organism as a whole.] | | The following is an illustrative example of 3.D.1.d: - Use of sex hormones to trigger reproduction-related pathways | |
| 3.D.2 | Cells communicate with each other through direct contact with other cells or from a distance via chemical signaling. [3.D.2.c Signals released by one cell type can travel long distances to target cells of another cell type.] |
| 2.E.2 | Timing and coordination of physiological events are regulated by multiple mechanisms. [2.E.2.b In animals, internal and external signals regulate a variety of physiological responses that synchronize with environmental cycles and cues.] |
| 2.D.3 | Biological systems are affected by disruptions to their dynamic homeostasis. [2.D.3.a Disruptions at the molecular and cellular levels affect the health of the organism.] |
| 3.D.4 | Changes in signal transduction pathways can alter cellular response. [3.D.4.a Conditions where signal transduction is blocked or defective can be deleterious, preventative or prophylactic.] |

### 47.4 Methods for Preventing Pregnancy: Contraception

3.D.4 Changes in signal transduction pathways can alter cellular response. [3.D.4.a Conditions where signal transduction is blocked or defective can be deleterious, preventative or prophylactic.]

48.0 Why It Matters

Chapter 48. Animal Development

48.0 Why It Matters

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<th>p.1090-1093 (Overview of developmental stages and processes)</th>
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<td>48.2 Major Patterns of Cleavage and Gastrulation</td>
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<td>X. Names of the specific stages of embryonic development are beyond the scope of the course and the AP Exam.</td>
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<td>48.3 From Gastrulation to Adult Body Structures: Organogenesis</td>
<td>2.E.1 Timing and coordination of specific events are necessary for the normal development of an organism, and these events are regulated by a variety of mechanisms. [2.E.1.c Programmed cell death (apoptosis) plays a role in the normal development and differentiation.]</td>
<td>p.1099-1100</td>
<td>The following are illustrative examples of 2.E.1.c: - Morphogenesis of fingers and toes, p.1099 - C. elegans development, p.1099-1100</td>
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<td>48.4 Embryonic Development of Humans and Other Mammals</td>
<td>2.E.2 Timing and coordination of physiological events are regulated by multiple mechanisms. [2.E.2.b In animals, internal and external signals regulate a variety of physiological responses that synchronize with environmental cycles and cues.]</td>
<td>The following is an illustrative example of 3.B.2.a: - Expression of the SRY gene triggers the male sexual development pathway in animals, p.1104-1105</td>
<td>p.1101-1105 (Stages and timing of human embryonic development)</td>
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<tr>
<td>2.C.1 Organisms use feedback mechanisms to maintain their internal environments and respond to external environmental changes. [2.C.1.b 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.]</td>
<td>The following is an illustrative example of 2.C.1.b: - Prostaglandins and the onset of birth in humans, p.1104</td>
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<th>48.5 The Cellular Basis of Development</th>
<th>3.B.2 A variety of intercellular and intracellular signal transmissions mediate gene expression. [3.B.2.b Signal transmission within and between cells mediates cell function.]</th>
<th>The following is an illustrative example of 3.B.2.b: - Morphogens stimulate cell differentiation and development, p.1108, 1110 Though not required, the Experimental Research box on p.1111 describes the classic Spemann and Mangold frog embryo transplantation experiment demonstrating the inducer activity of the blastopore lip (aligns with LO 3.34).</th>
<th>p.1105-1108 (Cell division and movement during development) p.1108 (Fate mapping) p.1108-1110 (Induction and differentiation)</th>
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<td>4.A.3 Interactions between external stimuli and regulated gene expression result in specialization of cells, tissues and organs. [4.A.3.b Structural and functional divergence of cells in development is due to expression of genes specific to a particular tissue or organ type.]</td>
<td>The following is an illustrative example of 4.A.3.b: - Lens cells produce mainly crystallin, p.1110</td>
