B-2 The student will demonstrate an understanding of the structure and function of cells and their organelles.

B-2.1 Recall the three major tenets of cell theory (all living things are composed of one or more cells; cells are the basic units of structure and function in living things; and all presently existing cells arose from previously existing cells).
Taxonomy Level: 1.2-B Remember Conceptual Knowledge

Key Concepts:
Cell theory
Unicellular organism, multicellular organism

Previous knowledge: In 5th grade (5-2.1), students recalled the cell as the smallest unit of life and identified its major structures (including cell membrane, cytoplasm, nucleus, and vacuole). In 7th grade, students summarized the structures and functions of the major components of plant and animal cells (including the cell wall, the cell membrane, the nucleus, chloroplasts, mitochondria, and vacuoles) (7-2.1), compared the major components of plant and animal cells (7-2.2), and explained how cellular processes (including respiration, photosynthesis in plants, mitosis, and waste elimination) are essential to the survival of the organism (7-2.4).

It is essential for students to know the three major tenets of the *cell theory*:

- All living things are composed of one or more cells.
- Cells are the basic unit of structure of all living things.
  - The lowest level of structure capable of performing all the activities of life is the cell.
  - A *unicellular organism* is composed of one cell and all of life's activities occur within that single cell.
  - In a *multicellular organism,* each cell carries on most of the major functions of life.
- All presently existing cells arose from previously existing cells.
  - The ability of cells to divide to form new cells is the basis for all reproduction (both sexual and asexual) and for the growth and repair of all multicellular organisms.

It is not essential for students to recall the history of cell theory, although the development of cell theory highlights its significance to the study of biology and would serve as an aide in helping students comprehend the value and relevance of this concept.

Assessment Guidelines:
The objective of this indicator is to *recall* the three major tenets of cell theory; therefore, the primary focus of assessment should be to remember the three principles as outlined in the indicator.

In addition to *recall*, assessment may require students to

- *identify* that unicellular and multicellular organisms must carry out all basic cell processes;
- *recall* reasons that new cells must be formed.

B-2 The student will demonstrate an understanding of the structure and function of cells and their organelles.

B-2.2 Summarize the structures and functions of organelles found in a eukaryotic cell (including the nucleus, mitochondria, chloroplasts, lysosomes, vacuoles, ribosomes, endoplasmic reticulum [ER], Golgi apparatus, cilia, flagella, cell membrane, nuclear membrane, cell wall, and cytoplasm).
Taxonomy Level: 2.4-B Understand Conceptual Knowledge

Key Concepts:
Organelles (*as stated in the indicator*)
Chlorophyll
Enzymes

Previous knowledge: In 5th grade (5-2.1), students recalled the cell as the smallest unit of life and identified its major structures (including cell membrane, cytoplasm, nucleus, and vacuole). In 7th grade, students summarized the structures and functions of the major components of plant and animal cells (including the cell wall, the cell membrane, the nucleus, chloroplasts, mitochondria, and vacuoles) (7-2.1), compared the major components of plant and animal cells (7-2.2), and explained how cellular processes (including respiration, photosynthesis in plants, mitosis, and waste elimination) are essential to the survival of the organism (7-2.4).

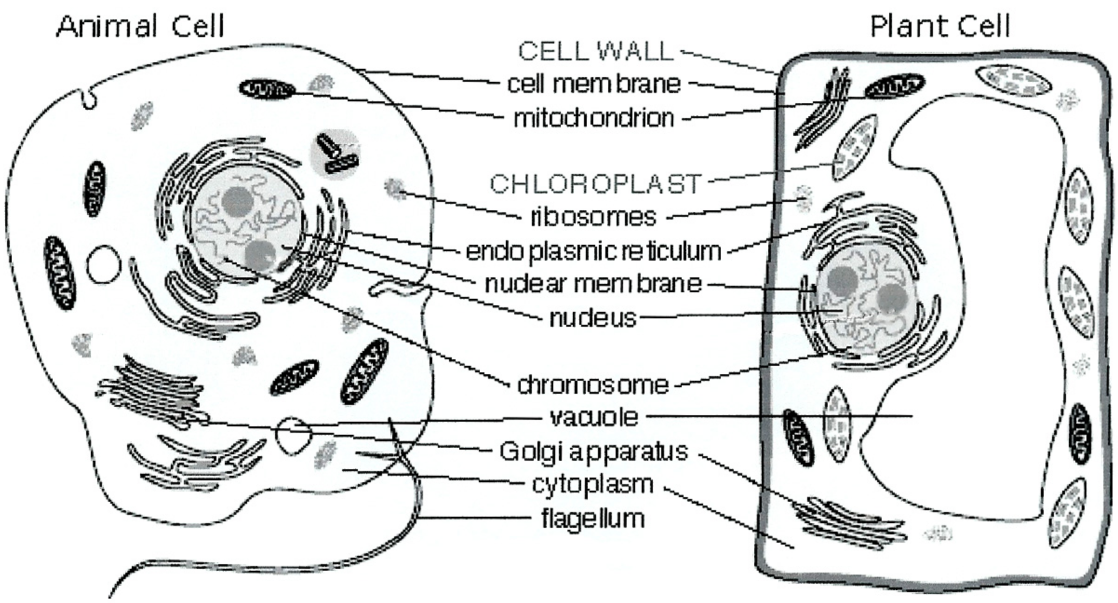
It is essential for students to understand that an *organelle* is a cell structure that performs a specialized function within a eukaryotic cell. Organelles found in a eukaryotic cell include:

- *Nucleus* contains the chromosomes which are composed of DNA (a chemical compound called deoxyribonucleic acid); functions in the genetic control of the cell.
- *Mitochondria* are the sites of cellular respiration, a process which supplies the cell with energy. TEACHER NOTE: Students will be responsible for understanding the process of cellular respiration in the context of standard B-3.
- *Chloroplasts* are found only in plant cells, contain the green pigment, *chlorophyll,* which absorbs energy from the Sun to convert carbon dioxide and water into sugar through the process of photosynthesis.
  TEACHER NOTE: Students will be responsible for understanding the process of photosynthesis in the context of standard B-3.
- *Lysosomes* contain chemicals called *enzymes* necessary for digesting certain materials in the cell. TEACHER NOTE: Students will be responsible for understanding the function of enzymes in the context of indicator B-2.8.
- *Vacuoles* store materials such as water, salts, proteins, and carbohydrates; vacuoles in animal cells (if they are present) are much smaller than those in plant cells.
- *Ribosomes* are the sites of protein synthesis; some are located on the ER, others are found in the cytoplasm.
- *Endoplasmic reticulum (ER)* is a complex, extensive network that transports materials throughout the inside of a cell.
  - Rough ER has ribosomes attached to the surface is ribosome-studded.
  - Smooth ER has no attached ribosomes.
- *Golgi apparatus* modifies, collects, packages, and distributes molecules within the cell or outside the cell.
- *Cilia* are short hair-like projections responsible for the movement of animal cells or protists.

