**Biochemistry Student Objectives**

**<u>Enduring understanding 2.A: Growth, reproduction and maintenance of the organization of living systems require free energy and matter.</u>**

**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.

*Evidence of student learning is a demonstrated understanding of each of the following:*

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.

3. Phosphorus moves from the environment to organisms where it is used in nucleic acids and certain lipids.

student objectives:

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

*To demonstrate understanding of this concept, be able to explain water's:*

- Cohesion
- Adhesion
- High specific heat capacity
- Universal solvent supports reactions
- Heat of vaporization
- Heat of fusion
- thermal conductivity

**student objectives:**

- **why is matter necessary for biological systems?**
- **explain the uses of carbon, hydrogen, oxygen, nitrogen, phosphorous and sulfur in biological systems.**
- **Diagram the exchange of matter between organisms and the environment.**
- **what function does nitrogen serve in proteins? In nucleic acids?**
- **what function does phosphorus serve in nucleic acids? In phospholipids?**
- **Why do biological systems need water?**
- **How does the structure of a water molecule relate to its function(s)?**
- **How does the polarity of water lead to the emergence of unique properties in liquid water?**

**<u>Enduring understanding 4.A: Interactions within biological systems lead to complex properties.</u>**

**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.

*Evidence of student learning is a demonstrated understanding of each of the following:*

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.

*Evidence of student learning is a demonstrated understanding of each of the following:*

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 ($NH_2$) 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.

**student objectives:**

- **Compare the synthesis and decomposition of biological macromolecules.**
- **Where does the energy needed to drive the synthesis of biological macromolecules come from?**
- **How does the structure of <polysaccharides, proteins, nucleic acids> influence the function of those molecules?**
- **How does the structure of DNA contribute to it's roles in protein synthesis and heritability?**
- **Why is DNA a good molecule for information storage?**
- **How do the differences in the structure of DNA and RNA contribute to the difference in the functions of those molecules?**
- **Explain how the sequence of amino acids in a protein determines each level of that protein's structure.**
- **Explain how the conditions of the environment that a protein is in affect the structure and function of that protein.**
- **Explain how the structure of lipids determines the polarity of the molecule.**
- **If the chemistry of water occurs in aqueous solution, why are lipids useful in biological systems?**
- **Why is starch easily digested by animals, while cellulose isn't?**
- **Explain how directionality influences structure and function of the following polymer:**
    1. **Nucleic acids**
    2. **Proteins**
    3. **Carbohydrates**

Learning Objectives:

- The student is able to explain the connection between the sequence and the subcomponents of a biological polymer and its properties.
- The student is able to refine representations and models to explain how the subcomponents of a biological polymer and their sequence determine the properties of that polymer.
- The student is able to use models to predict and justify that changes in the subcomponents of a biological polymer affect the functionality of the molecule.

# Evolution Student Objectives

**<u>Enduring understanding 1.A: Change in the genetic makeup of a population over time is evolution.</u>**
**Essential knowledge 1.A.1: Natural selection is a major mechanism of evolution.**

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.
b. Evolutionary fitness is measured by reproductive success.
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.
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
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.
f. In addition to natural selection, chance and random events can influence the evolutionary process, especially for small populations.
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.
h. Mathematical approaches are used to calculate changes in allele frequency, providing evidence for the occurrence of evolution in a population.
*To demonstrate understanding of this concept, make sure you can utilize the following:*

- Graphical analysis of allele frequencies in a population
- Application of the Hardy-Weinberg equilibrium equation

**Student Objectives:**

- **explain how natural selection leads to adaptation in a population. Provide an example to illustrate.**
- **define "fitness" as it relates to evolution.**
- **Explain why genetic variation and mutation are important for natural selection in a changing environment.**
- **Predict and explain the effect that decreased genetic diversity would have on the evolution of a species.**
- **How does the environment affect the evolution of a species? Provide an example to illustrate.**
- **Explain the relationship between evolution and random events.**
- **How does the study of a non-evolving population inform scientists as to the effects of evolution?**
- **What conditions must be met for a population to be non-evolving, are these conditions frequently met? Explain why or why not.**
- **Explain the kind of mathematical evidence that is used to investigate evolution.**

Learning Objectives:

- The student is able to convert a data set from a table of numbers that reflect a change in the genetic makeup of a population over time and to apply mathematical methods and conceptual understandings to investigate the cause(s) and effect(s) of this change.
- The student is able to evaluate evidence provided by data to qualitatively and quantitatively investigate the role of natural selection in evolution.
- The student is able to apply mathematical methods to data from a real or simulated population to predict what will happen to the population in the future.

**Essential knowledge 1.A.2: Natural selection acts on phenotypic variations in populations.**

a. Environments change and act as selective mechanism on populations.
b. Phenotypic variations are not directed by the environment but occur through random changes in the DNA and through new gene combinations.
c. Some phenotypic variations significantly increase or decrease fitness of the organism and the population.
d. Humans impact variation in other species.
*To demonstrate understanding, make sure you can explain examples like:*

- Flowering time in relation to global climate change
- Peppered moth

- Sickle cell anemia
- DDT resistance in insects
- Artificial selection
- Loss of genetic diversity within a crop species
- Overuse of antibiotics

**Student Objectives:**

- **Provide examples of changes to an environment and give examples of possible adaptations that such changes would select for in a population.**
- **The production of new variations is a random process. Is natural selection also a random process? Explain your reasoning.**
- **Can a particular variation decrease the fitness of an individual, but increase the fitness of a population?**
- **How has human society affected the evolution of other species? Provide examples to illustrate.**

Learning Objectives:

- The student is able to evaluate data-based evidence that describes evolutionary changes in the genetic makeup of a population over time.
- The student is able to connect evolutionary changes in a population over time to a change in the environment.

**Essential knowledge 1.A.3: Evolutionary change is also driven by random processes.**

a. Genetic drift is a nonselective process occurring in small populations.
b. Reduction of genetic variation within a given population can increase the differences between populations of the same species.

**Student Objectives:**

- **Explain why genetic drift is considered nonselective and how it causes evolution.**
- **Explain how reduction of genetic variation within a given population effects the difference between population of the same species.**

Learning Objectives:

- The student is able to use data from mathematical models based on the Hardy-Weinberg equilibrium to analyze genetic drift and effects of selection in the evolution of specific populations.
- The student is able to justify data from mathematical models based on the Hardy-Weinberg equilibrium to analyze genetic drift and the effects of selection in the evolution of specific populations.
- The student is able to make predictions about the effects of genetic drift, migration and artificial selection on the genetic makeup of a population.

**Essential knowledge 1.A.4: Biological evolution is supported by scientific evidence from many disciplines, including mathematics.**

a. Scientific evidence of biological evolution uses information from geographical, geological, physical, chemical and mathematical applications.
b. Molecular, morphological and genetic information of existing and extinct organisms add to our understanding of evolution.

*Evidence of student learning is a demonstrated understanding of each of the following:*

1. 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.
2. Morphological homologies represent features shared by common ancestry. Vestigial structures are remnants of functional structures, which can be compared to fossils and provide evidence for evolution.
3. Biochemical and genetic similarities, in particular DNA nucleotide and protein sequences, provide evidence for evolution and ancestry.
4. Mathematical models and simulations can be used to illustrate and support evolutionary concepts.

*To demonstrate understanding, make sure you can do the following:*

- Graphical analyses of allele frequencies in a population
- Analysis of sequence data sets
- Analysis of phylogenetic trees
- Construction of phylogenetic trees based on sequence data

**Student Objectives:**

- **Evidence of evolution draws from which other disciplines of science/math?**
- **What types of evidence are used to support evolution?**
- **How are fossils dated and how does this relate to phylogenetic trees?**
- **What is morphology and how is it used to support evolution?**
- **Why are DNA and protein similarities used as evidence of evolution?**
- **How are mathematical models applied to biological data sets to illustrate and support evolution.**

Learning Objectives:

- The student is able to evaluate evidence provided by data from many scientific disciplines that support biological evolution.
- The student is able to refine evidence based on data from many scientific disciplines that support biological evolution.
- The student is able to design a plan to answer scientific questions regarding how organisms have changed over time using information from morphology, biochemistry and geology.
- The student is able to connect scientific evidence from many scientific disciplines to support the modern concept of evolution.
- The student is able to construct and/or justify mathematical models, diagrams or simulations that represent processes of biological evolution.

**<u>Enduring understanding 1.B: Organisms are linked by lines of descent from common ancestry.</u>**

**Essential knowledge 1.B.1: Organisms share many conserved core processes and features that evolved and are widely distributed among organisms today.**

a. Structural and functional evidence supports the relatedness of all domains.

**Evidence of student learning is a demonstrated understanding of each of the following:**

1. DNA and RNA are carriers of genetic information through transcription, translation and replication.
2. Major features of the genetic code are shared by all modern living systems.
3. Metabolic pathways are conserved across all currently recognized domains.

b. Structural evidence supports the relatedness of all eukaryotes.

*To foster student understanding of this concept, instructors can choose an illustrative example such as:*

- Cytoskeleton (a network of structural proteins that facilitate cell movement, morphological integrity and organelle transport)
- Membrane-bound organelles (mitochondria and/or chloroplasts)
- Linear chromosomes
- Endomembrane systems, including the nuclear envelope

**Student Objectives:**

- **Explain how structural and functional evidence supports the relatedness of all domains.**
- **What is the role of DNA and RNA, how is this conversed through out all organisms.**
- **Explain the conservation of metabolic pathways across all currently recognized domains.**
- **To illustrate your understand that structural evidence supports the relatedness of all eukaryotes. Choose one of the following and relate it to the conservation of structure in all eukaryotes.**
  - **Cytoskeleton (a network of structural proteins that facilitate cell movement, morphological integrity and organelle transport)**
  - **Membrane-bound organelles (mitochondria and/or chloroplasts)**
  - **Linear chromosomes**
  - **Endomembrane systems, including the nuclear envelope**

Learning Objectives:

- The student is able to pose scientific questions that correctly identify essential properties of shared, core life processes that provide insights into the history of life on Earth.
- The student is able to describe specific examples of conserved core biological processes and features shared by all domains or within one domain of life, and how these shared, conserved core processes and features support the concept of common ancestry for all organisms.
- The student is able to justify the scientific claim that organisms share many conserved core processes and features that evolved and are widely distributed among organisms today.

**Essential knowledge 1.B.2: Phylogenetic trees and cladograms are graphical representations (models) of evolutionary history that can be tested.**

a. Phylogenetic trees and cladograms can represent traits that are either derived or lost due to evolution.
*To demonstrate understanding, make sure you can explain the following:*

- Number of heart chambers in animals
- Opposable thumbs
- Absence of legs in some sea mammals

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.
c. Phylogenetic trees and cladograms can be constructed from morphological similarities of living or fossil species, and from DNA and protein sequence similarities, by employing computer programs that have sophisticated ways of measuring and representing relatedness among organisms.
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.

**Student Objectives:**

- **Explain how phylogenetic trees and cladograms can represent traits that are either derived or lost due to evolution by using on the following examples:**
  - **Number of heart chambers in animals**
  - **Opposable thumbs**
  - **Absence of legs in some sea mammals**
- **How do phylogenetic trees and cladograms illustrate relatedness. How does this relate to speciation?**
- **Explain how phylogenetic trees and cladograms can be constructed.**
- **How does the biological data used, new mathematical and computational ideas, and current and emerging knowledge effect phylogenic trees and cladograms?**

Learning Objectives:

- The student is able to pose scientific questions about a group of organisms whose relatedness is described by a phylogenetic tree or cladogram in order to (1) identify shared characteristics, (2) make inferences about the evolutionary history of the group, and (3) identify character data that could extend or improve the phylogenetic tree.
- The student is able to evaluate evidence provided by a data set in conjunction with a phylogenetic tree or a simple cladogram to determine evolutionary history and speciation.
- The student is able create a phylogenetic tree or simple cladogram that correctly represents evolutionary history and speciation from a provided data set.

**<u>Enduring understanding 1.C: Life continues to evolve within a changing environment.</u>**
**Essential knowledge 1.C.1: Speciation and extinction have occurred throughout the Earth's history.**

a. Speciation rates can vary, especially when adaptive radiation occurs when new habitats become available.
b. Species extinction rates are rapid at times of ecological stress. [See also 4.C.3]
*To demonstrate understanding, make sure you can explain the following:*

- Five major extinctions
- Human impact on ecosystems and species extinction rates

**Student Objective:**

- **Explain how adaptive radiation and new habitats becoming available effects the speciation rate.**
- **Explain how species extinction rates are rapid at times of ecological stress by applying the concept to one of the following examples.**
  - **Five major extinctions**
  - **Human impact on ecosystems and species extinction rates**

Learning Objectives:

- The student is able to analyze data related to questions of speciation and extinction throughout the Earth's history.
- The student is able to design a plan for collecting data to investigate the scientific claim that speciation and extinction have occurred throughout the Earth's history.

**Essential knowledge 1.C.2: Speciation may occur when two populations become reproductively isolated from each other.**

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.

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.

**Student Objectives:**

- **Explain how speciation occurs, including allopatric, sympatric, and parapatric speciation. Be sure to discuss pre-and post-zygotic mechanisms that can maintain reproductive isolation and prevent gene flow.**
- **What is the rate of most speciation, and how does polyploidy change the rate of speciation.**

Learning Objectives:

- The student is able to use data from a real or simulated population(s), based on graphs or models of types of selection, to predict what will happen to the population in the future.
- The student is able to justify the selection of data that address questions related to reproductive isolation and speciation.
- The student is able to describe speciation in an isolated population and connect it to change in gene frequency, change in environment, natural selection and/or genetic drift.

**Essential knowledge 1.C.3: Populations of organisms continue to evolve.**

a. Scientific evidence supports the idea that evolution has occurred in all species.

b. Scientific evidence supports the idea that evolution continues to occur.

*To foster student understanding of this concept, make sure you can explain the following:*

- Chemical resistance (mutations for resistance to antibiotics, pesticides, herbicides or chemotherapy drugs occur in the absence of the chemical)
- Emergent diseases
- Observed directional phenotypic change in a population (Grants' observations of Darwin's finches in the Galapagos)
- A eukaryotic example that describes evolution of a structure or process such as heart chambers, limbs, the brain and the immune system

**Student Objectives:**

- **Describe the types of scientific evidence that supports the idea that evolution has occurred in all species.**
- **Using an example below, describe the scientific evidence that supports the idea that evolution continues to occur.**
  - **Chemical resistance (mutations for resistance to antibiotics, pesticides, herbicides or chemotherapy drugs occur in the absence of the chemical)**
  - **Emergent diseases**
  - **Observed directional phenotypic change in a population (Grants' observations of Darwin's finches in the Galapagos)**
  - **A eukaryotic example that describes evolution of a structure or process such as heart chambers, limbs, the brain and the immune system**

Learning Objectives:

- The student is able to describe a model that represents evolution within a population.
- The student is able to evaluate given data sets that illustrate evolution as an ongoing process.