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<td>3.D.2 Cells communicate with each other through direct contact with other cells or from a distance via chemical signaling. [3.D.2.a Cells communicate by cell-to-cell contact.]</td>
<td>The following is an illustrative example of 3.D.2.a: - Cell adhesion molecules and cadherins in development, p.1108</td>
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Chapter 49. Ecology and the Biosphere
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<th>4.B.4 Distribution of local and global ecosystems changes over time. [4.B.4.b Geological and meteorological events impact ecosystem distribution.]</th>
<th>The following is an illustrative example of 4.B.4.b: - El Nino, p.1116-1117</th>
<th>p.1116-1117 (El Nino and La Nina)</th>
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<td>p.1117-1118 (Levels of ecological study)</td>
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<td>49.2 Environmental Diversity of the Biosphere</td>
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<td>p.1118-1121 (Global climate patterns) p.1121-1122 (Local and regional climate determinants)</td>
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<td>49.3 Organismal Responses to Environmental Variation and Climate Change</td>
<td>1.A.2 Natural selection acts on phenotypic variations in populations. [1.A.2.a Environments change and act as selective mechanism on populations.]</td>
<td>The following is an illustrative example of 1.A.2.a: - Flowering time in relation to global climate change, p.1124-1125</td>
<td>p.1124-1125 (Climate change)</td>
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<td>4.C.2 Environmental factors influence the expression of the genotype in an organism. [4.C.2.b An organism’s adaptation to the local environment reflects a flexible response of its genome.]</td>
<td>The following is an illustrative example of 4.C.2.b: - Flowering time in relation to global climate change, p.1124-1125</td>
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<tr>
<td>2.D.1</td>
<td>All biological systems from cells and organisms to populations, communities and ecosystems are affected by complex biotic and abiotic interactions involving exchange of matter and free energy. [2.D.1.c The stability of populations, communities and ecosystems is affected by interactions with biotic and abiotic factors.]</td>
<td>The following is an illustrative example of 2.D.1: - Effect of global climate change on species distributions, p.1125</td>
<td></td>
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<td>2.E.3</td>
<td>Timing and coordination of behavior are regulated by various mechanisms and are important in natural selection. [2.E.3.b.3 Behaviors in animals are triggered by environmental cues and are vital to reproduction, natural selection and survival.]</td>
<td>The following is an illustrative example of 2.E.3.b.3: - Daily torpor in small birds, p.1124</td>
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<tr>
<td>2.E.2</td>
<td>Timing and coordination of physiological events are regulated by multiple mechanisms. [2.E.2.b In animals, internal and external signals regulate a variety of physiological responses that synchronize with environmental cycles and cues.]</td>
<td>The following are illustrative examples of 2.E.2.b: - Daily torpor in small birds, p.1124 - High altitude lizards bask more in the sun, p.1124</td>
<td></td>
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</table>
| 49.4 Terrestrial Biomes | 4.A.6 Interactions among living systems and with their environment result in the movement of matter and energy. [4.A.6.g Many adaptations of organisms are related to obtaining and using energy and matter in a particular environment.] | The following are illustrative examples of 4.A.6.g:  
- Epiphytes in tropical forests, p.1127  
- CAM photosynthesis and flowering time in deserts, p.1125  
- Dormancy and fire resistance of plants in chaparral, p.1125  
- Needle-shaped leaves of evergreens in boreal forests, p.1131  
- Quick flowering time and small size of plants in tundra, p.1132-1133 | p.1125-1132  
(Survey of terrestrial biomes) |
| --- | --- | --- | --- |
| 49.5 Freshwater Environments | 2.D.1 All biological systems from cells and organisms to populations, communities and ecosystems are affected by complex biotic and abiotic interactions involving exchange of matter and free energy. [2.D.1.c The stability of populations, communities and ecosystems is affected by interactions with biotic and abiotic factors.] | The following is an illustrative example of 3.B.2.b:  
- Algal blooms in previously oligotrophic lakes, p.1134 | p.1132  