B-2	The student will demonstrate an understanding of the structure and function of cells and their organelles.

- *Flagella* are long whip-like projections responsible for the movement of some animal cells, bacteria, or protists.
- *Cell membrane* (sometimes called the plasma membrane) is the cell structure that encloses the cell and regulates the passage of materials between the cell and its environment; the cell membrane also aids in protection and support of the cell.
- *Nuclear membrane* (sometimes called nuclear envelope) is the membrane that surrounds the nucleus of the cell and regulates the passage of materials between the nucleus and the cytoplasm.
- *Cell wall* is the cell structure that surrounds the cell membrane for protection and support in plant cells, bacteria, fungi, and some protists, and allows for specific substances to pass in and out of the cell.
- *Cytoplasm* is the semi-fluid material inside the cell containing molecules and the organelles, exclusive of the nucleus; is bound by the cell membrane.

It is also essential for students to locate and **identify** each of the above organelles when presented with a scientific drawing, diagram, or model of a eukaryotic cell. For example:



It is not essential for students to

- understand any additional functions of various organelles stated in the indicator;
- have any deeper comprehension of the structure of various organelles than what is depicted in the diagram above (such as the parts of the endoplasmic reticulum, the structure of the nucleus, or the structure of the cell membrane);
- understand the structure or function of any additional organelles.

B-2 The student will demonstrate an understanding of the structure and function of cells and their organelles.

Assessment Guidelines:
The objective of this indicator is to *summarize* the structures and functions of organelles found in a eukaryotic cell; therefore, the primary focus of assessment should be to generalize the functions of the organelles listed in the indicator.

In addition to *summarize* assessment may require students to

- *identify* organelles in a diagram or model;
- *recall* the functions of given organelles;
- *illustrate* appropriate organelles found in plant and animal cells;
- *classify* a cell as a plant or an animal cell based on a description of the organelles, a diagram, or a model;
- *compare* plant cells to animal cells.

B-2 The student will demonstrate an understanding of the structure and function of cells and their organelles.

B-2.3 Compare the structures and organelles of prokaryotic and eukaryotic cells.
Taxonomy Level: 2.6-B Understand Conceptual Knowledge

Key Concepts:
Prokaryotic cells: DNA
Eukaryotic cells

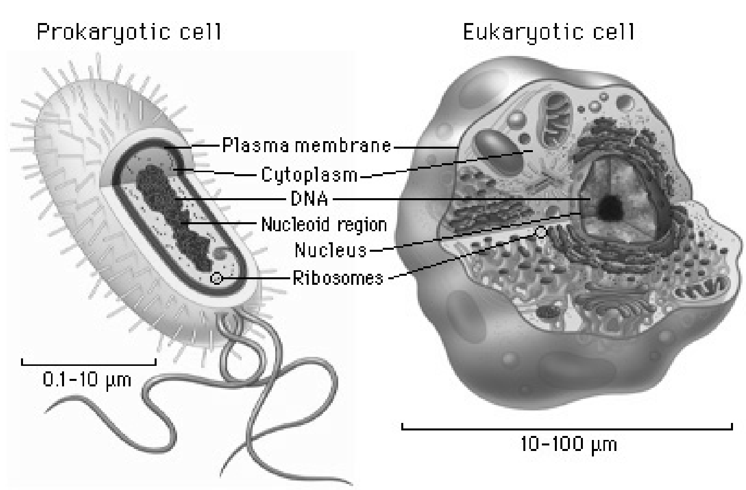
Previous knowledge: In 5th grade (5-2.1), students recalled the cell as the smallest unit of life and identified its major structures (including cell membrane, cytoplasm, nucleus, and vacuole). In 7th grade, students summarized the structures and functions of the major components of plant and animal cells (including the cell wall, the cell membrane, the nucleus, chloroplasts, mitochondria, and vacuoles) (7-2.1) and compared the major components of plant and animal cells (7-2.2).

It is essential for students to understand that the major difference between prokaryotic cells and eukaryotic cells is the presence of a nucleus.

- *Prokaryotic cells* do not have a true nucleus; the DNA in prokaryotic cells is not completely separated from the rest of the cell by a nuclear membrane (envelope) and is not arranged in strands called chromosomes.
  - *DNA (deoxyribonucleic acid)* is a chemical compound that stores and transmits genetic information
- In *eukaryotic cells*, the DNA is organized into structures called chromosomes and the chromosomes are separated from the cytoplasm by a nuclear membrane.
  TEACHER NOTE: Students will be responsible for understanding the structure and function of chromosomes and DNA in the context of standard B-4.

Prokaryotic cells differ from eukaryotic cells in other ways:

- Prokaryotic cells lack most of the other organelles which are present in the cytoplasm of eukaryotic cells.
- Prokaryotic cells do not contain mitochondria but they can obtain energy from either sunlight or from chemicals in their environment.
- Prokaryotic cells, however, do contain ribosomes, the site of protein synthesis.
- Most prokaryotes are unicellular organisms, such as bacteria.



B-2 The student will demonstrate an understanding of the structure and function of cells and their organelles.

Assessment Guidelines:
The major focus of assessment is to *compare* the structure and organelles of prokaryotic and eukaryotic cells; therefore, the primary focus of assessment should be to detect similarities and differences between the two types of cells.