**<u>Enduring understanding 1.D: The origin of living systems is explained by natural processes.</u>**

**Essential knowledge 1.D.1: There are several hypotheses about the natural origin of life on Earth, each with supporting scientific evidence.**

a. Scientific evidence supports the various models.

*Evidence of student learning is a demonstrated understanding of each of the following:*

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. In turn, these molecules served as monomers or building blocks for the formation of more complex molecules, including amino acids and nucleotides.
3. The joining of these monomers produced polymers with the ability to replicate, store and transfer information.
4. These complex reaction sets could have occurred in solution (organic soup model) or as reactions on solid reactive surfaces.
5. The RNA World hypothesis proposes that RNA could have been the earliest genetic material.

**Student Objectives:**

- **List the various hypothesis about the natural origin of life on earth with the scientific evidence that supports each model.**
- **Discuss what was required of Primitive Earth for the synthesis of organic molecules**
- **Identity what could have occurred to these newly synthesised organic molecules to further the development of earth.**
- **Why are polymers with the ability to replicate, store and transfer information important to the origin of life.**
- **Describe the organic soup model the solid reactive surfaces where these reactions could have occured.**
- **Explain the RNA World hypothesis**

Learning Objectives:

- The student is able to describe a scientific hypothesis about the origin of life on Earth.
- The student is able to evaluate scientific questions based on hypotheses about the origin of life on Earth.
- The student is able to describe the reasons for revisions of scientific hypotheses of the origin of life on Earth.
- The student is able to evaluate scientific hypotheses about the origin of life on Earth.
- The student is able to evaluate the accuracy and legitimacy of data to answer scientific questions about the origin of life on Earth.

**Essential knowledge 1.D.2: Scientific evidence from many different disciplines supports models of the origin of life.**

a. Geological evidence provides support for models of the origin of life on Earth.
*Evidence of student learning is a demonstrated understanding of each of the following:*

1. The Earth formed approximately 4.6 billion years ago (bya), and the environment was too hostile for life until 3.9 bya, while the earliest fossil evidence for life dates to 3.5 bya. Taken together, this evidence provides a plausible range of dates when the origin of life could have occurred.
2. Chemical experiments have shown that it is possible to form complex organic molecules from inorganic molecules in the absence of life.

b. Molecular and genetic evidence from extant and extinct organisms indicates that all organisms on Earth share a common ancestral origin of life.
*Evidence of student learning is a demonstrated understanding of each of the following:*

- Scientific evidence includes molecular building blocks that are common to all life forms.
- Scientific evidence includes a common genetic code.

**Student Objectives**

- **List the types of evidence provides support for models of the origin of life on Earth.**
- **Describe the timeline of the formation of the earth, the formation of life, and the evidence used to support this timeline.**
- **Describe the chemical experiments that show that it is possible to form complex organic molecules from inorganic molecules in the absence of life.**
- **Discuss the molecular and genetic evidence from extant and extinct organisms which indicates that all organisms on Earth share a common ancestral origin of life.**
- **Identify the scientific evidence which includes molecular building blocks and common genetic code that are common to all life forms.**

Learning Objective:

- The student is able to justify the selection of geological, physical, and chemical data that reveal early Earth conditions.

# Cells Student Objectives

**<u>Enduring understanding 2.A: Growth, reproduction and maintenance of the organization of living systems require free energy and matter.</u>**

**Essential knowledge 2.A.1: All living systems require constant input of free energy.**

a. Life requires a highly ordered system.

Evidence of student learning is a demonstrated understanding of each of the following:

1. Order is maintained by constant free energy input into the system.
2. Loss of order or free energy flow results in death.
3. Increased disorder and entropy are offset by biological processes that maintain or increase order.

b. Living systems do not violate the second law of thermodynamics, which states that entropy increases over time.

*Evidence of student learning is a demonstrated understanding of each of the following:*

1. Order is maintained by coupling cellular processes that increase entropy (and so have negative changes in free energy) with those thaecrease entropy (and so have positive changes in free energy).
2. Energy input must exceed free energy lost to entropy to maintain order and power cellular processes.

**Student Objectives**

- **Explain how cells are able to remain alive and increase in complexity in accordance with the second law of thermodynamics.**
- **Compare the strategies employed by different lineages of cells to acquire and utilize free energy.**

Learning Objectives:

- The student is able to explain how biological systems use free energy based on empirical data that all organisms require constant energy input to maintain organization, to grow and to reproduce.
- The student is able to justify a scientific claim that free energy is required for living systems to maintain organization, to grow or to reproduce, but that multiple strategies exist in different living systems.

**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.

*Evidence of student learning is a demonstrated understanding of each of the following:*

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.

b. Surface area-to-volume ratios affect a biological system's ability to obtain necessary resources or eliminate waste products.

*Evidence of student learning is a demonstrated understanding of each of the following:*

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.
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.

**Student Objectives**

- **Explain why surface area-to-volume ratios are important in affecting a biological system's ability to obtain necessary resources or eliminate waste products.**
- **Explain the physical considerations that determine the upper and lower limits to cell size.**
- **Explain why smaller cells have a more favorable surface area-to-volume ratio for exchange of materials with the environment.**

Learning Objectives:

- The student is able to use calculated surface area-to-volume ratios to predict which cell(s) might eliminate wastes or procure nutrients faster by diffusion.
- Students will be able to explain how cell size and shape affect the overall rate of nutrient intake and the rate of waste elimination.
- The student is able to justify the selection of data regarding the types of molecules that an animal, plant or bacterium will take up as necessary building blocks and excrete as waste products.
- The student is able to represent graphically or model quantitatively the exchange of molecules between an organism and its environment, and the subsequent use of these molecules to build new molecules that facilitate dynamic homeostasis, growth and reproduction.

**<u>Enduring understanding 2.B: Growth, reproduction and dynamic homeostasis require that cells create and maintain internal environments that are different from their external environments.</u>**

**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. Selective permeability is a direct consequence of membrane structure, as described by the fluid mosaic model.

**Evidence of student learning is a demonstrated understanding of each of the following:**

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. 3. 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.
4. Embedded proteins can be hydrophilic, with charged and polar side groups, or hydrophobic, with nonpolar side groups.
5. 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.

*Evidence of student learning is a demonstrated understanding of each of the following:*

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.

**Student Objectives**

- **Explain the role of the cell membrane?**
- **How is selective permeability related to the fluid mosaic model.**
- **Describe the components of the Cell membranes**
- **What properties do Phospholipids give the membrane?**
- **Describe the orientation of phospholipids in a cell membrane.**
- **Describe the chemical characteristics of membrane proteins, and how this effects their position in the membrane.**

- **Describe the movement of the following through the membrane: Small, uncharged polar molecules, small nonpolar molecules (e.g. $N_2$), Hydrophilic substances (e.g. large polar molecules and ions), and water.**
- **Describe the function of the cell walls.**
- **Describe the composition and location of plant cell walls.**
- **Describe the composition and location of cells walls of prokaryotes and fungi.**

Learning Objectives:

- The student is able to use representations and models to pose scientific questions about the properties of cell membranes and selective permeability based on molecular structure.
- The student is able to construct models that connect the movement of molecules across membranes with membrane structure and function.

**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.
*Evidence of student learning is a demonstrated understanding of each of the following:*

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.
*To demonstrate understanding, make sure you can explain examples like:*
    - Glucose transport
    - Na+/K+ transport
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.
*Evidence of student learning is a demonstrated understanding of each of the following:*

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.
*Evidence of student learning is a demonstrated understanding of each of the following:*

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.

**Student Objectives**

- **Describe passive transport and explain its role in cellular systems**
- **Explain how membrane proteins play a role in facilitated diffusion of charged and polar molecules in general and in relation to the specific molecules below.**
    - **Glucose transport**
    - **Na+/K+ transport**
- **Explain the terms: hypotonic, hypertonic or isotonic in relationship to the internal environments of cells.**
- **Describe active transport.**
- **Explain the relationship between active transport, free energy and proteins embedded in the membrane.**
- **Describe the processes of endocytosis and exocytosis.**

Learning Objective:

- The student is able to use representations and models to analyze situations or solve problems qualitatively and quantitatively to investigate whether dynamic homeostasis is maintained by the active movement of molecules across membranes.

**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. [See also **4.A.2**]

*To demonstrate understanding, make sure you can explain examples like:*

- Endoplasmic reticulum
- Mitochondria
- Chloroplasts
- Golgi
- Nuclear envelope

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

**Student Objectives:**

- **Explain how internal membranes facilitate simultaneous occurrence of diverse cellular processes.**
- **Using the examples from below to explain how membranes and membrane-bound organelles in eukaryotic cells localize (compartmentalize) intracellular metabolic processes and specific enzymatic reactions.**
    - **Endoplasmic reticulum**
    - **Mitochondria**
    - **Chloroplasts**
    - **Golgi**
    - **Nuclear envelope**
- **Why is compartmentalization limited to eukaryotic cells?**

Learning Objectives:

- The student is able to explain how internal membranes and organelles contribute to cell functions.
- The student is able to use representations and models to describe differences in prokaryotic and eukaryotic cells.

**<u>Enduring understanding 3.D: Cells communicate by generating, transmitting and receiving chemical signals.</u>**

**Essential knowledge 3.D.1: Cell communication processes share common features that reflect a shared evolutionary history.**

a. Communication involves transduction of stimulatory or inhibitory signals from other cells, organisms or the environment.

b. Correct and appropriate signal transduction processes are generally under strong selective pressure.

c. In single-celled organisms, signal transduction pathways influence how the cell responds to its environment.

*To demonstrate understanding, make sure you can explain examples like:*

- Use of chemical messengers by microbes to communicate with other nearby cells and to regulate specific pathways in response to population density (quorum sensing)
- Use of pheromones to trigger reproduction and developmental pathways
- Response to external signals by bacteria that influences cell movement

d. In multicellular organisms, signal transduction pathways coordinate the activities within individual cells that support the function of the organism as a whole.

*To demonstrate understanding, make sure you can explain examples like:*

- Epinephrine stimulation of glycogen breakdown in mammals

**Student Objectives**

- **List the types of signals involved in communication and where they come from.**
- **Describe why signal transduction pathways that are under strong selective pressure.**
- **Use an example to explain how signal transduction pathways influence how the cell responds to its environment in unicellular organisms.**
- **Using an example to explain how signal transduction pathways coordinate the activities within individual cells that support the function of the organism as a whole in multi-cellular organisms.**

Learning Objectives:

- The student is able to describe basic chemical processes for cell communication shared across evolutionary lines of descent.
- The student is able to generate scientific questions involving cell communication as it relates to the process of evolution.
- The student is able to use representation(s) and appropriate models to describe features of a cell signaling pathway.

**Essential knowledge 3.D.2: Cells communicate with each other through direct contact with other cells or from a distance via chemical signaling.**

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

*To demonstrate understanding, make sure you can explain examples like:*

- Immune cells interact by cell-cell contact, antigen-presenting cells (APCs), helper T-cells and killer T-cells.
- Plasmodesmata between plant cells that allow material to be transported from cell to cell.

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

*To demonstrate understanding, make sure you can explain examples like:*

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

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

**Student Objectives:**

- **Use an example to explain how cells communicate by cell-to-cell contact.**
- **Use an example to explain how cells communicate over short distances by using local regulators that target cells in the vicinity of the emitting cell.**
- **Explain how signals released by one cell type can travel long distances to target cells of another cell type.**

Learning Objectives:

- The student is able to construct explanations of cell communication through cell-to-cell direct contact or through chemical signaling.
- **T**he student is able to create representation(s) that depict how cell-to-cell communication occurs by direct contact or from a distance through chemical signaling.

**Essential knowledge 3.D.3: Signal transduction pathways link signal reception with cellular response.**

a. Signaling begins with the recognition of a chemical messenger, a ligand, by a receptor protein.

*Evidence of student learning is a demonstrated understanding of each of the following:*

1. Different receptors recognize different chemical messengers, which can be peptides, small chemicals or proteins, in a specific one-to-one relationship.
2. A receptor protein recognizes signal molecules, causing the receptor protein's shape to change, which initiates transduction of the signal.

*To demonstrate understanding, make sure you can explain examples like:*

- G-protein linked receptors
- Ligand-gated ion channels
- Receptor tyrosine kinases

b. Signal transduction is the process by which a signal is converted to a cellular response.

*Evidence of student learning is a demonstrated understanding of each of the following:*

1. Signaling cascades relay signals from receptors to cell targets, often amplifying the incoming signals, with the result of appropriate responses by the cell.
2. Second messengers are often essential to the function of the cascade.

*To demonstrate understanding, make sure you can explain examples like:*

- Ligand-gated ion channels
- Second messengers, such as cyclic GMP, cyclic AMP calcium ions ($Ca^{2+}$), and inositol triphosphate (IP3)

3. Many signal transduction pathways include:
   i. Protein modifications (an illustrative example could be how methylation changes the signaling process)
   ii. Phosphorylation cascades in which a series of protein kinases add a phosphate group to the next protein in the cascade sequence

**Student Objectives:**

- **Describe how signals are received by cells.**
- **List the types of different chemical messengers and explain the specific one-to-one relationship with their receptors.**
- **Using an example to explain how a receptor protein recognizes signal molecules, causing the receptor protein's shape to change, which initiates transduction of the signal.**
- **Describe the process of signal transduction.**
- **Explain the concept of signaling cascades.**
- **Use an example to explain how second messengers are often essential to the function of a signaling cascade.**
- **Explain the effects of protein modifications on the signaling cascade**
- **Explain the effects of phosphorylation on the signaling cascade.**

Learning Objectives:

- The student is able to describe a model that expresses the key elements of signal transduction pathways by which a signal is converted to a cellular response.

**<u>Enduring understanding 4.A: Interactions within biological systems lead to complex properties.</u>**

**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.

*Evidence of student learning is a demonstrated understanding of each of the following:*

1. Rough endoplasmic reticulum functions to compartmentalize 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).

*Evidence of student learning is a demonstrated understanding of the following:*

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.