(Streams)  
p.1133-1134  
(Lakes) |
| 49.6 Marine Environments | 4.A.6 Interactions among living systems and with their environment result in the movement of matter and energy. [4.A.6.g Many adaptations of organisms are related to obtaining and using energy and matter in a particular environment.] | The following are illustrative examples of 4.A.6.g:  
- Coral reefs in nutrient-poor tropical waters, p.1137 | p.1135-1136  
(Estuaries)  
p.1137  
(Intertidal zone)  
p.1138  
(Continental shelves)  
p.1138-1139  
(Open ocean) |
| 50.0 Why It Matters | Biological systems are affected by disruptions to their dynamic homeostasis. [2.D.3.b Disruptions to ecosystems impact the dynamic homeostasis or balance of the ecosystem.] | The following is an illustrative example of 2.D.3.b: - European rabbit as invasive species in Australia, p.1143 | p.1143-1144 (European rabbit population in Australia) |
| 4.B.4 Distribution of local and global ecosystems changes over time. [4.B.4.a Introduction of new diseases can devastate native species.] | The following is an illustrative example of 4.B.4.a: - European rabbit as invasive species in Australia, p.1143 |
| 4.A.6 Interactions among living systems and with their environment result in the movement of matter and energy [4.A.6. Human activities impact ecosystems on local, regional and global scales.] | The following is an illustrative example of 4.A.6.f: - Release of myxoma virus into exotic European rabbit population in Australia, p.1143 |
| 50.1 Population Characteristics | | p.1144-1146* (Population metrics) p.1145 (Mark-recapture method) |
| 50.2 Demography | Communities are composed of populations of organisms that interact in complex ways. [4.A.5.c Mathematical models and graphical representations are used to illustrate population growth patterns and interactions.] | p.1146-1149 |
| 50.3 The Evolution of Life Histories | 2.A.1 All living systems require constant input of free energy. [2.A.1.d Organisms use free energy to maintain organization, grow and reproduce.] | p.1149-1150 | The following is an illustrative example of 2.A.1.d: - Energy budget variations between coho salmon, oaks, and red deer, p.1149-1150 Though not required, the Basic Research box on p.1150-1151 describes an experiment demonstrating the effect of predatory fish on the life history of guppies (aligns with LO 1.2 and 4.26). | p.1150-1151 (Factors that affect life history) |
| 50.4 Models of Population Growth | 4.A.5 Communities are composed of populations of organisms that interact in complex ways. [4.A.5.c.1 Reproduction without constraints results in the exponential growth of a population.] [4.A.5.c.2 A population can produce a density of individuals that exceeds the system's resource availability.] | p.1152-1154 |  |  |
|  | 4.A.6 Interactions among living systems and with their environment result in the movement of matter and energy. [4.A.6.e.1 Competition for resources and other factors limits growth and can be described by the logistic model.] | p.1154-1155 |  |  |
| 50.5 Population Dynamics | 4.A.5 Communities are composed of populations of organisms that interact in complex ways. [4.A.5.c.1 As limits to growth due to density-dependent and density-independent factors are imposed, a logistic growth model generally ensues.] [4.A.5.b Mathematical or computer models are used to illustrate and investigate population interactions within and environmental impacts on a community.] | p.1156-1158 | The following is an illustrative example of 4.A.5.b:  
- Predator/prey relationships model and field data, p.1161-1162  
- Graphical representation of field data (demonstrating density-dependent interactions between lizards and spiders in the Bahamas), p.1159 |
| --- | --- | --- | --- |
| 4.A.6 Interactions among living systems and with their environment result in the movement of matter and energy. [4.A.6.e.2 Competition for resources, territoriality, health, predation, accumulation of wastes and other factors contribute to density-dependent population regulation.] [4.A.6.f. Human activities impact ecosystems on local, regional and global scales.] | p.1156-1162 | The following is an illustrative example of 4.A.6.f:  
- Habitat fragmentation and the bay checkerspot butterfly, p.1160-1161 |
| 50.6 Human Population Growth | 4.A.5 Communities are composed of populations of organisms that interact in complex ways. [4.A.5.c.4 Demographics data with respect to age distributions and fecundity can be used to study human populations.] | p.1162-1165 |  |
## Chapter 51. Population Interactions and Community Ecology