In addition to *compare*, assessment may require students to
- *recognize* a prokaryotic or eukaryotic cell based on a diagram showing the cell structure and the organelles are present;
- *recall* bacteria as examples of prokaryotic cells;
- *illustrate* the organelles that are found in prokaryotic and eukaryotic cells;
- *classify* a cell as prokaryotic or eukaryotic based on a diagram or a written description which includes the form and organelles present in the cell.

B-2 The student will demonstrate an understanding of the structure and function of cells and their organelles.

B-2.4 Explain the process of cell differentiation as the basis for the hierarchical organization of organisms (including cells, tissues, organs, and organ systems).
Taxonomy Level: 2.7-B Understand Conceptual Knowledge

Key Concepts:
Cell division: differentiation
Stem cells

Previous knowledge: In 7th grade, students summarized the levels of structural organization within the human body, including cells, tissues, organs, systems (7-3.1), and explained how cellular processes (including respiration, photosynthesis in plants, mitosis, and waste elimination) are essential to the survival of the organism (7-2.4).

It is essential for students to understand

- In the development of most multicellular organisms, a single cell (fertilized egg) gives rise to many different types of cells, each with a different structure and corresponding function.
    - The fertilized egg gives rise to a large number of cells through *cell division*, but the process of cell division alone could only lead to increasing numbers of identical cells.
    - As cell division proceeds, the cells not only increase in number but also undergo *differentiation* becoming specialized in structure and function. (Cell division is covered in B-2.6.)
    - The various types of cells (such as blood, muscle, or epithelial cells) arrange into tissues which are organized into organs, and, ultimately, into organ systems.
- Nearly all of the cells of a multicellular organism have exactly the same chromosomes and DNA.
    - During the process of differentiation, only specific parts of the DNA are activated; the parts of the DNA that are activated determine the function and specialized structure of a cell.
    - Because all cells contain the same DNA, all cells initially have the potential to become any type of cell.
    - Once a cell differentiates, the process can not be reversed.
- *Stem cells* are unspecialized cells that continually reproduce themselves and have, under appropriate conditions, the ability to differentiate into one or more types of specialized cells.
    - Embryonic cells, which have not yet differentiated into various cell types, are called embryonic stem cells.
    - Stem cells found in adult organisms, for instance in bone marrow, are called adult stem cells.
    - Scientists have recently demonstrated that stem cells, both embryonic and adult, with the right laboratory culture conditions, differentiate into specialized cells.

TEACHER NOTE: The process of cloning will be addressed in standard B-4.

It is not essential for students to understand how the process of transcriptional regulation in a cell produces specific proteins which results in cell differentiation.

B-2 The student will demonstrate an understanding of the structure and function of cells and their organelles.

Assessment Guidelines:
The objective of this indicator is to *explain* the process of cell differentiation; therefore, the primary focus of assessment should be to construct a cause-and-effect model showing how cell differentiation results in the hierarchical organization of an organism (including cells, tissues, organs, and organ systems). Assessments should ensure that students can model how the processes of cell division and cell differentiation result in identical cells specializing to become unique cells with specific functions which will form the organism's tissues and organs.

In addition to *explain*, assessments may require students to

- *recall* that all of the cells of a particular organism contain all of the genetic code for the organism;
- *summarize* the unique characteristics of embryonic and adult stem cells;
- *compare* the results of cell division and cell differentiation.

B-2 The student will demonstrate an understanding of the structure and function of cells and their organelles.

B-2.5 Explain how active, passive, and facilitated transport serve to maintain the homeostasis of the cell.

Taxonomy Level: 2.7-B Understand Conceptual Knowledge

Key Concepts:

Homeostasis: semipermeable membrane (selectively permeable)

Passive transport: diffusion, concentration gradient, osmosis, lyse, facilitated transport (diffusion), transport proteins

Active transport: endocytosis, ectocytosis

Previous knowledge: In 7th grade, students summarized the structures and functions of the major components of plant and animal cells (diffusion and osmosis across the cell membrane) (7-2.1) and explained how cellular processes (including respiration and waste elimination) are essential to the survival of the organism (7-2.4). The dynamics of homeostasis and active or passive transport of substances is new material in this course.

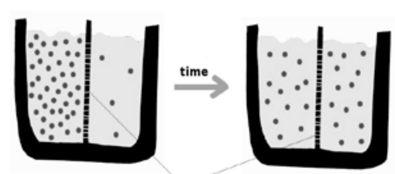
It is essential for students to understand that *homeostasis* refers to the necessity of an organism to maintain constant or stable conditions. In order to maintain homeostasis, all organisms have processes and structures which respond to stimuli in ways that keep conditions in their bodies conducive for life. Homeostasis depends in part on appropriate movement of materials across the cell membrane.

- Materials needed for cellular processes must pass into cells so they can be utilized. For example, oxygen and glucose are continuously needed for the process of cellular respiration.
- Waste materials from cellular processes must pass out of cells as they are produced. For example, carbon dioxide is continuously produced within the cell during the process of cellular respiration.
- The cell membrane regulates the passage of material into and out of the cell. Depending on the needs of the cell, excess substances must move out of the cell and needed substances must move into the cell.
- Each individual cell exists in a fluid environment, and the cytoplasm within the cell also has a fluid environment. The presence of a liquid makes it possible for substances (such as nutrients, oxygen, and waste products) to move into and out of the cell.
- A cell membrane is *semipermeable (selectively permeable)*, meaning that some substances can pass directly through the cell membrane while other substances can not.
- Materials can enter or exit through the cell membrane by passive transport or active transport.

Passive transport is a process by which substances move across a cell membrane but do not require energy from the cell. Types of passive transport are diffusion, osmosis, and facilitated diffusion.

- *Diffusion* is the spreading out of molecules across a cell membrane until they are equally concentrated. It results from the random motion of molecules and occurs along a *concentration gradient* (molecules move from an area of higher concentration to an area of lower concentration); substances that are able to pass directly across the cell membrane can diffuse either into a cell or out of a cell.