*Evidence of student learning is a demonstrated understanding of each of the following:*

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.

*Evidence of student learning is a demonstrated understanding of each of the following:*

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 NADPH2, which fuel carbon-fixing reactions in the Calvin-Benson cycle. Carbon fixation occurs in the stroma, where molecules of CO2 are converted to carbohydrates.

**Student Objectives**

- **Diagram the endomembrane system of eukaryotic cells.**
- **Describe ribosome structure and function.**
- **Describe the two types endoplasmic reticulum (ER) in both structure and function.**
- **Describe the Golgi complex structure and their function**
- **Describe mitochondria structure and function.**
- **Describe lysosome structure and function**
- **Describe a vacuole structure and function**
- **Compare the cellular organization of prokaryotic and eukaryotic cells.**
- **Compare the structural similarities and differences of prokaryotic and eukaryotic cell walls, chromosomes and ribosomes.**
- **Explain the structure and function relationship in the chloroplast.**
- **Explain what chlorophyll is and why they are important.**
- **Explain the structure and function relationships between chloroplasts and mitochondria**
- **Relate structural and functional evidence in chloroplasts and mitochondria to the endosymbiotic theory of their origins.**

Learning Objectives:

- The student is able to make a prediction about the interactions of subcellular organelles.
- The student is able to construct explanations based on scientific evidence as to how interactions of subcellular structures provide essential functions.

- The student is able to use representations and models to analyze situations qualitatively to describe how interactions of subcellular structures, which possess specialized functions, provide essential functions.

# Cell Division Student Objectives

**<u>Enduring understanding 3.A: Heritable information provides for continuity of life.</u>**

**Essential knowledge 3.A.1: DNA, and in some cases RNA, is the primary source of heritable information.**

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

*Evidence of student learning is a demonstrated understanding of each of the following:*

1. Genetic information is stored in and passed to subsequent generations through DNA molecules and, in some cases, RNA molecules.
2. Noneukaryotic organisms have circular chromosomes, while eukaryotic organisms have multiple linear chromosomes, although in biology there are exceptions to this rule.
3. DNA replication ensures continuity of hereditary information.

b. Genetic information flows from a sequence of nucleotides in a gene to a sequence of amino acids in a protein.

c. Phenotypes are determined through protein activities.

**Student Objectives:**

- **Explain how DNA allows for the passage of genetic information between generations.**
- **Compare the structure of prokaryotic and eukaryotic genetic information storage molecules.**

Learning Objectives:

- The student is able to describe representations and models that illustrate how genetic information is copied for transmission between generations.

**Essential knowledge 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.**

a. The cell cycle is a complex set of stages that is highly regulated with checkpoints, which determine the ultimate fate of the cell.

*Evidence of student learning is a demonstrated understanding of each of the following:*

1. Interphase consists of three phases: growth, synthesis of DNA, preparation for mitosis.
2. The cell cycle is directed by internal controls or checkpoints. Internal and external signals provide stop-and-go signs at the checkpoints.

   *To demonstrate understanding, make sure you can explain examples like:*

   - Mitosis-promoting factor (MPF)
   - Action of platelet-derived growth factor (PDGF)
3. Cancer results from disruptions in cell cycle control
4. Cyclins and cyclin-dependent kinases control the cell cycle.
5. Mitosis alternates with interphase in the cell cycle.
6. When a cell specializes, it often enters into a stage where it no longer divides, but it can reenter the cell cycle when given appropriate cues. Nondividing cells may exit the cell cycle; or hold at a particular stage in the cell cycle.

**Student Objectives:**

- **Explain the events of all stages of the cell cycle.**
- **Explain how cell division is controlled in cells, using examples like MPF and PDGF.**
- **Explain what cancer is and how it develops in an organism**

b. Mitosis passes a complete genome from the parent cell to daughter cells.

*Evidence of student learning is a demonstrated understanding of each of the following:*

1. Mitosis occurs after DNA replication.
2. Mitosis followed by cytokinesis produces two genetically identical daughter cells.

3. Mitosis plays a role in growth, repair, and asexual reproduction
4. Mitosis is a continuous process with observable structural features along the mitotic process. Evidence of student learning is demonstrated by knowing the order of the processes (replication, alignment, separation).

**Student Objectives:**

- **Explain the events of all stages of mitosis.**
- **Track chromosome and chromatid number through all stages of mitosis.**
- **Demonstrate how and when the processes of DNA replication, chromosomal alignment, and chromosomal separation are accomplished during a mitotic cell cycle.**
- **Compare the process of mitosis in plant-like and animal-like cells.**

c. Meiosis, a reduction division, followed by fertilization ensures genetic diversity in sexually reproducing organisms.

*Evidence of student learning is a demonstrated understanding of each of the following:*

1. Meiosis ensures that each gamete receives one complete haploid (1n) set of chromosomes.
2. During meiosis, homologous chromosomes are paired, with one homologue originating from the maternal parent and the other from the paternal parent.
3. Orientation of the chromosome pairs is random with respect to the cell poles.
4. Separation of the homologous chromosomes ensures that each gamete receives a haploid (1n) set of chromosomes composed of both maternal and paternal chromosomes.
5. During meiosis, homologous chromatids exchange genetic material via a process called "crossing over," which increases genetic variation in the resultant gametes.
6. 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.

**Student Objectives:**

- **Relate meiosis to the processes of sexual life cycles.**
- **Explain the similarities and differences among sexual life cycles seen in all organisms.**
- **Explain the events of all stages of meiosis.**
- **Track chromosome and chromatid number through all stages of meiosis.**
- **Demonstrate how and when the processes of DNA replication, chromosomal alignment, and chromosomal separation are accomplished during a meiotic cell cycle.**
- **Compare the process of meiosis to the process of mitosis.**
- **Explain how the processes of meiosis increase genetic variation in a population and be able to mathematically modify the effects of those processes.**

Learning Objectives:

- The student can make predictions about natural phenomena occurring during the cell cycle.
- The student can describe the events that occur in the cell cycle.
- The student is able to construct an explanation, using visual representations or narratives, as to how DNA in chromosomes is transmitted to the next generation via mitosis, or meiosis followed by fertilization.
- The student is able to represent the connection between meiosis and increased genetic diversity necessary for evolution.
- The student is able to evaluate evidence provided by data sets to support the claim that heritable information is passed from one generation to another generation through mitosis, or meiosis followed by fertilization.

**Essential knowledge 3.A.3: The chromosomal basis of inheritance provides an understanding of the pattern of passage (transmission) of genes from parent to offspring.**

a. Segregation and independent assortment of chromosomes result in genetic variation.

*Evidence of student learning is a demonstrated understanding of each of the following:*

1. Segregation and independent assortment can be applied to genes that are on different chromosomes.

b. Certain human genetic disorders can be attributed to the inheritance of single gene traits or specific chromosomal changes, such as nondisjunction.
*To demonstrate understanding, make sure you can explain examples like:*
- Trisomy 21/Down syndrome
- Klinefelter's syndrome

c. Many ethical, social and medical issues surround human genetic disorders.

**Student Objectives:**
- **Explain the etiology of specific examples of non-disjunction events in humans, including Down Syndrome and Klinefelter's syndrome.**
- **Explain why chromosomal disorders involving the sex chromosomes are generally more tolerated than disorders involving autosomes.**
- **Consider human genetic disorders from ethical, social and medical perspectives.**

**<u>Enduring understanding 3.C: The processing of genetic information is imperfect and is a source of genetic variation.</u>**

**Essential knowledge 3.C.1: Changes in genotype can result in changes in phenotype.**

a. Alterations in a DNA sequence can lead to changes in the type or amount of the protein produced and the consequent phenotype.
*Evidence of student learning is a demonstrated understanding of the following:*
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.

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.
*Evidence of student learning is a demonstrated understanding of the following:*
1. Whether or not a mutation is detrimental, beneficial or neutral depends on the environmental context. Mutations are the primary source of genetic variation.

c. Errors in mitosis or meiosis can result in changes in phenotype.
*Evidence of student learning is a demonstrated understanding of each of the following:*
1. Changes in chromosome number often result in new phenotypes, including sterility caused by triploidy and increased vigor of other polyploids.
2. Changes in chromosome number often result in human disorders with developmental limitations, including Trisomy 21 (Down syndrome) and XO (Turner syndrome).

**Student Objectives:**
- **Discuss the causes of mutations.**
- **Explain the relationship between mutations, variation, and evolution.**
- **Explain the relationship between mutations, and cancer.**
- **Describe why mutations can have a positive, negative, or neutral effect on the physiology of the organism.**
- **Explain how changes in chromosome number and structure can affect the physiology of the organism.**

**Essential knowledge 3.C.2: Biological systems have multiple processes that increase genetic variation.**

a. The imperfect nature of DNA replication and repair increases variation.
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.
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.

Learning Objectives:

- The student is able to compare and contrast processes by which genetic variation is produced and maintained in organisms from multiple domains.
- The student is able to construct an explanation of the multiple processes that increase variation within a population.

**Student Objectives:**

- **Explain how cell division can be used to either increase or maintain the amount of genetic variation in a population.**
- **Consider the evolutionary advantages and disadvantages of asexual and sexual reproduction.**

# Mendelian Genetics Student Objectives

**<u>Enduring understanding 3.A: Heritable information provides for continuity of life.</u>**
**Essential knowledge 3.A.1: DNA, and in some cases RNA, is the primary source of heritable information.**

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

*Evidence of student learning is a demonstrated understanding of each of the following:*

1. Noneukaryotic organisms have circular chromosomes, while eukaryotic organisms have multiple linear chromosomes, although in biology there are exceptions to this rule.

**Student Objectives:**

- **Explain how the transmission of DNA from generation to generation reflects the chromosomal nature of inheritance.**

Learning Objectives:

- The student is able to describe representations and models that illustrate how genetic information is copied for transmission between generations.
- The student is able to describe representations and models illustrating how genetic information is translated into polypeptides.

**Essential knowledge 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.**

a. Meiosis, a reduction division, followed by fertilization ensures genetic diversity in sexually reproducing organisms.

*Evidence of student learning is a demonstrated understanding of each of the following:*

1. Meiosis ensures that each gamete receives one complete haploid (1n) set of chromosomes.
2. During meiosis, homologous chromosomes are paired, with one homologue originating from the maternal parent and the other from the paternal parent.
3. Orientation of the chromosome pairs is random with respect to the cell poles.
4. Separation of the homologous chromosomes ensures that each gamete receives a haploid (1n) set of chromosomes composed of both maternal and paternal chromosomes.
5. During meiosis, homologous chromatids exchange genetic material via a process called “crossing over,” which increases genetic variation in the resultant gametes.
6. 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.

**Student Objectives:**

- **How do the events of meiosis explain the observations of Gregor Mendel?**
- **How do the events of meiosis explain the observations of Thomas Morgan?**

- **How can recombination during meiosis be explained?**
- **How can recombination during meiosis be utilized to locate genes on chromosomes and establish their relative distances?**

Learning Objectives:

- The student is able to construct an explanation, using visual representations or narratives, as to how DNA in chromosomes is transmitted to the next generation via mitosis, or meiosis followed by fertilization.
- The student is able to represent the connection between meiosis and increased genetic diversity necessary for evolution.
- The student is able to evaluate evidence provided by data sets to support the claim that heritable information is passed from one generation to another generation through mitosis, or meiosis followed by fertilization.

**Essential knowledge 3.A.3: The chromosomal basis of inheritance provides an understanding of the pattern of passage (transmission) of genes from parent to offspring.**

a. Rules of probability can be applied to analyze passage of single gene traits from parent to offspring.

b. Segregation and independent assortment of chromosomes result in genetic variation.

*Evidence of student learning is a demonstrated understanding of each of the following:*

1. Segregation and independent assortment can be applied to genes that are on different chromosomes.
2. Genes that are adjacent and close to each other on the same chromosome tend to move as a unit; the probability that they will segregate as a unit is a function of the distance between them.
3. The pattern of inheritance (monohybrid, dihybrid, sex-linked, and genes linked on the same homologous chromosome) can often be predicted from data that gives the parent genotype/phenotype and/or the offspring phenotypes/genotypes.

c. Certain human genetic disorders can be attributed to the inheritance of single gene traits or specific chromosomal changes, such as nondisjunction.

*To demonstrate your understanding, make sure you can explain examples like:*

- Sickle cell anemia
- Tay-Sachs disease
- Huntington's disease
- X-linked color blindness
- Trisomy 21/Down syndrome
- Klinefelter's syndrome

d. Many ethical, social and medical issues surround human genetic disorders.

*To demonstrate your understanding, make sure you can explain examples like:*

- Reproduction issues
- Civic issues such as ownership of genetic information, privacy, historical contexts, etc.

**Student Objectives:**

- **How do the processes of segregation and independent assortment explain mendelian and non-mendelian inheritance patterns?**
- **How do the processes of meiosis explain the inheritance patterns of unlinked and linked genes?**

- **How do the examples discussed in c demonstrate different modes of inheritance?**
- **What are some of the ethical, social, and medical issues surrounding human genetic disorders?**

Learning Objectives:
- The student is able to construct a representation that connects the process of meiosis to the passage of traits from parent to offspring.
- **T**he student is able to pose questions about ethical, social or medical issues surrounding human genetic disorders.
- The student is able to apply mathematical routines to determine Mendelian patterns of inheritance provided by data sets.

**Essential knowledge 3.A.4: The inheritance pattern of many traits cannot be explained by simple Mendelian genetics.**

a. Many traits are the product of multiple genes and/or physiological processes.
*Evidence of student learning is a demonstrated understanding of the following:*

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

b. Some traits are determined by genes on sex chromosomes.
*To demonstrate your understanding, make sure you can explain examples like:*
- Sex-linked genes reside on sex chromosomes (X in humans).
- In mammals and flies, the Y chromosome is very small and carries few genes.
- In mammals and flies, females are XX and males are XY; as such, X-linked recessive traits are always expressed in males.
- Some traits are sex limited, and expression depends on the sex of the individual, such as milk production in female mammals and pattern baldness in males.

c. Some traits result from nonnuclear inheritance.
*Evidence of student learning is a demonstrated understanding of each of the following:*

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

2. In animals, mitochondrial DNA is transmitted by the egg and not by sperm; as such, mitochondrial-determined traits are maternally inherited.