### 51.0 Why It Matters

**p.1169-1170**

(Cowbirds and brood parasitism)

### 51.1 Population Interactions

**4.B.3** Interactions between and within populations influence patterns of species distribution and abundance. [4.B.3.a Interactions between populations affect the distributions and abundance of populations.]

**p.1170-1177**

X. Specific symbiotic interactions are beyond the scope of the course and the AP Exam.

**3.E.1** Individuals can act on information and communicate it to others. [3.E.1.b.1 Living systems have a variety of signal behaviors or cues that produce changes in the behavior of other organisms and can result in differential reproductive success.] [3.E.1.b.2 Animals use visual, audible, tactile, electrical and chemical signals to indicate dominance, find food, establish territory and ensure reproductive success.]

The following is an illustrative example of 3.E.1.b.1:
- Herbivory responses, p.1171

The following is an illustrative example of 3.E.1.b.2:
- Predator warnings, p.1171-1173

**2.E.3** Timing and coordination of behavior are regulated by various mechanisms and are important in natural selection. [2.E.3.b.4 Cooperative behavior within or between populations contributes to the survival of the populations.]

The following is an illustrative example of 2.E.3.b.4:
- Niche and resource partitioning, p.1174-1176
| 2.A.1 | All living systems require constant input of free energy.  
[2.A.1.d Organisms use free energy to maintain organization, grow and reproduce.]  
[2.A.1.f Changes in free energy availability can result in disruptions to an ecosystem.] | The following is an illustrative example of 2.A.1.d:  
- Optimal foraging theory, p.1171  
- Distributions of two barnacle species (and the effect of removing one of them), p.1175  
- Differences in population dynamics in pure versus mixed cultures of *Paramecium*, p.1173 |
|---|---|---|
| 51.2 The Nature of Ecological Communities | 4.A.5 Communities are composed of populations of organisms that interact in complex ways.  
[4.A.5.a The structure of a community is measured and described in terms of species composition and species diversity.] | p.1179-1181 (Interactive and individualistic community hypotheses) |
| 51.3 Community Characteristics | 4.A.6 Interactions among living systems and with their environment result in the movement of matter and energy.  
[4.A.6.c Organisms within food webs and food chains interact.] | p.1181-1182 |
### 51.4 Effects of Population Interactions on Community Characteristics

4.C.4 The diversity of species within an ecosystem may influence the stability of the ecosystem. [4.C.4.b Keystone species, producers, and essential abiotic and biotic factors contribute to maintaining the diversity of an 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.]

p.1183

### 51.5 Effects of Disturbance on Community Characteristics

4.B.3 Interactions between and within populations influence patterns of species distribution and abundance. [4.B.3.c Species-specific and environmental catastrophes, geological events, the sudden influx/depletion of abiotic resources or increased human activities affect species distribution and abundance.]

p.1184-1186 The following are illustrative examples of 4.B.3.c:  
- Effect of cyclones on coral reef communities, p.1184  
- Effect of heavy rain on stream communities, p.1186

### 51.6 Ecological Succession: Responses to Disturbance

p.1186-1189 (Primary and secondary succession)

### 51.7 Variations in Species Richness among Communities

p.1189-1193 (Biogeography and high species richness)