Diffusion across a semipermeable membrane

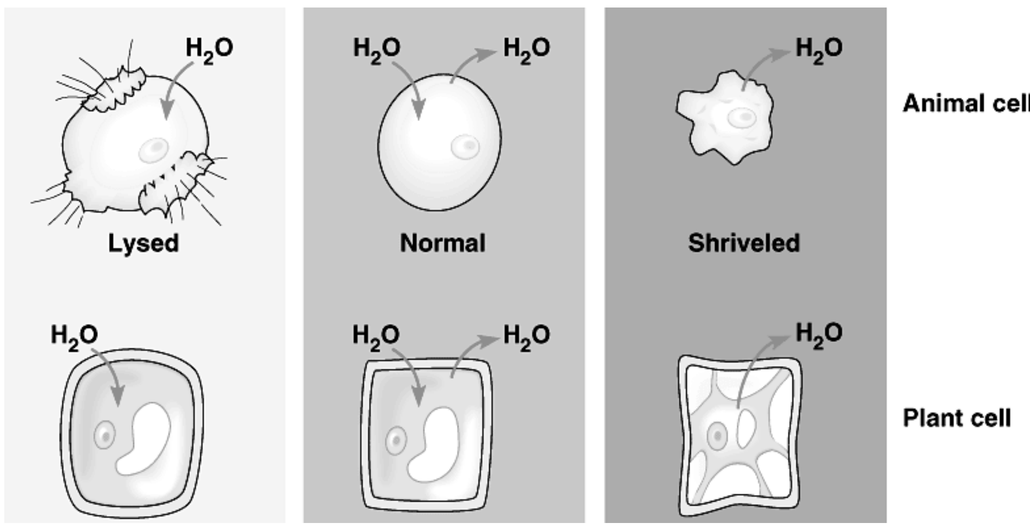


Semipermeable Membrane

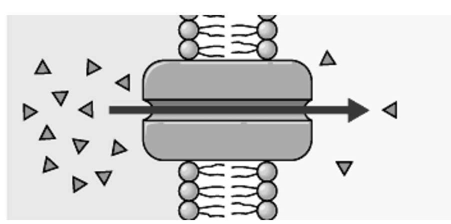
B-2	**The student will demonstrate an understanding of the structure and function of cells and their organelles.**

- *Osmosis* is the diffusion of water molecules through a selectively permeable membrane from an area of greater concentration of water to an area of lesser concentration of water.
  - If two solutions with the same solute concentration are separated by a selectively permeable membrane, water molecules will pass through the membrane in both directions at the same rate so the concentration of the solutions will remain constant.
  - The diffusion of water molecules is a passive transport process because it does not require the cell to expend energy.
  - If cells are placed in solutions that are very different in concentration from that of the cell, the cells may be damaged and even shrivel or burst (*lyse*).

Water concentration greater outside the cell than inside so water moves into the cell	Water concentration the same inside and outside the cell so there is no net movement of water	Water concentration greater inside the cell than outside so water moves out of the cell



- *Facilitated diffusion (transport)* is the process by which some substances that are not able to pass directly through a cell membrane are able to enter the cell with the aid of *transport proteins*. Facilitated diffusion occurs along a concentration gradient and does not require energy from the cell.
  - Some substances have chemical structures that prevent them from passing directly through a cell membrane. The cell membrane is not permeable to these substances.
  - Transport proteins provide access across the cell membrane.
  - Glucose is an example of a substance that passes through the cellular membrane using facilitated diffusion.



Facilitated Diffusion

Active transport is another one way that substances can move through a cell membrane. However, molecules move against the concentration gradient (from an area of low concentration to an area of high concentration) and require the cell to expend energy.

- One process of active transport happens when cells pump molecules through the cell membrane.
  - Unlike the process of facilitated diffusion, in active transport, molecules are “pumped” across the cell membrane by transport proteins. This pumping process requires an expenditure of chemical energy.
  - Because this process does not depend on diffusion, cells can use this process to concentrate molecules within the cell, or to remove waste from a cell.
  - Calcium, potassium, and sodium ions are examples of materials that must be forced across the cell membrane using active transport.
- Another process of active transport happens when molecules are too large to pass through a cell membrane even with the aid of transport proteins. These molecules require the use of *vesicles* to help them through the membrane.
  - If the large molecule is passing into the cell, the process is called *endocytosis*.
  - If the large molecule is passing out of the cell, the process is called *exocytosis*.

It is not essential for students to

- understand the structure of the cell membrane;
- understand how the specific mechanisms of active transport function (i.e., sodium-potassium pump, proton pump);
- calculate osmotic pressure.

Assessment Guidelines:

The objective of the indicator is to *explain* how active, passive, and facilitated transport serves to maintain the homeostasis of the cell; therefore, the primary focus of assessment should be to construct a cause-and-effect model showing how the various methods by which molecules are transported across a cell membrane to maintain balance in the cell.

In addition to *explain*, assessments may require students to:

- *illustrate* the ways that each type of cellular transport helps the cell maintain homeostasis;
- *classify* a specific description of cellular transport;
- *summarize* the ways that each method of cellular transport helps the cell to maintain homeostasis;
- *infer* which type of cellular transport would be best suited to transport a given type of substance into or out of a cell;
- *compare* the unique functions of each type of cellular transport.

B-2	**The student will demonstrate an understanding of the structure and function of cells and their organelles.**

B-2.6 Summarize the characteristics of the cell cycle: interphase (called G1, S, G2); the phases of mitosis (called prophase, metaphase, anaphase, and telophase); and plant and animal cytokinesis.
Taxonomy Level: 2.4-B Understand Conceptual Knowledge

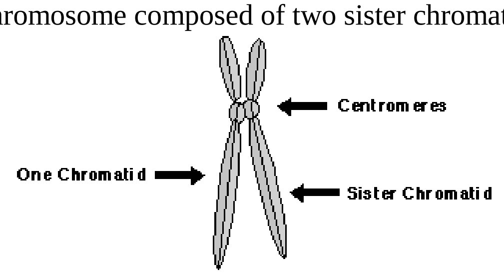
Key Concepts:
Cell cycle
Interphase: gap 1 phase (G1); synthesis phase (S), chromatid, centromere; gap 2 phase (G2)
Mitosis: prophase, metaphase, anaphase, telophase
Cytokinesis: cleavage furrow, cell plate

Previous knowledge: In 7th grade (7-2.4), students explained how cellular processes (including respiration, photosynthesis in plants, mitosis, and waste elimination) are essential to the survival of the organism.