**Student Objectives:**
- **How do the interactions of multiple genes affect inheritance patterns and the expression of particular phenotypes?**
- **How does the location of genes on sex chromosomes affect inheritance patterns and the expression of particular phenotypes?**
- **How does the transmission of non-nuclear genes affect inheritance patterns and the expression of particular phenotypes?**

Learning Objectives:
- The student is able to explain deviations from Mendel's model of the inheritance of traits.
- The student is able to explain how the inheritance patterns of many traits cannot be accounted for by Mendelian genetics.

- The student is able to describe representations of an appropriate example of inheritance patterns that cannot be explained by Mendel's model of the inheritance of traits.

**Essential knowledge 3.C.2: Biological systems have multiple processes that increase genetic variation.**

a. The imperfect nature of DNA replication and repair increases variation.
b. 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.

Learning Objectives:

- The student is able to compare and contrast processes by which genetic variation is produced and maintained in organisms from multiple domains.
- The student is able to construct an explanation of the multiple processes that increase variation within a population.

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

**Essential knowledge 4.C.2: Environmental factors influence the expression of the genotype in an organism.**

a. Environmental factors influence many traits both directly and indirectly.
b. An organism's adaptation to the local environment reflects a flexible response of its genome.
*To demonstrate your understanding, make sure you can explain examples like:*

- Height and weight in humans
- Flower color based on soil pH
- Seasonal fur color in arctic animals

**Student Objectives:**

- **Explain the relationship between an organisms environment, its genome, and its phenotype. Cite specific examples.**

Learning Objectives:

- **T**he student is able to construct explanations of the influence of environmental factors on the phenotype of an organism.
- **T**he student is able to predict the effects of a change in an environmental factor on the genotypic expression of the phenotype.

# Molecular Genetics Student Objectives

## Exam 1:

**<u>Enduring understanding 3.A: Heritable information provides for continuity of life.</u>**
**Essential knowledge 3.A.1: DNA, and in some cases RNA, is the primary source of heritable information.**

a. Genetic information is transmitted from one generation to the next through DNA or RNA.
*Evidence of student learning is a demonstrated understanding of each of the following:*

1. Genetic information is stored in and passed to subsequent generations through DNA molecules and, in some cases, RNA molecules.
2. Noneukaryotic organisms have circular chromosomes, while eukaryotic organisms have multiple linear chromosomes, although in biology there are exceptions to this rule.
3. Prokaryotes, viruses and eukaryotes can contain plasmids, which are small extra-chromosomal, double-stranded circular DNA molecules.
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
5. DNA replication ensures continuity of hereditary information.
    i. Replication is a semiconservative process; that is, one strand serves as the template for a new, complementary strand.
    ii. Replication requires DNA polymerase plus many other essential cellular enzymes, occurs bidirectionally, and differs in the production of the leading and lagging strands.

b. DNA and RNA molecules have structural similarities and differences that define function.
*Evidence of student learning is a demonstrated understanding of each of the following:*

1. Both have three components — sugar, phosphate and a nitrogenous base — which form nucleotide units that are connected by covalent bonds to form a linear molecule with 3' and 5' ends, with the nitrogenous bases perpendicular to the sugar-phosphate backbone.
2. The basic structural differences include:
    i. DNA contains deoxyribose (RNA contains ribose).
    ii. RNA contains uracil in lieu of thymine in DNA.
    iii. DNA is usually double stranded, RNA is usually single stranded.
    iv. The two DNA strands in double-stranded DNA are antiparallel in directionality.
3. Both DNA and RNA exhibit specific nucleotide base pairing that is conserved through evolution: adenine pairs with thymine or uracil (A-T or A-U) and cytosine pairs with guanine (C-G).
    i. Purines (G and A) have a double ring structure.
    ii. Pyrimidines (C, T and U) have a single ring structure.
4. The sequence of the RNA bases, together with the structure of the RNA molecule, determines RNA function.
    i. mRNA carries information from the DNA to the ribosome.
    ii. tRNA molecules bind specific amino acids and allow information in the mRNA to be translated to a linear peptide sequence.
    iii. rRNA molecules are functional building blocks of ribosomes.
    iv. The role of RNAi includes regulation of gene expression at the level of mRNA transcription.

c. Genetic information flows from a sequence of nucleotides in a gene to a sequence of amino acids in a protein.
*Evidence of student learning is a demonstrated understanding of each of the following:*

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.
2. In eukaryotic cells the mRNA transcript undergoes a series of enzyme-regulated modifications.
    *To demonstrate student understanding of this concept, make sure you can explain:*
    i. Addition of a poly-A tail
    ii. Addition of a GTP cap
    iii. Excision of introns
3. Translation of the mRNA occurs in the cytoplasm on the ribosome.

4. In prokaryotic organisms, transcription is coupled to translation of the message. 5. Translation involves energy and many steps, including initiation, elongation and termination. The salient features include:
    i. The mRNA interacts with the rRNA of the ribosome to initiate translation at the (start) codon.
    ii. The sequence of nucleotides on the mRNA is read in triplets called codons.
    iii. Each codon encodes a specific amino acid, which can be deduced by using a genetic code chart. Many amino acids have more than one codon.
    iv. tRNA brings the correct amino acid to the correct place on the mRNA.
    v. The amino acid is transferred to the growing peptide chain.
    vi. The process continues along the mRNA until a "stop" codon is reached.
    vii. The process terminates by release of the newly synthesized peptide/protein.

d. Phenotypes are determined through protein activities.

*To demonstrate student understanding of this concept, make sure you can explain:*

- Enzymatic reactions
- Transport by proteins
- Synthesis
- Degradation

**Student Objectives:**

- **Explain how contributions from each of the following scientists led to an understanding of DNA structure and function:**
    - **Griffith**
    - **Avery McCarty & McLeod**
    - **Hershey & Chase**
    - **Erwin Chargaff**
    - **Watson, Crick, Franklin, & Wilkins**
- **Diagram a molecule of DNA and explain how its features allow for both heredity and protein synthesis.**
- **Explain how RNA and DNA differ in structure and function.**
- **Explain the role of mRNA, tRNA and rRNA in protein synthesis**
- **Explain the relationship between DNA, RNA, Protein, Cells and the Organism.**
- **Explain the evidence that demonstrates the relationship between phenotype and protein activity.**
- **Diagram the process of DNA replication. Discuss all inputs, processes, and outputs. Explain the roles of all pertinent enzymes.**
- **Diagram the process of transcription. Discuss all inputs, processes, and outputs. Explain the roles of all pertinent enzymes.**
- **Diagram the process of translation. Discuss all inputs, processes, and outputs. Explain the roles of all pertinent enzymes, the ribosome, and relevant RNA molecules..**
- **Compare replication, transcription, and translation among prokaryotes and eukaryotes. Explain the functions of all differences.**

Learning Objectives:

- The student is able to construct scientific explanations that use the structures and mechanisms of DNA and RNA to support the claim that DNA and, in some cases, that RNA are the primary sources of heritable information.
- The student is able to justify the selection of data from historical investigations that support the claim that DNA is the source of heritable information.
- The student is able to describe representations and models that illustrate how genetic information is copied for transmission between generations.
- The student is able to describe representations and models illustrating how genetic information is translated into polypeptides.
- The student can predict how a change in a specific DNA or RNA sequence can result in changes in gene expression.

**<u>Enduring understanding 3.B: Expression of genetic information involves cellular and molecular mechanisms.</u>**

**Essential knowledge 3.B.1: Gene regulation results in differential gene expression, leading to cell specialization.**

a. Both DNA regulatory sequences, regulatory genes, and small regulatory RNAs are involved in gene expression.

*Evidence of student learning is a demonstrated understanding of each of the following:*

1. Regulatory sequences are stretches of DNA that interact with regulatory proteins to control transcription.
   *To demonstrate student understanding of this concept, make sure you can explain:*
   i. Promoters
   ii. Terminators
   iii. Enhancers
2. A regulatory gene is a sequence of DNA encoding a regulatory protein or RNA.

b. Both positive and negative control mechanisms regulate gene expression in bacteria and viruses.
*Evidence of student learning is a demonstrated understanding of each of the following:*

1. The expression of specific genes can be turned on by the presence of an inducer.
2. The expression of specific genes can be inhibited by the presence of a repressor.
3. Inducers and repressors are small molecules that interact with regulatory proteins and/or regulatory sequences.
4. Regulatory proteins inhibit gene expression by binding to DNA and blocking transcription (negative control).
5. Regulatory proteins stimulate gene expression by binding to DNA and stimulating transcription (positive control) or binding to repressors to inactivate repressor function.
6. Certain genes are continuously expressed; that is, they are always turned "on," e.g., the ribosomal genes.

c. In eukaryotes, gene expression is complex and control involves regulatory genes, regulatory elements and transcription factors that act in concert.
*Evidence of student learning is a demonstrated understanding of each of the following:*

1. Transcription factors bind to specific DNA sequences and/or other regulatory proteins.
2. Some of these transcription factors are activators (increase expression), while others are repressors (decrease expression).
3. The combination of transcription factors binding to the regulatory regions at any one time determines how much, if any, of the gene product will be produced.

d. Gene regulation accounts for some of the phenotypic differences between organisms with similar genes.

**Student Objectives:**

- **Compare regulation of gene expression in prokaryotes and eukaryotes.**
- **Diagram inducible and repressible operons. Give examples of each.**
- **Compare the function of transcription factors and enhancers.**
- **Explain the structures, processes, and functions of regulation that operate at all stages of gene expression in eukaryotes.**
- **Explain the relationship between gene expression and differentiation in eukaryotes.**
- **Explain the relationship between gene expression and differences in phenotypes in eukaryotes.**

Learning Objectives:

- The student is able to describe the connection between the regulation of gene expression and observed differences between different kinds of organisms.
- The student is able to describe the connection between the regulation of gene expression and observed differences between individuals in a population.
- The student is able to explain how the regulation of gene expression is essential for the processes and structures that support efficient cell function.
- The student can use representations to describe how gene regulation influences cell products and function.

**Essential knowledge 3.B.2: A variety of intercellular and intracellular signal transmissions mediate gene expression.**

a. Signal transmission within and between cells mediates gene expression.
*To demonstrate student understanding of this concept, make sure you can explain:*

- Mating pheromones in yeast trigger mating gene expression.
- Levels of cAMP regulate metabolic gene expression in bacteria.

**Student Objectives:**

- **Using examples from cellular communication, explain how signal transduction can effect gene expression in organisms.**

Learning Objectives:

- The student is able to explain how signal pathways mediate gene expression, including how this process can affect protein production.
- The student can use representations to describe mechanisms of the regulation of gene expression.

**Enduring understanding 3.C: The processing of genetic information is imperfect and is a source of genetic variation.**

**Essential knowledge 3.C.1: Changes in genotype can result in changes in phenotype.**

a. Alterations in a DNA sequence can lead to changes in the type or amount of the protein produced and the consequent phenotype.

*Evidence of student learning is a demonstrated understanding of the following:*

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.

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.

*Evidence of student learning is a demonstrated understanding of the following:*

1. Whether or not a mutation is detrimental, beneficial or neutral depends on the environmental context. Mutations are the primary source of genetic variation.

**Student Objectives:**

- **Explain the cause and effect of mutations at the DNA sequence level. Provide examples of all types.**

Learning Objectives:

- The student is able to predict how a change in genotype, when expressed as a phenotype, provides a variation that can be subject to natural selection.
- The student can create a visual representation to illustrate how changes in a DNA nucleotide sequence can result in a change in the polypeptide produced.
- The student is able to explain the connection between genetic variations in organisms and phenotypic variations in populations.

**Essential knowledge 3.C.2: Biological systems have multiple processes that increase genetic variation.**

a. The imperfect nature of DNA replication and repair increases variation.

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.

**Student Objectives:**

- **Provide examples of all processes discussed in this course (to this point in time) that illustrate the generation of genetic variation in prokaryotes and eukaryotes.**

Learning Objectives:

- The student is able to compare and contrast processes by which genetic variation is produced and maintained in organisms from multiple domains.
- The student is able to construct an explanation of the multiple processes that increase variation within a population.

## Exam 2:

**<u>Enduring understanding 3.A: Heritable information provides for continuity of life.</u>**
**Essential knowledge 3.A.1: DNA, and in some cases RNA, is the primary source of heritable information.**

a. Genetic information is transmitted from one generation to the next through DNA or RNA.
*Evidence of student learning is a demonstrated understanding of each of the following:*

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

b. Genetic engineering techniques can manipulate the heritable information of DNA and, in special cases, RNA.
*To demonstrate student understanding of this concept, make sure you can explain:*

- Electrophoresis
- Plasmid-based transformation
- Restriction enzyme analysis of DNA
- Polymerase Chain Reaction (PCR)

c. Illustrative examples of products of genetic engineering include:

- Genetically modified foods
- Transgenic animals
- Cloned animals
- Pharmaceuticals, such as human insulin or factor X

**Student Objectives:**

- **Describe the inputs, processes, and outputs of all biotechnological tools and techniques discussed in this course. Provide multiple examples of the applications of each of these tools.**
- **Explain the aspects of molecular biology and DNA that each tool and technique discussed in this course utilizes.**
- **Discuss the ethical and legal considerations that the biotechnology revolution has generated. Provide multiple real-life examples of these issues. Offer multiple lines of evidence to support and refute these considerations.**

Learning Objectives:

- The student is able to construct scientific explanations that use the structures and mechanisms of DNA and RNA to support the claim that DNA and, in some cases, that RNA are the primary sources of heritable information.
- The student can justify the claim that humans can manipulate heritable information by identifying at least two commonly used technologies.
- The student can predict how a change in a specific DNA or RNA sequence can result in changes in gene expression.

**Enduring understanding 3.B: Expression of genetic information involves cellular and molecular mechanisms.**
**Essential knowledge 3.B.2: A variety of intercellular and intracellular signal transmissions mediate gene expression.**

a. Signal transmission within and between cells mediates cell function.

*To demonstrate student understanding of this concept, make sure you can explain:*

- Mating pheromones in yeast trigger mating genes expression and sexual reproduction.
- Morphogens stimulate cell differentiation and development.
- Changes in p53 activity can result in cancer.
- HOX genes and their role in development.

**Student Objectives:**

- **Explain the relationship between signal transduction and cellular differentiation.**
- **Describe how morphogens and HOX genes contribute to the development of an animal.**

Learning Objectives:

- The student is able to explain how signal pathways mediate gene expression, including how this process can affect protein production.
- The student can use representations to describe mechanisms of the regulation of gene expression.