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Chapter 52. Ecosystems

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<th>52.1 Modeling Ecosystem Processes</th>
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<td>4.A.6 Interactions among living systems and with their environment result in the movement of matter and energy. [4.A.6.e Models allow the prediction of the impact of change in biotic and abiotic factors.]</td>
<td>p.1199-1201</td>
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<td>4.A.6 Interactions among living systems and with their environment result in the movement of matter and energy.</td>
<td>p.1202-1207</td>
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<td>2.D.1 All biological systems from cells and organisms to populations, communities and ecosystems are affected by complex biotic and abiotic interactions involving exchange of matter and free energy. [2.D.1.c The stability of populations, communities and ecosystems is affected by interactions with biotic and abiotic factors.]</td>
<td>The following is an illustrative example of 2.D.1.c: - Sunlight and nutrient availability, p.1202 - Food web for an aquatic ecosystem (Silver Springs, Florida), p.1205</td>
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<td>2.A.1 All living systems require constant input of free energy. [2.A.1.e Changes in free energy availability can result in changes in population size.] [2.A.1.f Changes in free energy availability can result in disruptions to an ecosystem.]</td>
<td>p.1206-1207</td>
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<td>52.3 Nutrient Cycling in Ecosystems</td>
<td>4.A.6 Interactions among living systems and with their environment result in the movement of matter and energy. [4.A.6.a Energy flows, but matter is recycled.]</td>
<td>p.1210-1215 Though not required, the Applied Research box on p.1208 describes the effects of the biological magnification of DDT (aligns with LO 4.21). Also not required, the Basic Research box on p.1211 describes an experiment designed to measure the effects of deforestation on a New Hampshire watershed (also aligns with LO 4.21).</td>
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<td>2.A.3 Organisms must exchange matter with the environment to grow, reproduce and maintain organization. [2.A.3.a.1 Carbon moves from the environment to organisms where it is used to build carbohydrates, proteins, lipids or nucleic acids. Carbon is used in storage compounds and cell formation in all organisms.] [2.A.3.a.2 Nitrogen moves from the environment to organisms where it is used in building proteins and nucleic acids. Phosphorus moves from the environment to organisms where it is used in nucleic acids and certain lipids.]</td>
<td>p.1212-1215</td>
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<td>52.4 Human Disruption of Ecosystem Processes</td>
<td>4.A.6 Interactions among living systems and with their environment result in the movement of matter and energy. [4.A.6.f Human activities impact ecosystems on local, regional and global scales.]</td>
<td>p.1215-1218</td>
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<td>4.B.4 Distribution of local and global ecosystems changes over time. [4.B.4.a Human impact accelerates change at local and global levels.]</td>
<td>p.1215-1218</td>
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<td>2.D.3 Biological systems are affected by disruptions to their dynamic homeostasis. [2.D.3.b Disruptions to ecosystems impact the dynamic homeostasis or balance of the ecosystem.]</td>
<td>The following is an illustrative example of 2.D.3.b: - Human impact, p.1215-1218</td>
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<td>2.D.3 Biological systems are affected by disruptions to their dynamic homeostasis. [2.D.3.b Disruptions to ecosystems impact the dynamic homeostasis or balance of the ecosystem.]</td>
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<tr>
<td>4.B.4 Distribution of local and global ecosystems changes over time. [4.B.4.a Human impact accelerates change at local and global levels.]</td>
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<td>4.A.6 Interactions among living systems and with their environment result in the movement of matter and energy. [4.A.6.f Human activities impact ecosystems on local, regional and global scales.]</td>
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<td>4.B.3 Interactions between and within populations influence patterns of species distribution and abundance. [4.B.3.c Species-specific and environmental catastrophes, geological events, the sudden influx/depletion of abiotic resources or increased human activities affect species distribution and abundance.]</td>
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<td>The following are illustrative examples of 4.B.3.c: - Overfishing of haddock and yellowtail flounder off the coast of Newfoundland, p.1224 - Loss of spawning grounds for Chinook salmon due to damming, p.1226</td>
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<td>53.2 Specific Threats to Biodiversity</td>
<td>2.D.3 Biological systems are affected by disruptions to their dynamic homeostasis. [2.D.3.b Disruptions to ecosystems impact the dynamic homeostasis or balance of the ecosystem.]</td>
<td>4.B.4 Distribution of local and global ecosystems changes over time. [4.B.4.a Human impact accelerates change at local and global levels.]</td>
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- Habitat fragmentation, p.1226-1227
- Pollution, p.1227-1228
- Introduction of exotic species, p.1228-1229
| 4.B.3 | Interactions between and within populations influence patterns of species distribution and abundance. [4.B.3.c Species-specific and environmental catastrophes, geological events, the sudden influx/depletion of abiotic resources or increased human activities affect species distribution and abundance.] | The following are illustrative examples of 4.B.3.c: - Habitat fragmentation makes songbird nests more vulnerable to predation, p.1227 - Disappearance of vultures in South Asia due to use of synthetic drugs in agriculture, p.1228 - Spread of European starling across North America and effect on native species, p.1229 - Spread of kudzu across United States, p.1229 - Amphibian extinctions due to chytrid pathogen, p.1230 |