It is essential for students to understand that the *cell cycle* is a repeated pattern of growth and division that occurs in eukaryotic cells. This cycle consists of three phases. The first phase represents cell growth while the last two phases represent cell division.

Interphase
- Cells spend the majority of their cell cycle in interphase. The purpose of interphase is for cell growth. By the end of interphase a cell has two full sets of DNA (chromosomes) and is large enough to begin the division process.
- Interphase is divided into three phases. Each phase is characterized by specific processes involving different structures.
  - During the *G1 (gap 1) phase*, the cell grows and synthesizes proteins.
  - During the *S (synthesis) phase,* chromosomes replicate and divide to form identical sister *chromatids* held together by a *centromere.*
  - During the *G2 (gap 2) phase*, cells continue to grow and produce the proteins necessary for cell division.

Chromosome composed of two sister chromatids



Mitosis
- The purpose of mitosis is cell division: making two cells out of one. Each cell has to have its own cytoplasm and DNA. The DNA that replicated in Interphase when two chromosome strands became four strands (two strands per chromatid). In mitosis the four strands (two sister chromatids) have to break apart so that each new cell only has one double-stranded chromosome.
- Mitosis, which follows Interphase, is divided into four phases. Each phase is characterized by specific processes involving different structures.
  - *Prophase* is characterized by four events:
    - ♦ Chromosomes condense and are more visible.
    - ♦ The nuclear membrane (envelope) disappears.

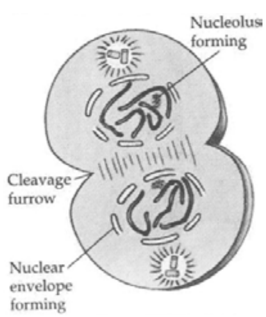
- ♦ By the end of prophase the centrioles (cell organelles that produce spindle fibers) have separated and taken positions on the opposite poles of the cell.
- ♦ Spindle fibers form and radiate toward the center of the cell.

○ *Metaphase* (the shortest phase of mitosis) is characterized by two events:
- ♦ Chromosomes line up across the middle of the cell.
- ♦ Spindle fibers connect the centromere of each sister chromatid to the poles of the cell.

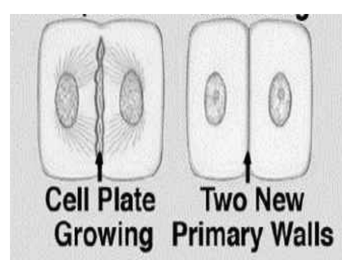
○ *Anaphase* is characterized by three events:
- ♦ Centromeres that join the sister chromatids split.
- ♦ Sister chromatids separate becoming individual chromosomes.
- ♦ Separated chromatids move to opposite poles of the cell.

○ *Telophase* (the last phase of mitosis) consists of four events:
- ♦ Chromosomes (each consisting of a single chromatid) uncoil.
- ♦ A nuclear envelope forms around the chromosomes at each pole of the cell.
- ♦ Spindle fibers break down and dissolve.
- ♦ Cytokinesis begins.

Cytokinesis
Cytokinesis is the division of the cytoplasm into two individual cells. The process of cytokinesis differs somewhat in plant and animal cells.
- In animal cells the cell membrane forms a *cleavage furrow* that eventually pinches the cell into two nearly equal parts, each part containing its own nucleus and cytoplasmic organelles.
- In plant cells a structure known as a *cell plate* forms midway between the divided nuclei, which gradually develops into a separating membrane. The cell wall forms in the cell plate.



Animal Cell Telophase/Cytokinesis



Plant Cell Telophase/Cytokinesis

TEACHER NOTE: The replication of DNA, the formation of RNA, or protein synthesis will be addressed in indicator B-4.3 and B-4.4.

It is not essential for students to
- recognize any structures other than those listed in the essential content;
- understand cell division in prokaryotic cells.

B-2 The student will demonstrate an understanding of the structure and function of cells and their organelles.

Assessment Guidelines:
The objective of this indicator is to *summarize* the characteristics of the cell cycle; therefore the major focus of assessment should be to give major points about the events in each phase of the cell cycle. Assessments must also show that students understand the relevance of interphase, mitosis and cytokinesis to the survival of the organism.

In addition to *summarize*, assessments may require students to
- *identify* the phases of the cell cycle;
- *recall* the events that occur in each phase of the cell cycle;
- *illustrate* the phases of the cell cycle with pictures, diagrams, models, or words;
- *classify* a specific description or diagram as a particular phase of the cell cycle;
- *compare* the phases of the cell cycle;
- *explain* the purpose of each event in each phases of the cell cycle to the survival of the cell or organism.

B-2 The student will demonstrate an understanding of the structure and function of cells and their organelles.

B-2.7 Summarize how cell regulation controls and coordinates cell growth and division and allows cells to respond to the environment, and recognize the consequences of uncontrolled cell division.

Taxonomy Level: 2.4-B Understand Conceptual Knowledge
1.1-B Remember Conceptual Knowledge

Key Concepts:
Chemical control system: internal signal, external signal, checkpoint
Cancer cells: malignant tumor, benign tumor

Previous knowledge: This concept has not been addressed in earlier grades

It is essential for students to understand that the cell cycle is driven by a *chemical control system* that both triggers and coordinates key events in the cell cycle. The cell cycle control system is regulated at certain checkpoints.

- Signals from inside the cell (internal signals) and from outside the cell (external signals) are involved in turning the process of cell division off and on.
  - An *internal signal* involves the cell sensing the presence of chemicals, called enzymes, which are produced inside the cell
  - An *external signal* involves the cell sensing the presence of a chemical (such as a growth factor) which was produced in other specialized cells.
- Cells can also respond to physical signals from their environment.
  - Cells sense when they are too closely packed and cell division is turned off.
  - Cells sense when they are not in contact with a surface and cell division is turned on.
- A *checkpoint* in the cell cycle is a critical control point where stop and go signals can regulate the cycle. The cell division mechanism in most animal cells is in the "off" position when there is no stimulus present. Specific stimuli are required to start the processes.