**Enduring understanding 3.C: The processing of genetic information is imperfect and is a source of genetic variation.**
**Essential knowledge 3.C.3: Viral replication results in genetic variation, and viral infection can introduce genetic variation into the hosts.**

a. Viral replication differs from other reproductive strategies and generates genetic variation via various mechanisms.

*Evidence of student learning is a demonstrated understanding of each of the following:*

1. Viruses have highly efficient replicative capabilities that allow for rapid evolution and acquisition of new phenotypes.
2. Viruses replicate via a component assembly model allowing one virus to produce many progeny simultaneously via the lytic cycle.
3. Virus replication allows for mutations to occur through usual host pathways.
4. RNA viruses lack replication error-checking mechanisms, and thus have higher rates of mutation.
5. Related viruses can combine/recombine information if they infect the same host cell.
6. HIV is a well-studied system where the rapid evolution of a virus within the host contributes to the pathogenicity of viral infection.

b. The reproductive cycles of viruses facilitate transfer of genetic information.

*Evidence of student learning is a demonstrated understanding of each of the following:*

1. Viruses transmit DNA or RNA when they infect a host cell.
2. To foster student understanding of this concept, instructors can choose an
3. illustrative example such as:
4. Transduction in bacteria
5. Transposons present in incoming DNA
6. Some viruses are able to integrate into the host DNA and establish a latent (lysogenic) infection. These latent viral genomes can result in new properties for the host such as increased pathogenicity in bacteria.

**Student Objectives:**

- **Diagram all modes of viral replication discussed in this course and provide example viruses that follow each course of replication.**
- **Compare prokaryotic viruses and eukaryotic viruses.**
- **Explain the structure and function of HIV.**
- **Describe how viral processes increase genetic variation in prokaryotes and eukaryotes.**

- **Diagram and describe the structure and function of transposons and retrotransposons.**

Learning Objectives:
- The student is able to construct an explanation of how viruses introducegenetic variation in host organisms.
- The student is able to use representations and appropriate models to describe how viral replication introduces genetic variation in the viral population.

**Enduring understanding 4.A: Interactions within biological systems lead to complex properties.**
**Essential knowledge 4.A.3: Interactions between external stimuli and regulated gene expression result in specialization of cells, tissues and organs.**

a. Differentiation in development is due to external and internal cues that trigger gene regulation by proteins that bind to DNA.
b. Structural and functional divergence of cells in development is due to expression of genes specific to a particular tissue or organ type.
c. Environmental stimuli can affect gene expression in a mature cell.

**Student Objectives:**
- **Explain the process of cellular divergence and differentiation.**
- **Provide examples of external and internal cues that direct divergence and differentation.**

Learning Objective:
- The student is able to refine representations to illustrate how interactions between external stimuli and gene expression result in specialization of cells, tissues and organs.

**Enduring understanding 4.C: Naturally occurring diversity among and between components within biological systems affects interactions with the environment.**
**Essential knowledge 4.C.1: Variation in molecular units provides cells with a wider range of functions.**

a. Multiple copies of alleles or genes (gene duplication) may provide new phenotypes.
*To demonstrate student understanding of this concept, make sure you can explain:*

1. 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.
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.
   *To demonstrate student understanding of this concept, make sure you can explain:*
   - The antifreeze gene in fish

**Student Objectives:**
- **Describe the evolutionary processes that are seen in genomic analysis and how these processes affect the structure of genomes.**
- **Explain the structure and function of all major segments of the human genome.**
- **Explain how gene duplication can lead to an increase in genetic information in an organism.**
- **Cite evidence from genomic analysis that relates to the evolution of the human lineage.**

Learning Objective:
- The student is able to construct explanations based on evidence of how variation in molecular units provides cells with a wider range of functions.

# Metabolism Student Objectives

**<u>Enduring understanding 2.A: Growth, reproduction and maintenance of the organization of living systems require free energy and matter.</u>**

**Essential knowledge 2.A.1: All living systems require constant input of free energy.**

a. Life requires a highly ordered system.

*Evidence of student learning is a demonstrated understanding of each of the following:*

1. Order is maintained by constant free energy input into the system.
2. Loss of order or free energy flow results in death.
3. Increased disorder and entropy are offset by biological processes that maintain or increase order.

b. Living systems do not violate the second law of thermodynamics, which states that entropy increases over time.

*Evidence of student learning is a demonstrated understanding of each of the following:*

1. Order is maintained by coupling cellular processes that increase entropy (and so have negative changes in free energy) with those that decrease entropy (and so have positive changes in free energy).
2. Energy input must exceed free energy lost to entropy to maintain order and power cellular processes.
3. Energetically favorable exergonic reactions, such as ATP→ADP, that have a negative change in free energy can be used to maintain or increase order in a system by being coupled with reactions that have a positive free energy change.

c. Energy-related pathways in biological systems are sequential and may be entered at multiple points in the pathway.

*To demonstrate student understanding of this concept, make sure you can explain the following:*

- Krebs cycle
- Glycolysis
- Calvin cycle
- Fermentation

d. Organisms use free energy to maintain organization, grow and reproduce.

*Evidence of student learning is a demonstrated understanding of each of the following:*

1. Excess acquired free energy versus required free energy expenditure results in energy storage or growth.
2. Insufficient acquired free energy versus required free energy expenditure results in loss of mass and, ultimately, the death of an organism.

**Student Objectives:**

- **Explain the consequences of the first and second laws of thermodynamics for living systems.**
- **Explain how life is able to adhere to the laws of thermodynamics and accomplish the following life processes:**
  - **Growth**
  - **Increase in Order**
  - **Decrease in Entropy**
  - **Reproduction**
- **Describe the features of metabolic pathways that lead to maximized efficiency and controlled release of free energy.**
- **Describe the role of ATP in the production of cellular work.**
- **Compare exergonic and endergonic processes. Provide examples of each.**
- **Compare anabolic and catabolic processes. Provide examples of each.**

Learning Objectives:

- The student is able to explain how biological systems use free energy based on empirical data that all organisms require constant energy input to maintain

- The student is able to justify a scientific claim that free energy is required for living systems to maintain organization, to grow or to reproduce, but that multiple strategies exist in different living systems.

**Essential knowledge 2.A.2: Organisms capture and store free energy for use in biological processes.**

a. Autotrophs capture free energy from physical sources in the environment.

*Evidence of student learning is a demonstrated understanding of each of the following:*

1. Photosynthetic organisms capture free energy present in sunlight.
2. Chemosynthetic organisms capture free energy from small inorganic molecules present in their environment, and this process can occur in the absence of oxygen.

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

*Evidence of student learning is a demonstrated understanding of each of the following:*

1. Heterotrophs may metabolize carbohydrates, lipids and proteins by hydrolysis as sources of free energy.
2. Fermentation produces organic molecules, including alcohol and lactic acid, and it occurs in the absence of oxygen.

c. Different energy-capturing processes use different types of electron acceptors.

*To demonstrate student understanding of this concept, make sure you can explain*

- NADP+ in photosynthesis
- Oxygen in cellular respiration

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.

*Evidence of student learning is a demonstrated understanding of each of the following:*

1. During photosynthesis, chlorophylls absorb free energy from light, boosting electrons to a higher energy level in Photosystems I and II.
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).
3. When electrons are transferred between molecules in a sequence of reactions as they pass through the ETC, an electrochemical gradient of hydrogen ions (protons) across the thykaloid membrane is established.
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.
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.

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.

f. Cellular respiration in eukaryotes involves a series of coordinated enzyme-catalyzed reactions that harvest free energy from simple carbohydrates.

*Evidence of student learning is a demonstrated understanding of each of the following:*

1. Glycolysis rearranges the bonds in glucose molecules, releasing free energy to form ATP from ADP and inorganic phosphate, and resulting in the production of pyruvate.
2. Pyruvate is transported from the cytoplasm to the mitochondrion, where further oxidation occurs.
3. In the Krebs cycle, carbon dioxide is released from organic intermediates ATP is synthesized from ADP and inorganic phosphate via substrate level phosphorylation and electrons are captured by coenzymes.
4. Electrons that are extracted in the series of Krebs cycle reactions are carried by NADH and $FADH_2$ to the electron transport chain.

g. The electron transport chain captures free energy from electrons in a series of coupled reactions that establish an electrochemical gradient across membranes.

*Evidence of student learning is a demonstrated understanding of each of the following:*

1. Electron transport chain reactions occur in chloroplasts (photosynthesis), mitochondria (cellular respiration) and prokaryotic plasma membranes.
2. In cellular respiration, electrons delivered by NADH and FADH2 are passed to a series of electron acceptors as they move toward the terminal electron acceptor, oxygen. In photosynthesis, the terminal electron acceptor is NADP+.
3. The passage of electrons is accompanied by the formation of a proton gradient across the inner mitochondrial membrane or the thylakoid membrane of chloroplasts, with the membrane(s) separating a region of high proton concentration from a region of low proton concentration. In prokaryotes, the passage of electrons is accompanied by the outward movement of protons across the plasma membrane.
4. The flow of protons back through membrane-bound ATP synthase by chemiosmosis generates ATP from ADP and inorganic phosphate.
5. In cellular respiration, decoupling oxidative phosphorylation from electron transport is involved in thermoregulation.

h. Free energy becomes available for metabolism by the conversion of ATP→ADP, which is coupled to many steps in metabolic pathways.

**Student Objectives:**

- **Compare the major features of chemoheterotrophic and photoautotrophic nutritional processes.**
- **Explain the necessity of electron shuttles in metabolic pathways.**
- **Explain the inputs, major processes, and outputs of glycolysis, fermentation, and aerobic cellular respiration.**
- **Trace the movement of energy and matter through all respiratory processes.**
- **Localize all respiratory processes to their locations in a typical eukaryotic cell.**
- **Explain the inputs, major processes, and outputs of the light reactions and the Calvin Cycle.**
- **Trace the movement of energy and matter through all photosynthetic processes.**
- **Localize all photosynthetic processes to their location sin a typical eukaryotic, autotrophic cell.**
- **Describe the process of chemiosmosis and compare its function in photosynthetic and respiratory pathways.**
- **Explain the relationship between photosynthesis and respiration at the subcellular, organismal, and ecosystem levels of organization.**
- **Compare the relative efficiencies of photosynthesis, anaerobic cellular respiration and aerobic cellular respiration.**
- **Explain how energetic requirements contribute to the adaptations of organisms. Provide examples to support your statements.**
- **Propose experimental designs by which the rate of photosynthesis and respiration can be measured and studied.**

Learning Objectives:

- The student is able to use representations to pose scientific questions about what mechanisms and structural features allow organisms to capture, store and use free energy.
- The student is able to construct explanations of the mechanisms and structural features of cells that allow organisms to capture, store or use free energy.

**<u>Enduring understanding 4.B: Competition and cooperation are important aspects of biological systems.</u>**

**Essential knowledge 4.B.1: Interactions between molecules affect their structure and function.**

a. Change in the structure of a molecular system may result in a change of the function of the system.
b. The shape of enzymes, active sites and interaction with specific molecules are essential for basic functioning of the enzyme.

*Evidence of student learning is a demonstrated understanding of each of the following:*

1. For an enzyme-mediated chemical reaction to occur, the substrate must be complementary to the surface properties (shape and charge) of the active site. In other words, the substrate must fit into the enzyme's active site.

2. Cofactors and coenzymes affect enzyme function; this interaction relates to a structural change that alters the activity rate of the enzyme. The enzyme may only become active when all the appropriate cofactors or coenzymes are present and bind to the appropriate sites on the enzyme.

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.

d. The change in function of an enzyme can be interpreted from data regarding the concentrations of product or substrate as a function of time. These representations demonstrate the relationship between an enzyme's activity, the disappearance of substrate, and/or presence of a competitive inhibitor.

**Student Objectives:**

- **Describe the relationship between the structure and function of enzymes.**
- **Explain how environmental conditions can affect enzyme function. Provide examples.**
- **Explain how enzymes accomplish biological catalysis. Provide examples.**
- **Describe how enzyme-mediated reactions can be controlled through competitive and non-competitive interactions.**
- **Propose experimental designs by which the rate of enzyme function can be measured and studied.**

Learning Objective:

- The student is able to analyze data to identify how molecular interactions affect structure and function.

# Physiology Student Objectives

**<u>Enduring understanding 2.C: Organisms use feedback mechanisms to regulate growth and reproduction, and to maintain dynamic homeostasis.</u>**

**Essential knowledge 2.C.1: Organisms use feedback mechanisms to maintain their internal environments and respond to external environmental changes.**

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.

*To demonstrate student understanding of this concept, make sure you can explain the following:*

- Temperature regulation in animals
- Plant responses to water limitations

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.

*To demonstrate student understanding of this concept, make sure you can explain the following:*

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

c. Alteration in the mechanisms of feedback often results in deleterious consequences.

*To demonstrate student understanding of this concept, make sure you can explain the following:*

- Diabetes mellitus in response to decreased insulin
- Dehydration in response to decreased antidiuretic hormone (ADH)
- Graves' disease (hyperthyroidism)
- Blood clotting

**Student Objectives:**

- **What do organisms use feedback mechanisms for?**
- **How do negative feedback mechanisms work to maintain dynamic homeostasis for a particular condition? Focus your answer using the following examples:**
  - **Temperature regulation in animals**
  - **Plant responses to water limitations**
- **How do Positive feedback mechanisms work to maintain dynamic homeostasis for a particular condition? Focus your answer using the following examples:**
  - **Lactation in mammals**
  - **Onset of labor in childbirth**
  - **Ripening of fruit**
- **Explain the effects of alteration in the mechanisms of feedback. Use the following to help illustrate your explanation:**
  - **Diabetes mellitus in response to decreased insulin**
  - **Dehydration in response to decreased antidiuretic hormone (ADH)**
  - **Graves' disease (hyperthyroidism)**
  - **Blood clotting**

Learning Objectives:

- The student can justify a claim made about the effect(s) on a biological system at the molecular, physiological or organismal level when given a scenario in which one or more components within a negative regulatory system is altered.
- The student is able to connect how organisms use negative feedback to maintain their internal environments.
- The student is able to evaluate data that show the effect(s) of changes in concentrations of key molecules on negative feedback mechanisms.
- The student can make predictions about how organisms use negative feedback mechanisms to maintain their internal environments.
- The student is able to make predictions about how positive feedback mechanisms amplify activities and processes in organisms based on scientific theories and models.
- The student is able to justify that positive feedback mechanisms amplify responses in organisms.