| 53.3 The Value of Biodiversity | p.1231-1232 (How biodiversity benefits us) |
| 53.4 Where Biodiversity Is Most Threatened | p.1232-1233 (Conservation hotspots and trigger sites) |
| 53.5 Conservation Biology: Principles and Theory | 4.C.3 The level of variation in a population affects population dynamics. [4.C.3.a Population ability to respond to changes in the environment is affected by genetic diversity. Species and populations with little genetic diversity are at risk for extinction.] | The following is an illustrative example of 4.C.3.a: - Whooping crane bottleneck and effects, p.1234 |
| 4.C.4 | The diversity of species within an ecosystem may influence the stability of the ecosystem. [4.C.4.a Natural and artificial ecosystems with fewer component parts and with little diversity among the parts are often less resilient to changes in the environment.] [4.C.4.b Keystone species, producers, and essential abiotic and biotic factors contribute to maintaining the diversity of an 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.] |
| The following is an illustrative example of 4.C.4.a: |
| - Species/area relationship and sensitivity of small habitat patches, p.1236-1237 |
| - Effect of landscape corridors on species richness, p.1237-1238 |
| The following is an illustrative example of 4.C.4.b: |
| - Sea otter as keystone species, p.1235 |


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| 54.0 Why It Matters | p.1245 (Species-specific birdsong) |</p>
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<th>p.1246-1247</th>
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<td>4.C.2 Environmental factors influence the expression of the genotype in an organism. [4.C.2.a Environmental factors influence many traits both directly and indirectly.]</td>
<td>The following is an illustrative example of 4.C.2.a: - Learned and instinctive components of behavior, p.1246-1247</td>
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<td>54.2 Instinctive Behaviors</td>
<td>2.E.3 Timing and coordination of behavior are regulated by various mechanisms and are important in natural selection. [2.E.3.b.3 Behaviors in animals are triggered by environmental cues and are vital to reproduction, natural selection and survival.] 3.E.1 Individuals can act on information and communicate it to others. [3.E.1.c.1 Natural selection favors innate and learned behaviors that increase survival and reproductive fitness.]</td>
<td>p.1247-1249</td>
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<td>The following is an illustrative example of 2.E.3.b.3 and 3.E.1.c.1: - Chick pecking on herring gull beak causes regurgitation response in parents, p.1247</td>
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</table>
| 54.3 Learned Behaviors | 2.E.3 Timing and coordination of behavior are regulated by various mechanisms and are important in natural selection. [2.E.3.b.3 Behaviors in animals are triggered by environmental cues and are vital to reproduction, natural selection and survival.] | 2.E.3.b.3 | The following are illustrative examples of 2.E.3.b.3 and 3.E.1.c.1:  
- Classical conditioning, p.1250-1251  
- Operant conditioning, p.1251  
- Habituation, p.1251 |
| | 3.E.1 Individuals can act on information and communicate it to others. [3.E.1.c.1 Natural selection favors innate and learned behaviors that increase survival and reproductive fitness.] | 3.E.1.c.1 |  |
| 54.4 Neurophysiological Control of Behavior | 3.D.1 Cell communication processes share common features that reflect a shared evolutionary history. [3.D.1.d In multicellular organisms, signal transduction pathways coordinate the activities within individual cells that support the function of the organism as a whole.] | 3.D.1.d | The following are illustrative examples of 3.D.1.d:  
- Role of hormones in development of the higher vocal center in songbirds, p.1253  
- Role of GnRH and testosterone in male territorial behavior in cichlids, p.1253-1254 |
| 54.5 Hormones and Behavior | | | |
### 54.6 Nervous System Anatomy and Behavior

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<tr>
<th>3.E.2</th>
<th>Animals have nervous systems that detect external and internal signals, transmit and integrate information, and produce responses. [3.E.2.d Different regions of the vertebrate brain have different functions.]</th>
<th>The following is an illustrative example of 3.E.2.d: - Tactile processing centers in star-nosed mole, p.1257-1258</th>
<th>p.1255-1258 (Nervous system specializations underlying behavioral adaptations)</th>
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<td>3.E.1</td>
<td>Individuals can act on information and communicate it to others. [3.E.1.a Organisms exchange information with each other in response to internal changes and external cues, which can change behavior.]</td>
<td>The following are illustrative examples of 3.E.1.a: - Escape behavior in black field cricket in response to bat echolocation, p.1255-1256 - Escape behavior of fiddler crabs in response to specific visual stimuli, p.1256-1257</td>
<td>p.1255-1258 (Escape behavior)</td>
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### Chapter 55. The Ecology and Evolution of Animal Behavior