It is also essential for students to recognize consequences of uncontrolled cell division. Sometimes cells do not respond normally to the body's control mechanisms and divide excessively.

- *Cancer cells* are an example of cells that do not heed the normal signals which shut down the cell division process; they continue to divide even when they are very densely packed and/or there is no growth factor present.
- Cancer begins when a single cell is transformed into a cancer cell, one that does not heed the regulation mechanism.
  - Normally the body's immune system will recognize that the cell is damaged and destroy it, but if it evades destruction, it will continue to divide and each daughter cell will be a cancer cell.
  - A mass of these cells that invades and impairs the functions of one or more organs is called a *malignant tumor*.
  - A *benign tumor* is a mass of abnormal cells that remains at the original site.
- Cancer cells may also separate from the original tumor, enter the blood and lymph vessels of the circulatory system, and invade other parts of the body, where they grow to form new tumors.

It is not essential for students to understand the chemical mechanism of cell regulation.

B-2 The student will demonstrate an understanding of the structure and function of cells and their organelles.

Assessment Guidelines:
The first objective of this indicator is to *summarize* how cell regulation controls and coordinates cell growth and division and allows cells to respond to the environment; therefore, the primary focus of assessment should be to give major points about the ways that inside and outside stimuli can regulate and control cell growth.

Another objective of this indicator is to *recognize* the consequences of uncontrolled cell division, therefore, the primary focus of assessment should be to remember that uncontrolled cell division can result in cancer cells forming tumors and possibly spreading throughout the body.

In addition to *summarize* and *recognize*, assessments may require students to

- *exemplify* internal signals (enzymes) and the external signals (cell density) that activate the process of cellular growth and division;
- *classify* a signal as an internal signal or an external signal;
- *recall* that a breakdown in the cellular regulatory process can result in growth of tumors.

B-2 The student will demonstrate an understanding of the structure and function of cells and their organelles.

B-2.8 Explain the factors that affect the rates of biochemical reactions (including pH, temperature, and the role of enzymes as catalysts).
Taxonomy Level: 2.7-B Understand Conceptual Knowledge

Key Concepts:
Biochemical reactions: activation energy
pH: buffers
Catalyst: enzyme

Previous knowledge: In 7th grade (7-5.6), students distinguished between acids and bases and used indicators (including litmus paper, pH paper, and phenolphthalein) to determine their relative pH. In physical science, students classified various solutions as acids or bases according to their physical properties, chemical properties, generalized formulas, and pH (using pH meters, pH paper, and litmus paper) (PS 3.8) and explained the effects of temperature, concentration, surface area, and the presence of a catalyst on reaction rates (PS 4-1.1).

It is essential for students to understand that *biochemical reactions* allow organisms to grow, develop, reproduce, and adapt. A chemical reaction breaks down some substances and forms other substances. There are several factors that affect the rates of biochemical reactions.

- Chemical reactions (including biochemical reactions) can occur when reactants collide with sufficient energy to react. The amount of energy that is sufficient for a particular chemical reaction to occur is called the *activation energy*.
  - Sometimes a chemical reaction must absorb energy for the reaction to start; often, but not always, this energy is in the form of heat.
  - Energy, as heat or light, can also be given off as a result of biochemical reactions, such as with cellular respiration or bioluminescence.
- Changes in temperature (gaining or losing heat energy) can affect a chemical reaction.
- *pH* (a measure of the acidity of a solution) in most organisms needs to be kept within a very narrow range. *Buffers* within an organism are used to regulate pH so that pH homeostasis can be maintained. A small change in pH can disrupt cell processes.
- A *catalyst* is a substance that changes the rate of a chemical reaction or allows a chemical reaction to occur (activate) at a lower than normal temperature. Catalysts work by lowering the activation energy of a chemical reaction. A catalyst is not consumed or altered during a chemical reaction, so, it can be used over and over again. *Enzymes* are proteins which serve as catalysts in living organisms.
  - Enzymes are very specific. Each particular enzyme can catalyze only one chemical reaction by working on one particular reactant (substrate).
  - Enzymes are involved in many of the chemical reactions necessary for organisms to live, reproduce, and grow, such as digestion, respiration, reproduction, movement and cell regulation.
  - The structure of enzymes can be altered by temperature and pH; therefore, each catalyst works best at a specific temperature and pH.

It is not essential for students to understand the

- specific mechanisms by which a catalyst lowers activation energy;
- mechanism of chemical reactions (i.e. atoms, ions, bonding);
- role of cofactors or coenzymes;
- role of enzyme inhibitors.

B-2 The student will demonstrate an understanding of the structure and function of cells and their organelles.

Assessment Guidelines:
The objective of this indicator is to *explain* the factors that affect the rates of biochemical reactions; therefore, the primary focus of assessment should be to construct a cause-and-effect model showing how temperature, pH, and enzymes are used to control chemical reactions in living systems.

In addition to *explain*, assessments may require students to
- *interpret* diagrams, charts, and graphs of biochemical reactions;
- *summarize* factors that affect the rate of biochemical reactions;
- *recall* the purpose of a catalyst.

Standard B-3: The student will demonstrate an understanding of the flow of energy within and between living systems.

B-3.1 Summarize the overall process by which photosynthesis converts solar energy into chemical energy and interpret the chemical equation for the process.
Taxonomy Level: 2.4-B and 2.1-B Understand Conceptual Knowledge

Key Concepts:
Photosynthesis: light-dependent reactions, dark (light-independent) reactions

Previous knowledge: In 6th grade (6-2.7), students summarized the processes required for plant survival (including photosynthesis, respiration, and transpiration). In 7th grade, students explained how cellular processes (including respiration, photosynthesis in plants, mitosis, and waste elimination) are essential to the survival of the organism (7-2.4) and explained how a balanced chemical equation supports the law of conservation of matter (7-5.8).

It is essential for students to understand that all organisms need a constant source of energy to survive. The ultimate source of energy for most life on Earth is the Sun. *Photosynthesis* is the overall process by which sunlight (solar energy) chemically converts water and carbon dioxide into chemical energy stored in simple sugars (glucose). This process occurs in two stages.