**Essential knowledge 2.C.2: Organisms respond to changes in their external environments.**

a. Organisms respond to changes in their environment through behavioral and physiological mechanisms.
*To demonstrate student understanding of this concept, make sure you can explain the following:*

- Photoperiodism and phototropism in plants
- Hibernation and migration in animals
- Taxis and kinesis in animals
- Chemotaxis in bacteria, sexual reproduction in fungi
- Nocturnal and diurnal activity: circadian rhythms
- Shivering and sweating in humans

**Student Objectives:**

- **Explain how organisms respond to changes in their environment through behavioral and physiological mechanisms. Use the following to help illustrate your explanation:**
  - **Photoperiodism and phototropism in plants**
  - **Hibernation and migration in animals**
  - **Taxis and kinesis in animals**
  - **Chemotaxis in bacteria, sexual reproduction in fungi**
  - **Nocturnal and diurnal activity: circadian rhythms**
  - **Shivering and sweating in humans**

Learning Objective:

- The student is able to justify the selection of the kind of data needed to answer scientific questions about the relevant mechanism that organisms use to respond to changes in their external environment.

**Enduring understanding 2.D: Growth and dynamic homeostasis of a biological system are influenced by changes in the system's environment.**

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

a. Continuity of homeostatic mechanisms reflects common ancestry, while changes may occur in response to different environmental conditions.
b. Organisms have various mechanisms for obtaining nutrients and eliminating wastes.
*To demonstrate student understanding of this concept, make sure you can explain the following:*

- Gas exchange in aquatic and terrestrial plants
- Digestive mechanisms in animals such as food vacuoles, gastrovascular cavities, one-way digestive systems
- Respiratory systems of aquatic and terrestrial animals
- Nitrogenous waste production and elimination in aquatic and terrestrial animals

c. Homeostatic control systems in species of microbes, plants and animals support common ancestry.
*To demonstrate student understanding of this concept, make sure you can explain the following:*

- Excretory systems in flatworms, earthworms and vertebrates
- Osmoregulation in bacteria, fish and protists
- Osmoregulation in aquatic and terrestrial plants
- Circulatory systems in fish, amphibians and mammals
- Thermoregulation in aquatic and terrestrial animals (countercurrent exchange mechanisms)

**Student Objectives:**

- **How do homeostatic mechanisms relate to evolution?**
- **How is the concept of common ancestry supposed by continuity in homeostatic mechanisms. How do changes in environmental conditions affect this continuity.**
- **Explain how the following mechanisms are used for obtaining nutrients and eliminating wastes.**
  - **Gas exchange in aquatic and terrestrial plants**
  - **Digestive mechanisms in animals such as food vacuoles, gastrovascular cavities, one-way digestive systems**
  - **Respiratory systems of aquatic and terrestrial animals**
  - **Nitrogenous waste production and elimination in aquatic and terrestrial animals**
- **Explain how homeostatic control systems in species of microbes, plants an animals support common ancestry. Use the following to help illustrate your explanation:**
  - **Excretory systems in flatworms, earthworms and vertebrates**
  - **Osmoregulation in bacteria, fish and protists**
  - **Osmoregulation in aquatic and terrestrial plants**

- **Circulatory systems in fish, amphibians and mammals**
- **Thermoregulation in aquatic and terrestrial animals (countercurrent exchange mechanisms)**

Learning Objectives:

- The student can construct explanations based on scientific evidence that homeostatic mechanisms reflect continuity due to common ancestry and/or divergence due to adaptation in different environments.
- The student is able to analyze data to identify phylogenetic patterns or relationships, showing that homeostatic mechanisms reflect both continuity due to common ancestry and change due to evolution in different environments.
- The student is able to connect differences in the environment with the evolution of homeostatic mechanisms.

**Essential knowledge 2.D.3: Biological systems are affected by disruptions to their dynamic homeostasis.**

a. Disruptions at the molecular and cellular levels affect the health of the organism.

*To demonstrate student understanding of this concept, make sure you can explain the following:*

- Physiological responses to toxic substances
- Dehydration
- Immunological responses to pathogens, toxins and allergens

**Student Objectives:**

- **How do disruptions at the molecular and cellular levels affect the health of the organism? Use the following to explain your answer:**
  - **Physiological responses to toxic substances**
  - **Dehydration**
  - **Immunological responses to pathogens, toxins and allergens**

Learning Objective:

- The student is able to use representations or models to analyze quantitatively and qualitatively the effects of disruptions to dynamic homeostasis in biological systems.

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

a. Plants, invertebrates and vertebrates have multiple, nonspecific immune responses.

*To demonstrate student understanding of this concept, make sure you can explain the following:*

- Invertebrate immune systems have nonspecific response mechanisms, but they lack pathogen-specific defense responses.
- Plant defenses against pathogens include molecular recognition systems with systemic responses; infection triggers chemical responses that destroy infected and adjacent cells, thus localizing the effects.
- Vertebrate immune systems have nonspecific and nonheritable defense mechanisms against pathogens.

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

*Evidence of student learning is a demonstrated understanding of each of the following:*

1. The mammalian immune system includes two types of specific responses: cell mediated and humoral.
2. In the cell-mediated response, cytotoxic T cells, a type of lymphocytic white blood cell, “target” intracellular pathogens when antigens are displayed on the outside of the cells.
3. In the humoral response, B cells, a type of lymphocytic white blood cell, produce antibodies against specific antigens.
4. Antigens are recognized by antibodies to the antigen.
5. Antibodies are proteins produced by B cells, and each antibody is specific to a particular antigen.
6. A second exposure to an antigen results in a more rapid and enhanced immune response.

**Student Objectives:**

- **Explain how plants, invertebrates and vertebrates have multiple, nonspecific immune responses. Use the following to explain your answer:**
  - **Invertebrate immune systems have nonspecific response mechanisms, but they lack pathogen-specific defense responses.**

    - **Plant defenses against pathogens include molecular recognition systems with systemic responses; infection triggers chemical responses that destroy infected and adjacent cells, thus localizing the effects.**
    - **Vertebrate immune systems have nonspecific and nonheritable defense mechanisms against pathogens.**
- **Describe mammalian specific immune responses.**
- **Describe the two types of specific responses in the Mammalian immune system**
- **In the cell-mediated response, what is the role of cytotoxic T cells?**
- **In the humoral response, what is the role of B cells?**
- **Explain how antigens and antibodies work together.**
- **What is an antibodies**
- **How does a second exposure to an antigen differ from the primary exposure?**

Learning Objectives:

- The student can create representations and models to describe immune responses.
- The student can create representations or models to describe nonspecific immune defenses in plants and animals.

**Enduring understanding 2.E: Many biological processes involved in growth, reproduction and dynamic homeostasis include temporal regulation and coordination.**

**Essential knowledge 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.**

a. Observable cell differentiation results from the expression of genes for tissue-specific proteins.
b. Induction of transcription factors during development results in sequential gene expression.
*Evidence of student learning is a demonstrated understanding of each of the following:*

1. Homeotic genes are involved in developmental patterns and sequences.
2. Embryonic induction in development results in the correct timing of events.
3. Temperature and the availability of water determine seed germination in most plants.
4. Genetic mutations can result in abnormal development.
5. Genetic transplantation experiments support the link between gene expression and normal development.
6. Genetic regulation by microRNAs plays an important role in the development of organisms and the control of cellular functions.

c. Programmed cell death (apoptosis) plays a role in the normal development and differentiation.
*To demonstrate student understanding of this concept, make sure you can explain the following:*

- Morphogenesis of fingers and toes
- Immune function
- *C. elegans* development
- Flower development

**Student Objectives:**

- **What is necessary for the normal development of an organism, and how is it regulated?**
- **What causes observable cell differentiation?**
- **Explain the roll of transcription factors during development and how they results in sequential gene expression.**
- **Homeotic genes are involved in the development of what?**
- **Explain how see germination is regulated in most plants.**
- **What is the effect of genetic mutations in development?**
- **Genetic transplantation experiments have given evidence of what?**
- **What is the role of microRNAs in the development of organisms?**
- **Explain how programmed cell death (apoptosis) effect normal development and differentiation by using the following examples.**
    - **Morphogenesis of fingers and toes**
    - **Immune function**
    - ***C. elegans* development**
    - **Flower development**

Learning Objectives:

- The student can connect concepts in and across domains to show that timing and coordination of specific events are necessary for normal development in an organism and that these events are regulated by multiple mechanisms.
- The student is able to use a graph or diagram to analyze situations or solve problems (quantitatively or qualitatively) that involve timing and coordination of events necessary for normal development in an organism.
- The student is able to justify scientific claims with scientific evidence to show that timing and coordination of several events are necessary for normal development in an organism and that these events are regulated by multiple mechanisms.
- The student is able to describe the role of programmed cell death in development and differentiation, the reuse of molecules, and the maintenance of dynamic homeostasis.

**Essential knowledge 2.E.2: Timing and coordination of physiological events are regulated by multiple mechanisms.**

a. In plants, physiological events involve interactions between environmental stimuli and internal molecular signals. [See also 2.C.3]

*To demonstrate student understanding of this concept, make sure you can explain the following:*

1. Phototropism, or the response to the presence of light
2. Photoperiodism, or the response to change in length of the night, that results in flowering in long-day and short-day plants

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

*To demonstrate student understanding of this concept, make sure you can explain the following:*

- Circadian rhythms, or the physiological cycle of about 24 hours that is present in all eukaryotes and persists even in the absence of external cues
- Diurnal/nocturnal and sleep/awake cycles
- Jet lag in humans
- Seasonal responses, such as hibernation, estivation and migration
- Release and reaction to pheromones
- Visual displays in the reproductive cycle

c. In fungi, protists and bacteria, internal and external signals regulate a variety of physiological responses that synchronize with environmental cycles and cues.

*To demonstrate student understanding of this concept, make sure you can explain the following:*

- Fruiting body formation in fungi, slime molds and certain types of bacteria
- Quorum sensing in bacteria

**Student Objectives:**

- **Describe how in plants, physiological events involve interactions between environmental stimuli and internal molecular signals.**
- **Explain how plants undergo phototropism, or the response to the presence of light**
- **Explain the effect of change in length of night or Photoperiodism.**
- **Use the following examples to illustrate how in animals, internal and external signals regulate a variety of physiological responses that synchronize with environmental cycles and cues.**
    - **Circadian rhythms, or the physiological cycle of about 24 hours that is present in all eukaryotes and persists even in the absence of external cues**
    - **Diurnal/nocturnal and sleep/awake cycles**
    - **Jet lag in humans**
    - **Seasonal responses, such as hibernation, estivation and migration**
    - **Release and reaction to pheromones**
    - **Visual displays in the reproductive cycle**
- **Use the following examples to describe how in fungi, protists and bacteria, internal and external signals regulate a variety of physiological responses that synchronize with environmental cycles and cues.**
    - **Fruiting body formation in fungi, slime molds and certain types of bacteria**
    - **Quorum sensing in bacteria**

Learning Objectives:

- The student is able to design a plan for collecting data to support the scientific claim that the timing and coordination of physiological events involve regulation.

- The student is able to justify scientific claims with evidence to show how timing and coordination of physiological events involve regulation.
- The student is able to connect concepts that describe mechanisms that regulate the timing and coordination of physiological events.

**<u>Enduring understanding 3.D: Cells communicate by generating, transmitting and receiving chemical signals.</u>**

**Essential knowledge 3.D.1: Cell communication processes share common features that reflect a shared evolutionary history.**

a. Communication involves transduction of stimulatory or inhibitory signals from other cells, organisms or the environment.

b. Correct and appropriate signal transduction processes are generally under strong selective pressure.

c. In single-celled organisms, signal transduction pathways influence how the cell responds to its environment.

*To demonstrate student understanding of this concept, make sure you can explain the following:*

- Use of chemical messengers by microbes to communicate with other nearby cells and to regulate specific pathways in response to population density (quorum sensing)
- Use of pheromones to trigger reproduction and developmental pathways
- Response to external signals by bacteria that influences cell movement

d. In multicellular organisms, signal transduction pathways coordinate the activities within individual cells that support the function of the organism as a whole.

*To demonstrate student understanding of this concept, make sure you can explain the following:*

- Epinephrine stimulation of glycogen breakdown in mammals
- Temperature determination of sex in some vertebrate organisms
- DNA repair mechanisms

**Student objectives:**

- **Describe how cells communicate using transduction of stimulatory or inhibitory signals from other cells, organisms or the environment.**
- **Relate correct and appropriate signal transduction processes to selective pressure.**
- **Use the below examples to explain how, in single-celled organisms, signal transduction pathways influence how the cell responds to its environment.**
    - **Use of chemical messengers by microbes to communicate with other nearby cells and to regulate specific pathways in response to population density (quorum sensing)**
    - **Use of pheromones to trigger reproduction and developmental pathways**
    - **Response to external signals by bacteria that influences cell movement**
- **Use the below examples to explain how, in multicellular organisms, signal transduction pathways coordinate the activities within individual cells that support the function of the organism as a whole.**
    - **Epinephrine stimulation of glycogen breakdown in mammals**
    - **Temperature determination of sex in some vertebrate organisms**
    - **DNA repair mechanisms**

Learning Objectives:

- The student is able to describe basic chemical processes for cell communication shared across evolutionary lines of descent.
- The student is able to generate scientific questions involving cell communication as it relates to the process of evolution.
- The student is able to use representation(s) and appropriate models to describe features of a cell signaling pathway.

**Essential knowledge 3.D.2: Cells communicate with each other through direct contact with other cells or from a distance via chemical signaling.**

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

*To demonstrate student understanding of this concept, make sure you can explain the following:*

- Immune cells interact by cell-cell contact, antigen-presenting cells (APCs), helper T-cells and killer T-cells. [See also 2.D.4]
- Plasmodesmata between plant cells that allow material to be transported from cell to cell.

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

*To demonstrate student understanding of this concept, make sure you can explain the following:*

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

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

*Evidence of student learning is a demonstrated understanding of the following:*

1. Endocrine signals are produced by endocrine cells that release signaling molecules, which are specific and can travel long distances through the blood to reach all parts of the body.

