Enduring Understanding 2.A: Growth, reproduction and maintenance of the organization of living systems require free energy and matter.

Essential Knowledge 2.A.3: Organisms must exchange matter with the environment to grow, reproduce and maintain organization.

a. Molecules and atoms from the environment are necessary to build new molecules.
   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. 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.
   3. Living systems depend on properties of water that result from its polarity and hydrogen bonding.
      • Cohesion
      • Adhesion
      • High specific heat capacity
      • Universal solvent supports reactions
      • Heat of vaporization
      • Heat of fusion
      • Water’s thermal conductivity

b. Surface area-to-volume ratios affect a biological system’s ability to obtain necessary resources of to eliminate waste products.
   1. As cells increase in volume, the relative surface area decreases and demand for material resources increases; more cellular structures are necessary to adequately exchange materials and energy with the environment. These limitations restrict cell size.
      • Root hairs
      • Cells of the alveoli
      • Cells of the villi
      • Microvilli
   2. The surface area of the plasma membrane must be large enough to adequately exchange materials; smaller cells have a more favorable surface area-to-volume ratio for exchange of materials with the environment.
Enduring Understanding 2.B: Growth, reproduction and dynamic homeostasis require that cells create and maintain internal environments that are different from their external environments.

Essential Knowledge 2.B.1: Cell membranes are selectively permeable due to their structure.

a. Cell membranes separate the internal environment of the cell from the external environment.

b. Selectively permeable is a direct consequence of membrane structure, as described by the fluid mosaic model.

1. Cell membranes consist of a structural framework of phospholipid molecules, embedded proteins, cholesterol, glycoproteins and glycolipids.

2. Phospholipids give the membrane both hydrophilic and hydrophobic properties. The hydrophilic phosphate portions of the phospholipids are oriented toward the aqueous external or internal environments, while the hydrophobic fatty acid portions face each other within the interior of the membrane itself.

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

4. Small, uncharged polar molecules and small nonpolar molecules, such as N₂, freely pass across the membrane. Hydrophilic substances such as large polar molecules and ions move across the membrane through embedded channel and transport proteins. Water moves across membranes and through channel proteins called aquaporins.

c. Cell walls provide a structural boundary, as well as a permeability barrier for some substances to the internal environments.

1. Plant cell walls are made of cellulose and are external to the cell membrane.

2. Other examples are cells walls of prokaryotes and fungi.

Essential Knowledge 2.B.2: Growth and dynamic homeostasis are maintained by the constant movement of molecules across membranes.

a. Passive transport does not require the input of metabolic energy; the net movement of molecules is from high concentration to low concentration.

1. Passive transport plays a primary role in the import of resources and the export of wastes.

2. Membrane proteins play a role in facilitated diffusion of charged and polar molecules through a membrane.

3. External environments can be hypotonic, hypertonic or isotonic to internal environments of cells.
b. **Active transport requires free energy to move molecules from regions of low concentration to regions of high concentration.**

1. Active transport is a process where free energy (often provided by ATP) is used by proteins embedded in the membrane to “move” molecules and/or ions across the membrane and to establish and maintain concentration gradients.

2. Membrane proteins are necessary for active transport.

c. **The processes of endocytosis and exocytosis move large molecules from the external environment to the internal environment and vice versa, respectively.**

1. In exocytosis, internal vesicles fuse with the plasma membrane to secrete large macromolecules out of the cell.

2. In endocytosis, the cell takes in macromolecules and particulate matter by forming new vesicles derived from the plasma membrane.

**Essential Knowledge 2.B.3:** Eukaryotic cells maintain internal membranes that partition the cell into specialized regions.

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

b. **Membranes and membrane-bound organelles in eukaryotic cells localize (compartmentalize) intracellular metabolic processes and specific enzymatic reactions.**
   - Endoplasmic reticulum
   - Mitochondria
   - Chloroplasts
   - Golgi
   - Nuclear envelope

c. **Archaea and Bacteria generally lack internal membranes and organelles and have a cell wall.**

**Big Idea 4**

**Enduring Understanding 4.A: Interactions within biological systems lead to complex properties.**

**Essential Knowledge 4.A.1:** The subcomponents of biological molecules and their sequence determine the properties of that molecule.

a. **Structure and function of polymers are derived from the way their monomers are assembled.**

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

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.

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.

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. Illustrative examples include: cellulose versus starch.

b. Directionality influences structure and function of the polymer.

1. Nucleic acids have ends, defined by the 3’ and 5’ carbons of the sugar in the nucleotide, that determine the direction in which complementary nucleotides are added during DNA synthesis and the direction in which transcription occurs (from 5’ to 3’).

2. Proteins have an amino (NH\textsubscript{2}) end 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.

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.

**Essential Knowledge 4.A.2: The structure and function of subcellular components, and their interactions, provide essential cellular processes.**

a. Ribosomes are small, universal structures comprised of two interacting parts: ribosomal RNA and protein. In a sequential manner, these cellular components interact to become the site of protein synthesis where the translation of the genetic instructions yields specific polypeptides.

b. Endoplasmic reticulum (ER) occurs in two forms: smooth and rough.

1. Rough endoplasmic reticulum functions to compartmentalized the cell, serves as mechanical support, provides site-specific protein synthesis with membrane-bound ribosomes and plays a role in intracellular transport.
2. In most cases, smooth ER synthesizes lipids.

c. **The Golgi complex is a membrane-bound structure that consists of a series of flattened membrane sacs (cisternae).**

   1. Functions of the Golgi include synthesis and packaging of materials (small molecules) for transport (in vesicles), and production of lysosomes.

d. **Mitochondria specialize in energy capture and transformation.**

   1. Mitochondria have a double membrane that allows compartmentalization within the mitochondria and is important to its function.

   2. The outer membrane is smooth, but the inner membrane is highly convoluted, forming folds called cristae.

   3. Cristae contain enzymes important to ATP production; cristae also increase the surface area for ATP production.

e. **Lysosomes are membrane-enclosed sacs that contain hydrolytic enzymes, which are important in intracellular digestion, the recycling of a cell’s organic materials and programmed cell death (apoptosis). Lysosomes carry out intracellular digestion in a variety of ways.**

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.**

g. **Chloroplasts are specialized organelles found in algae and higher plants that capture energy through photosynthesis.**

   1. The structure and function relationship in the chloroplast allows cells to capture the energy available in sunlight and convert it to chemical bond energy via photosynthesis.

   2. Chloroplasts contain chlorophylls, which are responsible for the green color of a plant and are the key light-trapping molecules in photosynthesis. There are several types of chlorophyll, but the predominant form in plants is chlorophyll a.

   3. Chloroplasts have a double outer membrane that creates a compartmentalized structure, which supports its function. Within the chloroplasts are membrane-bound structures called thylakoids. Energy-capturing reactions housed in the thylakoids are organized in stacks, called “grana,” to produce ATP and NADPH$_2$, which fuel carbon-fixing reactions in the Calvin-Benson cycle. Carbon fixation occurs in the stroma, where molecules of CO$_2$ are converted to carbohydrates.