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<th>p.1262 (White-crowned sparrow migration)</th>
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<td>55.1</td>
<td>Migration and Wayfinding</td>
<td>The following are illustrative examples of 3.E.1.a and 3.E.1.c.1: - Female digger wasp uses visual cues to navigate, p.1263-1264 - Migratory behavior, p.1266-1267</td>
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3.E.1 Individuals can act on information and communicate it to others. [3.E.1.a Organisms exchange information with each other in response to internal changes and external cues, which can change behavior.]
### 55.2 Habitat Selection and Territoriality

<table>
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<th>2.E.3</th>
<th>Timing and coordination of behavior are regulated by various mechanisms and are important in natural selection. [2.E.3.b.3 Behaviors in animals are triggered by environmental cues and are vital to reproduction, natural selection and survival.]</th>
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<tbody>
<tr>
<td>3.E.1</td>
<td>Individuals can act on information and communicate it to others. [3.E.1.c.1 Natural selection favors innate and learned behaviors that increase survival and reproductive fitness.]</td>
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The following is an illustrative example of 2.E.3.b.3 and 3.E.1.c.1:
- Innate preferences during habitat selection, p.1267
- Territoriality, p.1267-1268

### 55.3 The Evolution of Communication

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<th>3.E.1</th>
<th>Individuals can act on information and communicate it to others. [3.E.1.a Organisms exchange information with each other in response to internal changes and external cues, which can change behavior.] [3.E.1.b Communication occurs through various mechanisms.] [3.E.1.c Responses to information and communication of information are vital to natural selection and evolution.]</th>
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The following are illustrative examples of 3.E.1.a:
- Pheromone release by female silkworm moths, p.1269
- Bioluminescence in fireflies and fish, p.1268
- Electrical signals from knifefish, p.1269
- Honeybee dance, p.1269-1270
- Raven call, p.1270-1271

X. The details of the various communications and community behavioral systems are beyond the scope of the course and the AP Exam.
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<th>55.4 The Evolution of Reproductive Behavior and Mating Systems</th>
<th>3.E.1 Individuals can act on information and communicate it to others. [3.E.1.a Organisms exchange information with each other in response to internal changes and external cues, which can change behavior.] [3.E.1.b Communication occurs through various mechanisms.] [3.E.1.c Responses to information and communication of information are vital to natural selection and evolution.]</th>
<th>The following are illustrative examples of 3.E.1.a: - Courtship displays of the northern elephant seal, p.1271 - Lekking grouses, p.1271-1272 - Peacock ornamentation and mate selection, p.1272</th>
<th>p.1271-1274 (Sexual selection and parental behavior)</th>
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<td>55.5 The Evolution of Social Behavior</td>
<td>1.B.2 Phylogenetic trees and cladograms are graphical representations (models) of evolutionary history that can be tested. [1.B.2.a Phylogenetic trees and cladograms can represent traits that are either derived or lost due to evolution.]</td>
<td>The following is an illustrative example of 1.B.2.a: - Nest-building behavior in swallows and martins, p.1273-1274</td>
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<td>2.E.3 Timing and coordination of behavior are regulated by various mechanisms and are important in natural selection. [2.E.3.b.4 Cooperative behavior within or between populations contributes to the survival of the populations.]</td>
<td>The following are illustrative examples of 2.E.3.b.4: - Cooperative defensive behavior among prey species, p.1274 - Reciprocal altruism, p.1277 - Eusocial insect social structure, p.1277-1278</td>
<td>p.1274-1277</td>
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<td>4.C.3 The level of variation in a population affects population dynamics.</td>
<td>The following is an illustrative example of 4.C.3: - Honeybee colony structure (low genetic diversity, high cooperation), p.1277-1278</td>
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