*To demonstrate student understanding of this concept, make sure you can explain the following:*

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

**Student Objectives:**

- **Explain how cells communicate by cell-to-cell contact, by discussing the two examples below:**
  - **Immune cells interact by cell-cell contact, antigen-presenting cells (APCs), helper T-cells and killer T-cells.**
  - **Plasmodesmata between plant cells that allow material to be transported from cell to cell.**
- **Use the examples below to explain how it relates to cell communication over short distances.**
  - **Neurotransmitters**
  - **Plant immune response**
  - **Quorum sensing in bacteria**
  - **Morphogens in embryonic development**
- **Explain the concept of a target cell, when discussing long distance cellular communication.**
- **Use the examples below to explain how endocrine signals are produced by endocrine cells that release signaling molecules, which are specific and can travel long distances through the blood to reach all parts of the body.**
  - **Insulin**
  - **Human growth hormone**
  - **Thyroid hormones**
  - **Testosterone**
  - **Estrogen**

Learning Objectives:

- The student is able to construct explanations of cell communication through cell-to-cell direct contact or through chemical signaling.
- The student is able to create representation(s) that depict how cell-to-cell communication occurs by direct contact or from a distance through chemical signaling.

**Essential knowledge 3.D.4: Changes in signal transduction pathways can alter cellular response.**

a. Conditions where signal transduction is blocked or defective can be deleterious, preventative or prophylactic.

*To demonstrate student understanding of this concept, make sure you can explain the following:*

- Diabetes, heart disease, neurological disease, autoimmune disease, cancer, cholera
- Effects of neurotoxins, poisons, pesticides
- Drugs (Hypertensives, Anesthetics, Antihistamines and Birth Control Drugs)

**Student Objectives:**

- **Use the examples below to explain how the condition relates to signal transduction being blocked or defective and describe if the condition is deleterious, preventative or prophylactic.**
  - **Diabetes, heart disease, neurological disease, autoimmune disease, cancer, cholera**
  - **Effects of neurotoxins, poisons, pesticides**
  - **Drugs (Hypertensives, Anesthetics, Antihistamines and Birth Control Drugs)**

Learning Objectives:

- The student is able to justify claims based on scientific evidence that changes in signal transduction pathways can alter cellular response.

- The student is able to describe a model that expresses key elements to show how change in signal transduction can alter cellular response.
- The student is able to construct an explanation of how certain drugs affect signal reception and, consequently, signal transduction pathways.

**Enduring understanding 3.E: Transmission of information results in changes within and between biological systems.**

**Essential knowledge 3.E.2: Animals have nervous systems that detect external and internal signals, transmit and integrate information, and produce responses.**

a. The neuron is the basic structure of the nervous system that reflects function.

*Evidence of student learning is a demonstrated understanding of each of the following:*

1. A typical neuron has a cell body, axon and dendrites. Many axons have a myelin sheath that acts as an electrical insulator.
2. The structure of the neuron allows for the detection, generation, transmission and integration of signal information.
3. Schwann cells, which form the myelin sheath, are separated by gaps of unsheathed axon over which the impulse travels as the signal propagates along the neuron.

b. Action potentials propagate impulses along neurons.

*Evidence of student learning is a demonstrated understanding of each of the following:*

1. Membranes of neurons are polarized by the establishment of electrical potentials across the membranes.
2. In response to a stimulus, Na+ and K+ gated channels sequentially open and cause the membrane to become locally depolarized.
3. Na+/K+ pumps, powered by ATP, work to maintain membrane potential.

c. Transmission of information between neurons occurs across synapses.

*Evidence of student learning is a demonstrated understanding of each of the following:*

1. In most animals, transmission across synapses involves chemical messengers called neurotransmitters.

*To demonstrate student understanding of this concept, make sure you can explain the effects of the following:*

- Acetylcholine
- Epinephrine
- Norepinephrine
- Dopamine
- Serotonin
- GABA

2. Transmission of information along neurons and synapses results in a response.
3. The response can be stimulatory or inhibitory.

d. Different regions of the vertebrate brain have different functions.

*To demonstrate student understanding of this concept, make sure you can explain the following:*

- Vision
- Hearing
- Muscle movement
- Abstract thought and emotions
- Neuro-hormone production
- Forebrain (cerebrum), midbrain (brainstem) and hindbrain (cerebellum)
- Right and left cerebral hemispheres in humans

**Student Objectives:**

- **Identify the parts of a typical neuron.**
- **Describe the structure of the neuron and explain how it's structure relates to the detection, generation, transmission and integration of signal information.**
- **Identify the role of Schwann cells in relationship to signal propagation.**
- **Discuss how membranes of neurons are polarized.**
- **Describe how local depolarization occurs.**
- **Explain how membrane potential is maintained.**
- **Explain how transmission of neurotransmitters across synapses occurs, and the effects of each of the following neurotransmitters:**
    - **Acetylcholine**

    - **Epinephrine**
    - **Norepinephrine**
    - **Dopamine**
    - **Serotonin**
    - **GABA**
- **Describe how transmission along neurons and across synapses results in a response.**
- **Explain how a response can be stimulatory or inhibitory.**
- **Describe the anatomy of the vertebrate brain and relate the anatomy with the following functions.**
    - **Vision**
    - **Hearing**
    - **Muscle movement**
    - **Abstract thought and emotions**
    - **Neuro-hormone production**
    - **Forebrain (cerebrum), midbrain (brainstem) and hindbrain (cerebellum)**
    - **Right and left cerebral hemispheres in humans**

Learning Objectives:

- The student is able to construct an explanation, based on scientific theories and models, about how nervous systems detect external and internal signals, transmit and integrate information, and produce responses.
- The student is able to describe how nervous systems detect external and internal signals.
- The student is able to describe how nervous systems transmit information.
- The student is able to describe how the vertebrate brain integrates information to produce a response.
- The student is able to create a visual representation of complex nervous systems to describe/explain how these systems detect external and internal signals, transmit and integrate information, and produce responses.
- The student is able to create a visual representation to describe how nervous systems detect external and internal signals.
- The student is able to create a visual representation to describe how nervous systems transmit information.
- The student is able to create a visual representation to describe how the vertebrate brain integrates information to produce a response.

**<u>Enduring understanding 4.A: Interactions within biological systems lead to complex properties.</u>**
**Essential knowledge 4.A.4: Organisms exhibit complex properties due to interactions between their constituent parts.**

a. Interactions and coordination between organs provide essential biological activities.
*To demonstrate student understanding of this concept, make sure you can explain the following:*

- Stomach and small intestines
- Kidney and bladder
- Root, stem and leaf

b. Interactions and coordination between systems provide essential biological activities.
*To demonstrate student understanding of this concept, make sure you can explain the following:*

- Respiratory and circulatory
- Nervous and muscular
- Plant vascular and leaf

**Student Objective:**

- **Use the following examples to discuss the importance of Interactions and coordination between organs.**
    - **Stomach and small intestines**
    - **Kidney and bladder**
    - **Root, stem and leaf**
- **Using the following examples to discuss the importance of Interactions and coordination between systems**
    - **Respiratory and circulatory**
    - **Nervous and muscular**
    - **Plant vascular and leaf**

Learning Objectives:

- The student is able to evaluate scientific questions concerning organisms that exhibit complex properties due to the interaction of their constituent parts.
- The student is able to predict the effects of a change in a component(s) of a biological system on the functionality of an organism(s).

- The student is able to refine representations and models to illustrate biocomplexity due to interactions of the constituent parts.

**<u>Enduring understanding 4.B: Competition and cooperation are important aspects of biological systems.</u>**
**Essential knowledge 4.B.2: Cooperative interactions within organisms promote efficiency in the use of energy and matter.**

a. Organisms have areas or compartments that perform a subset of functions related to energy and matter, and these parts contribute to the whole.

*To demonstrate student understanding of this concept, make sure you can explain the following:*

1. At the cellular level, the plasma membrane, cytoplasm and, for eukaryotes, the organelles contribute to the overall specialization and functioning of the cell.
2. Within multicellular organisms, specialization of organs contributes to the overall functioning of the organism.

*To demonstrate student understanding of this concept, make sure you can explain the following:*

- Exchange of gases
- Circulation of fluids
- Digestion of food
- Excretion of wastes

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.

*To demonstrate student understanding of this concept, make sure you can explain the following:*

- Bacterial community in the rumen of animals
- Bacterial community in and around deep sea vents

**Student Objectives:**

- **Explain how at the cellular level, the plasma membrane, cytoplasm and, for eukaryotes, the organelles contribute to the overall specialization and functioning of the cell.**
- **Using the examples below to illustrate how specialization of organs contributes to the overall functioning of the organism.**
  - **Exchange of gases**
  - **Circulation of fluids**
  - **Digestion of food**
  - **Excretion of wastes**
- **Using the examples below to explain how 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.**
  - **Bacterial community in the rumen of animals**
  - **Bacterial community in and around deep sea vents**

Learning Objective:

- The student is able to use representations and models to analyze how cooperative interactions within organisms promote efficiency in the use of energy and matter.

# Ecology Student Objectives

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

**Essential knowledge 2.A.1: All living systems require constant input of free energy.**

a. Life requires a highly ordered system.

*To demonstrate student understanding of this concept, make sure you can explain the following:*

1. Order is maintained by constant free energy input into the system.
2. Loss of order or free energy flow results in death.
3. Increased disorder and entropy are offset by biological processes that maintain or increase order.

b. Living systems do not violate the second law of thermodynamics, which states that entropy increases over time.

*To demonstrate student understanding of this concept, make sure you can explain the following:*

1. Order is maintained by coupling cellular processes that increase entropy (and so have negative changes in free energy) with those that decrease entropy (and so have positive changes in free energy).
2. Energy input must exceed free energy lost to entropy to maintain order and power cellular processes.
3. Energetically favorable exergonic reactions, such as ATP→ADP, that have a negative change in free energy can be used to maintain or increase order in a system by being coupled with reactions that have a positive free energy change.

c. Organisms use free energy to maintain organization, grow and reproduce.

*To demonstrate student understanding of this concept, make sure you can explain the following:*

1. Organisms use various strategies to regulate body temperature and metabolism.

*To demonstrate student understanding of this concept, make sure you can explain the following:*

- Endothermy (the use of thermal energy generated by metabolism to maintain homeostatic body temperatures)
- Ectothermy (the use of external thermal energy to help regulate and maintain body temperature)
- Elevated floral temperatures in some plant species

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.

*To demonstrate student understanding of this concept, make sure you can explain the following:*

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

3. There is a relationship between metabolic rate per unit body mass and the size of multicellular organisms — generally, the smaller the organism, the higher the metabolic rate.
4. Excess acquired free energy versus required free energy expenditure results in energy storage or growth.
5. Insufficient acquired free energy versus required free energy expenditure results in loss of mass and, ultimately, the death of an organism.

d. Changes in free energy availability can result in changes in population size.

e. Changes in free energy availability can result in disruptions to an ecosystem.

*To demonstrate student understanding of this concept, make sure you can explain the following:*

- Change in the producer level can affect the number and size of other trophic levels.
- Change in energy resources levels such as sunlight can affect the number and size of the trophic levels.

**Student Objectives:**

- **How do energetic considerations contribute to the structure of populations, communities, and ecosystems?**
- **Provide examples of how energetic considerations affect the reproductive and life-history strategies of organisms.**
- **Provide examples of how disruptions to the free energy available in ecosystems can affect the structure of those ecosystems.**

Learning Objectives:

- The student is able to explain how biological systems use free energy based on empirical data that all organisms require constant energy input to maintain organization, to grow and to reproduce.
- The student is able to justify a scientific claim that free energy is required for living systems to maintain organization, to grow or to reproduce, but that multiple strategies exist in different living systems.
- The student is able to predict how changes in free energy availability affect organisms, populations and ecosystems.

**Enduring understanding 2.D: Growth and dynamic homeostasis of a biological system are influenced by changes in the system's environment.**

**Essential knowledge 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.**

a. Cell activities are affected by interactions with biotic and abiotic factors.
*To demonstrate student understanding of this concept, make sure you can explain the following:*
- Cell density
- Biofilms
- Temperature
- Water availability
- Sunlight

b. Organism activities are affected by interactions with biotic and abiotic factors.
*To demonstrate student understanding of this concept, make sure you can explain the following:*
- Symbiosis (mutualism, commensalism, parasitism)
- Predator–prey relationships
- Water and nutrient availability, temperature, salinity, pH

c. The stability of populations, communities and ecosystems is affected by interactions with biotic and abiotic factors.
*To demonstrate student understanding of this concept, make sure you can explain the following:*
- Water and nutrient availability
- Availability of nesting materials and sites
- Food chains and food webs
- Species diversity
- Population density
- Algal blooms

**Student Objectives:**
- **Provide examples of how biotic and abiotic factors affect organism behavior, community interactions, and ecosystem structure. Utilize the following examples in your responses:**
  - **Water availability**
  - **Sunlight**
  - **Symbiosis (mutualism, commensalism, parasitism)**
  - **Predator–prey relationships**
  - **Water and nutrient availability, temperature, salinity, pH**
  - **Availability of nesting materials and sites**
  - **Food chains and food webs**
  - **Species diversity**
  - **Population density**
  - **Algal blooms**

Learning Objectives:
- The student is able to refine scientific models and questions about the effect of complex biotic and abiotic interactions on all biological systems, from cells and organisms to populations, communities and ecosystems.
- The student is able to design a plan for collecting data to show that all biological systems (cells, organisms, populations, communities and ecosystems) are affected by complex biotic and abiotic interactions.
- The student is able to analyze data to identify possible patterns and relationships between a biotic or abiotic factor and a biological system (cells, organisms, populations, communities or ecosystems).

**Essential knowledge 2.D.3: Biological systems are affected by disruptions to their dynamic homeostasis.**

a. Disruptions to ecosystems impact the dynamic homeostasis or balance of the ecosystem.
*To demonstrate student understanding of this concept, make sure you can explain the following:*
- Invasive and/or eruptive species
- Human impact
- Hurricanes, floods, earthquakes, volcanoes, fires
- Water limitation
- Salination

**Student Objectives:**
- **Provide examples of how disruptions to ecosystems can affect the dynamics of the ecosystem. Utilize the following examples in your responses:**
  - **Invasive and/or eruptive species**
  - **Human impact**
  - **Hurricanes, floods, earthquakes, volcanoes, fires**
  - **Water limitation**
  - **Salination**

Learning Objective:

- The student is able to use representations or models to analyze quantitatively and qualitatively the effects of disruptions to dynamic homeostasis in biological systems.