- The first stage is called the *light-dependent reactions* because they require solar energy.
  - During the light-dependent reactions, solar energy is absorbed by chloroplasts (see B-2.2) and two energy storing molecules (ATP and NADPH) are produced.
  - The solar energy is used to split water molecules which results in the release of oxygen as a waste product, an essential step in the process of photosynthesis.
- The second stage is called the *dark (light-independent) reactions* because they do not require solar energy.
  - During the dark (light-independent) reactions, energy stored in ATP and NADPH is used to produce simple sugars (such as glucose) from carbon dioxide. These simple sugars are used to store chemical energy for use by the cells at later times.
  - Glucose can be used as an energy source through the process of cellular respiration or it can be converted to organic molecules (such as proteins, carbohydrates, fats/lipids, or cellulose) by various biologic processes.

TEACHER NOTE: The structure of ATP molecules and a deeper treatment of its function are addressed in B-3.3.

It is also essential for students to understand that the process photosynthesis is generally represented using a balanced chemical equation. However, this equation does not represent all of the steps that occur during the process of photosynthesis.

$$6CO_2 + 6H_2O \xrightarrow{\text{Solar energy}} C_6H_{12}O_6 + 6O_2$$

- In general, six carbon dioxide molecules and six water molecules are needed to produce one glucose molecule and six oxygen molecules.
- Each of the reactants (carbon dioxide and water) is broken down at different stages of the process.
- Each of the products (oxygen and glucose) is formed in different stages of the process.
- Solar energy is needed to break down the water molecules.

Standard B-3: The student will demonstrate an understanding of the flow of energy within and between living systems.

It is not essential for students to understand
- the chemical processes of the Calvin cycle (carbon fixation);
- how the structure of chloroplast is important to the process of photosynthesis (the thylakoid and stroma).

Assessment Guidelines:
The first objective of this indicator is to *summarize* the process by which photosynthesis converts solar energy into chemical energy; therefore, the primary focus of assessment should be to give major points about the process of photosynthesis, including light-dependent and light-independent/dark reactions.

The second objective of this indicator is to *interpret* the chemical equation for photosynthesis; therefore, the primary focus of assessment should be to represent the process of photosynthesis through the use of a chemical equation and its chemical symbols.

In addition to *summarize* and *interpret*, assessments may require students to
- *recognize* the formulas for the components of the overall equation for photosynthesis;
- *recognize* ATP, NADPH, and glucose as chemical compounds that store energy in their bonds;
- *compare* the energy transformations that occur in the dark reactions to those that occur in the light reactions.

Standard B-3: The student will demonstrate an understanding of the flow of energy within and between living systems.

B-3.2 Summarize the basic aerobic and anaerobic processes of cellular respiration and interpret the chemical equation for cellular respiration.
Taxonomy Level: 2.4-B and 2.1-B Understand Conceptual Knowledge

Key Concepts:
Cellular respiration: adenosine triphosphate (ATP)
Glycolysis
Aerobic respiration: Krebs cycle (citric acid cycle), electron transport chain
Anaerobic respiration: fermentation, lactic acid fermentation, alcohol fermentation

Previous knowledge: In 6th grade (6-2.7), students summarized the processes required for plant survival (including photosynthesis, respiration, and transpiration). In 7th grade, students explained how cellular processes (including respiration, photosynthesis in plants, mitosis, and waste elimination) are essential to the survival of the organism (7-2.4) and explained how a balanced chemical equation supports the law of conservation of matter (7-5.8).

It is essential for students to understand that the ultimate goal of *cellular respiration* is to convert the chemical energy in nutrients to chemical energy stored in *adenosine triphosphate (ATP).* ATP can then release the energy for cellular metabolic processes, such as active transport across cell membranes, protein synthesis, and muscle contraction.

- Any food (organic) molecule, or nutrient, including carbohydrates, fats/lipids, and proteins can be processed and broken down as a source of energy to produce ATP molecules.

$$\text{nutrients} + \text{oxygen} \longrightarrow \text{water} + \text{energy (ATP)} + \text{carbon dioxide}$$

TEACHER NOTE: The structure of ATP molecules and a deeper treatment of its function are addressed in B-3.3.

To transfer the energy stored in glucose to the ATP molecule, a cell must break down glucose slowly and capture the energy in stages.

- The first stage is *glycolysis*.
  - In the process of glycolysis a glucose molecule is broken down into pyruvic acid molecules and ATP molecules.
  - Glycolysis is a series of reactions using enzymes that takes place in the cytoplasm.

TEACHER NOTE: Pyruvic acid is a pyruvate molecule that has combined with a hydrogen ion. Many texts use the terms interchangeably.

- If oxygen is available, the next stage is the two-step process of *aerobic respiration*, which takes place primarily in the mitochondria of the cell.
  - The first step of aerobic respiration is called the *citric acid* or *Krebs cycle.*
    - ♦ The pyruvic acid formed in glycolysis travels to the mitochondria where it is chemically transformed in a series of steps, releasing carbon dioxide, water, and energy (which is used to form 2 ATP molecules)

$$\text{Pyruvic acid} \longrightarrow \text{carbon dioxide} + \text{water} + \text{energy (2 ATP)}$$

  - The second step of aerobic respiration is the *electron transport chain*.
    - ♦ Most of the energy storing ATP molecules is formed during this part of the cycle.

Standard B-3: The student will demonstrate an understanding of the flow of energy within and between living systems.

- ♦ The electron transport chain is a series of chemical reactions ending with hydrogen combining with oxygen to form water. Carbon dioxide is released as a waste product as it is formed in several stages of the Krebs cycle.
- ♦ Each reaction produces a small amount of energy, which by the end of the cycle produces many (up to 36) ATP molecules.
- ♦ The ATP synthesized can be used by the cell for cellular metabolism

It is also essential for students to understand that the process aerobic respiration is generally represented using a balanced chemical equation. However, this equation does not represent all of the steps that occur during the process of aerobic respiration.

$$C_6H_{12}O_6 + 6O_2 \longrightarrow 6CO_2 + 6H_2O + \text{energy}$$

- In general, one glucose molecule and six oxygen molecules are needed to produce six carbon dioxide molecules and six water molecules.
- Each of the reactants (glucose and oxygen) is used during different stages of aerobic respiration.
- Each of the products (carbon dioxide and water) is formed during different stages of the process.
- The energy that is released is primarily used to produce approximately 34 to 36 molecules of ATP per glucose molecule.