**<u>Enduring understanding 2.E: Many biological processes involved in growth, reproduction and dynamic homeostasis include temporal regulation and coordination.</u>**

**Essential knowledge 2.E.3: Timing and coordination of behavior are regulated by various mechanisms and are important in natural selection.**

a. Individuals can act on information and communicate it to others.

*To demonstrate student understanding of this concept, make sure you can explain the following:*

1. Innate behaviors are behaviors that are inherited.
2. Learning occurs through interactions with the environment and other organisms.

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

*To demonstrate student understanding of this concept, make sure you can explain the following:*

1. In phototropism in plants, changes in the light source lead to differential growth, resulting in maximum exposure of leaves to light for photosynthesis.
2. In photoperiodism in plants, changes in the length of night regulate flowering and preparation for winter.
3. Behaviors in animals are triggered by environmental cues and are vital to reproduction, natural selection and survival.

*To demonstrate student understanding of this concept, make sure you can explain the following:*

- Hibernation
- Estivation
- Migration
- Courtship

4. Cooperative behavior within or between populations contributes to the survival of the populations.

*To demonstrate student understanding of this concept, make sure you can explain the following:*

- Availability of resources leading to fruiting body formation in fungi and certain types of bacteria
- Niche and resource partitioning
- Mutualistic relationships (lichens; bacteria in digestive tracts of animals; mycorrhizae)
- Biology of pollination

**Student Objectives:**

- **Describe how information is communicated between organisms.**
- **Compare innate and learned behaviors. Provide examples of each.**
- **Describe how environmental cues trigger behaviors that are related to reproduction, natural selection, and survival. Utilize the following behaviors in your response:**
  - **Hibernation**
  - **Estivation**
  - **Migration**
  - **Courtship**
- **Describe how cooperative behavior within or between populations contributes to the survival of the populations. Utilize the following behaviors in your response:**
  - Availability of resources leading to fruiting body formation in fungi and certain types of bacteria
  - Niche and resource partitioning
  - Mutualistic relationships (lichens; bacteria in digestive tracts of animals; mycorrhizae)
  - Biology of pollination

Learning Objectives:

- The student is able to analyze data to support the claim that responses to information and communication of information affect natural selection.
- The student is able to justify scientific claims, using evidence, to describe how timing and coordination of behavioral events in organisms are regulated by several mechanisms.
- The student is able to connect concepts in and across domain(s) to predict how environmental factors affect responses to information and change behavior.

**<u>Enduring understanding 3.E: Transmission of information results in changes within and between biological systems.</u>**

**Essential knowledge 3.E.1: Individuals can act on information and communicate it to others.**

a. Organisms exchange information with each other in response to internal changes and external cues, which can change behavior.

*To demonstrate student understanding of this concept, make sure you can explain the following:*

- Fight or flight response
- Predator warnings
- Protection of young

- Plant-plant interactions due to herbivory
- Avoidance responses

b. Communication occurs through various mechanisms.

*To demonstrate student understanding of this concept, make sure you can explain the following:*

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.

*To demonstrate student understanding of this concept, make sure you can explain the following:*

- Herbivory responses
- Territorial marking in mammals
- Coloration in flowers

2. Animals use visual, audible, tactile, electrical and chemical signals to indicate dominance, find food, establish territory and ensure reproductive success.

*To demonstrate student understanding of this concept, make sure you can explain the following:*

- Bee dances
- Birds songs
- Territorial marking in mammals
- Pack behavior in animals
- Herd, flock, and schooling behavior in animals
- Predator warning
- Colony and swarming behavior in insects
- Coloration

c. Responses to information and communication of information are vital to natural selection and evolution. [See also 1.A.2]

*To demonstrate student understanding of this concept, make sure you can explain the following:*

1. Natural selection favors innate and learned behaviors that increase survival and reproductive fitness.

*To demonstrate student understanding of this concept, make sure you can explain the following:*

- Parent and offspring interactions
- Migration patterns
- Courtship and mating behaviors
- Foraging in bees and other animals
- Avoidance behavior to electric fences, poisons, or traps

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

*To demonstrate student understanding of this concept, make sure you can explain the following:*

- Pack behavior in animals
- Herd, flock and schooling behavior in animals
- Predator warning
- Colony and swarming behavior in insects

**Student Objectives:**

- **Explain how the exchange of information between organisms is triggered by internal/external cues and how it can change behavior. Utilize the following behaviors in your response:**
  - **Fight or flight response**
  - **Predator warnings**
  - **Protection of young**
  - **Plant-plant interactions due to herbivory**
  - **Avoidance responses**
- **Compare the various mechanisms of communication among organisms**
- **Explain how signaling behaviors can result in differential reproductive success. Utilize the following signals and behaviors in your response:**
  - **Herbivory responses**
  - **Territorial marking in mammals**
  - **Coloration in flowers.**
  - **Bee Dances**
  - **Bird Songs**
  - **Pack Behavior in animals**
  - **Herd/flock/schooling behavior in animals**
  - **Predator warnings**
  - **Colony and swarming behavior in insects**
  - **Coloration in animals.**
- **Explain how natural selection can result in the evolution of innate and learned behaviors that increase survival and reproductive success. Utilize the following behaviors in your response:**
  - **Parent and offspring interactions**
  - **Migration patterns**

- **Courtship/Mating Behaviors**
- **Foraging in bees and other animals**
- **Avoidance behavior to electric fences, poisons, or traps**

- **Explain how natural selection can result in the evolution of cooperative behaviors that increase either the fitness of the individual or the survival of the population at the expense of the fitness of the individual. Provide examples of behaviors that do both.**

Learning Objectives:

- The student is able to analyze data that indicate how organisms exchange information in response to internal changes and external cues, and which can change behavior.
- The student is able to create a representation that describes how organisms exchange information in response to internal changes and external cues, and which can result in changes in behavior.
- The student is able to describe how organisms exchange information in response to internal changes or environmental cues.

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

**Essential knowledge 4.A.5: Communities are composed of populations of organisms that interact in complex ways.**

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

b. Mathematical or computer models are used to illustrate and investigate population interactions within and environmental impacts on a community.

*To demonstrate student understanding of this concept, make sure you can explain the following:*

- Predator/prey relationships spreadsheet model
- Symbiotic relationship
- Graphical representation of field data
- Introduction of species
- Global climate change models

c. Mathematical models and graphical representations are used to illustrate population growth patterns and interactions.

*To demonstrate student understanding of this concept, make sure you can explain the following:*

- Reproduction without constraints results in the exponential growth of a population.
- A population can produce a density of individuals that exceeds the system's resource availability.
- As limits to growth due to density-dependent and density-independent factors are imposed, a logistic growth model generally ensues.
- Demographics data with respect to age distributions and fecundity can be used to study human populations.

**Student Objectives:**

- **Explain how species composition and diversity can be used to describe the structure of a community.**
- **Explain why mathematical/computer models are used to illustrate and investigate population growth patterns, population interactions, and environmental impacts on a community. Describe the strengths and limitations of these analytical approaches.**
- **Compare the exponential and logistic growth models for a population.**
- **Explain how demographic data can be used to analyze populations.**
- **Describe the major demographic features of the human population locally and globally.**

Learning Objectives:

- The student is able to justify the selection of the kind of data needed to answer scientific questions about the interaction of populations within communities.
- The student is able to apply mathematical routines to quantities that describe communities composed of populations of organisms that interact in complex ways.
- The student is able to predict the effects of a change in the community's populations on the community.

**Essential knowledge 4.A.6: Interactions among living systems and with their environment result in the movement of matter and energy.**

a. Energy flows, but matter is recycled.

b. Changes in regional and global climates and in atmospheric composition influence patterns of primary productivity.

c. Organisms within food webs and food chains interact.

d. Food webs and food chains are dependent on primary productivity.

e. Models allow the prediction of the impact of change in biotic and abiotic factors.

*To demonstrate student understanding of this concept, make sure you can explain the following:*

- Competition for resources and other factors limits growth and can be described by the logistic model.
- Competition for resources, territoriality, health, predation, accumulation of wastes and other factors contribute to density-dependent population regulation.

f. Human activities impact ecosystems on local, regional and global scales.
*To demonstrate student understanding of this concept, make sure you can explain the following:*

- As human populations have increased in numbers, their impact on habitats for other species have been magnified.
- In turn, this has often reduced the population size of the affected species and resulted in habitat destruction and, in some cases, the extinction of species.

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

**Student Objectives:**

- **Describe how ecosystems provide organisms with their energetic and matter requirements.**
- **Explain how changes in climate can influence primary productivity in an ecosystem.**
- **Compare food chains and food webs.**
- **Describe the major interactions among organisms in a food web.**
- **Explain how modeling of the trophic structure of an ecosystem can be used to make predictions about the effects of changes in biotic and abiotic factors on that ecosystem. Describe the strengths and limitations of this approach.**
- **Provide examples to demonstrate how human activities have impacted ecosystems on local, regional, and global scales. Describe the causes, and effects of these impacts, and discuss possible avenues of mitigating these impacts.**
- **Provide examples of species that have been driven to extinction by human activities.**

Learning Objectives:

- The student is able to apply mathematical routines to quantities that describe interactions among living systems and their environment, which result in the movement of matter and energy.
- The student is able to use visual representations to analyze situations or solve problems qualitatively to illustrate how interactions among living systems and with their environment result in the movement of matter and energy.
- The student is able to predict the effects of a change of matter or energy availability on communities.

**<u>Enduring understanding 4.B: Competition and cooperation are important aspects of biological systems.</u>**
**Essential knowledge 4.B.3: Interactions between and within populations influence patterns of species distribution and abundance.**

a. Interactions between populations affect the distributions and abundance of populations.
*To demonstrate student understanding of this concept, make sure you can explain the following:*

- Competition, parasitism, predation, mutualism and commensalism can affect population dynamics.
- Relationships among interacting populations can be characterized by positive and negative effects, and can be modeled mathematically (predator/prey, epidemiological models, invasive species).
- Many complex symbiotic relationships exist in an ecosystem, and feedback control systems play a role in the functioning of these ecosystems.

b. A population of organisms has properties that are different from those of the individuals that make up the population. The cooperation and competition between individuals contributes to these different properties.
c. Species-specific and environmental catastrophes, geological events, the sudden influx/ depletion of abiotic resources or increased human activities affect species distribution and abundance.
*To demonstrate student understanding of this concept, make sure you can explain the following:*

- Loss of keystone species
- Kudzu
- Dutch elm disease

**Student Objectives:**

- **Explain how interactions among populations affect the pattern of species distribution and abundance.**
- **Explain how competition, parasitism, predation, mutualism, and commensalism can all affect the distribution and abundance of populations. Provide examples of each effect.**
- **Explain why it is impossible to model the totality of interactions among populations in an ecosystem.**
- **Provide examples of the emergent properties that a population possesses that the individuals that comprise the population do not possess. Explain how cooperation and competition between individuals contributes to these emergent properties.**
- **Provide examples of how species-specific and environmental catastrophes, geological events, and the sudden influx/ depletion of abiotic resources or increased human activities can affect species distribution and abundance.**

Learning Objective:

- The student is able to use data analysis to refine observations and measurements regarding the effect of population interactions on patterns of species distribution and abundance.

**Essential knowledge 4.B.4: Distribution of local and global ecosystems changes over time.**

a. Human impact accelerates change at local and global levels.
*To demonstrate student understanding of this concept, make sure you can explain the following:*

- Logging, slash and burn agriculture, urbanization, monocropping, infrastructure development (dams, transmission lines, roads), and global climate change threaten ecosystems and life on Earth.
- An introduced species can exploit a new niche free of predators or competitors, thus exploiting new resources.
- Introduction of new diseases can devastate native species.
  *Illustrative examples include*:
    - Dutch elm disease
    - Potato blight
    - Small pox [historic example for Native Americans]

b. Geological and meteorological events impact ecosystem distribution.
*To demonstrate student understanding of this concept, make sure you can explain the following:*

1. Biogeographical studies illustrate these changes.
*To demonstrate student understanding of this concept, make sure you can explain the following:*
- El Niño
- Continental drift
- Meteor impact on dinosaurs

**Student Objectives:**
- **Explain how human impact can accelerate change at local and global levels of ecosystem structure. Provide examples of each.**
- **Explain how introduced species can disrupt the structure of an ecosystem. Provide examples to support your answer.**
- **Explain how geological and meteorological events can impact the distribution of ecosystems. Provide examples to support your answer..**

Learning Objectives:
- The student is able to explain how the distribution of ecosystems changes over time by identifying large-scale events that have resulted in these changes in the past.
- The student is able to predict consequences of human actions on both local and global ecosystems.

**Enduring understanding 4.C: Naturally occurring diversity among and between components within biological systems affects interactions with the environment.**

**Essential knowledge 4.C.3: The level of variation in a population affects population dynamics.**

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.
*To demonstrate student understanding of this concept, make sure you can explain the following:*
- California condors
- Black-footed ferrets
- Prairie chickens
- Potato blight causing the potato famine
- Corn rust affects on agricultural crops
- Tasmanian devils and infectious cancer

b. Genetic diversity allows individuals in a population to respond differently to the same changes in environmental conditions.
*To demonstrate student understanding of this concept, make sure you can explain the following:*
- Not all animals in a population stampede.
- Not all individuals in a population in a disease outbreak are equally affected; some may not show symptoms, some may have mild symptoms, or some may be naturally immune and resistant to the disease.

c. Allelic variation within a population can be modeled by the Hardy-Weinberg equation(s).

**Student Objectives:**
- **Explain how the genetic diversity present in a population is related to the resiliency of the population and its ability to respond to changes in the environment.**
- **Explain why populations with limited genetic diversity are at greater risk of extinction. Provide examples to support your answer.**

Learning Objectives:
- The student is able to use evidence to justify a claim that a variety of phenotypic responses to a single environmental factor can result from different genotypes within the population.
- The student is able to use theories and models to make scientific claims and/or predictions about the effects of variation within populations on survival and fitness.

**Essential knowledge 4.C.4: The diversity of species within an ecosystem may influence the stability of the ecosystem.**

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.

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.

**Student Objectives:**

- **Explain the relationship between the diversity present in an ecosystem and its resiliency when subjected to changes in the environment.**
- **Describe how keystone species, producers, and limiting abiotic and biotic factors contribute to maintaining the diversity of an ecosystem.**
- **Provide examples of how disruption to keystone species populations can trigger disproportionately large-scale changes to the structure of an ecosystem.**

Learning Objective:

- The student is able to make scientific claims and predictions about how species diversity within an ecosystem influences ecosystem stability.