It is essential for students to understand that if no oxygen is available, cells can obtain energy through the process of *anaerobic respiration.* A common anaerobic process is *fermentation*.

- Fermentation is not an efficient process and results in the formation of far fewer ATP molecules than aerobic respiration.
- There are two primary fermentation processes:
  - ○ *Lactic acid fermentation* occurs when oxygen is not available, for example, in muscle tissues during rapid and vigorous exercise when muscle cells may be depleted of oxygen.
    - ♦ The pyruvic acid formed during glycolysis is broken down to lactic acid, and in the process energy is released (which is used to form ATP).

Glucose → Pyruvic acid → Lactic acid + energy

- ♦ The process of lactic acid fermentation replaces the process of aerobic respiration so that the cell can continue to have a continual source of energy even in the absence of oxygen, however this shift is only temporary and cells need oxygen for sustained activity.
- ♦ Lactic acid that builds up in the tissue causes a burning, painful sensation.

TEACHER NOTE: Lactic acid is lactate which has acquired a hydrogen ion. Many texts use the two interchangeably.

- ○ *Alcohol fermentation* occurs in yeasts and some bacteria.
  - ♦ In this process, pyruvic acid formed during glycolysis is broken down to produce alcohol and carbon dioxide, and in the process energy is released (which is used to form ATP).

Glucose → Pyruvic acid → alcohol + carbon dioxide + energy

TEACHER NOTE: At this point teachers may want to compare the processes of photosynthesis and aerobic respiration.

Standard B-3: The student will demonstrate an understanding of the flow of energy within and between living systems.

It is not essential for students to understand

- the specific chemical reactions of cellular respiration;
- the role of excited electrons or the mechanism of the electron transport system in the process of respiration;
- the role of NADH in respiration or fermentation.

Assessment Guidelines:

The first objective of this indicator is to *summarize* the basic aerobic and anaerobic processes of cellular respiration; therefore, the primary focus of assessment should be to give major points about the process of cellular respiration, both aerobic and anaerobic.

The second objective of this indicator is to interpret the chemical equation for cellular respiration; therefore, the primary focus of assessment should be to represent the process of aerobic respiration through the use of a chemical equation and its chemical symbols.

In addition to summarize and interpret, assessments may require students to

- *recognize* the formulas for the components of the overall equation for cellular respiration;
- *recognize* glucose and ATP as chemical compounds that store energy in their bonds;
- *explain* why cellular respiration is critical to an organism;
- *compare* aerobic and anaerobic respiration as processes that produce energy.

Standard B-3: The student will demonstrate an understanding of the flow of energy within and between living systems.

B-3.3 Recognize the overall structure of adenosine triphosphate (ATP)—namely, adenine, the sugar ribose, and three phosphate groups—and summarize its function (including the ATP-ADP [adenosine diphosphate] cycle).

Taxonomy Level: 1.1-A Remember Factual knowledge
2.4-B Understand Conceptual Knowledge

Key Concepts:
ATP structure: nitrogenous base (adenine), ribose, phosphate group
ATP-ADP cycle

Previous knowledge: This concept has not been addressed in previous grades.

It is essential for students to remember that *adenosine triphosphate (ATP)* is the most important biological molecule that supplies energy to the cell. A molecule of ATP is composed of three parts:

- A *nitrogenous base (adenine)*
- A sugar *(ribose)*
- Three *phosphate groups* (therefore the name triphosphate) bonded together by "high energy" bonds

It is also essential for students to understand the *ATP-ADP cycle*.

- Cells break phosphate bonds as needed to supply energy for most cellular functions, leaving adenosine diphosphate (ADP) and a phosphate available for reuse.
  - When any of the phosphate bonds are broken or formed, energy is involved.
    - Energy is released each time a phosphate is removed from the molecule.
    - Energy is used each time a phosphate attaches to the molecule.
  - To constantly supply the cell with energy, the ADP is recycled creating more ATP which carries much more energy than ADP.
- The steps in the ATP-ADP cycle are
  - To supply cells with energy, a "high energy" bond in ATP is broken. ADP is formed and a phosphate is released back into the cytoplasm.

    $$\text{ATP} \rightarrow \text{ADP} + \text{phosphate} + \text{energy}$$

  - As the cell requires more energy, ADP becomes ATP when a free phosphate attaches to the ADP molecule. The energy required to attach the phosphate to ADP is much less than the energy produced when the phosphate bond is broken.

    $$\text{ADP} + \text{phosphate} + \text{energy} \rightarrow \text{ATP}$$

It is not essential for students to remember

- the chemical formula for ATP or ADP;
- the starting molecule (AMP) or the ADP-AMP cycle.

Standard B-3: The student will demonstrate an understanding of the flow of energy within and between living systems.

Assessment Guidelines:
The first objective of this indicator is to *recognize* the overall structure of the ATP molecule; therefore, the primary focus of assessment should be to remember the three main parts of ATP (adenine, ribose, and three phosphate groups).

The second objective of this indicator is to *summarize* the function of ATP; therefore the primary focus of assessment should be to give major points about the function of an ATP molecule as a source of stored chemical energy for the cell, including the ATP-ADP cycle. Assessments should ensure that students understand the relevance of the process of breaking the high energy bonds in order to provide energy for cellular functions and how the ATP gets recycled through the ATP-ADP cycle.

In addition to *recognize* and *summarize*, assessments may require students to

- *identify* the components of ATP from diagrams;
- *interpret* diagrams and equations of the ATP-ADP cycle.

Standard B-3: The student will demonstrate an understanding of the flow of energy within and between living systems.

B-3.4 Summarize how the structures of organic molecules (including proteins, carbohydrates, and fats) are related to their relative caloric values.
Taxonomy Level: 2.4-B Understand Conceptual Knowledge

Key Concepts:
Organic molecules (as listed in the indicator)
Caloric value
Protein: amino acid
Carbohydrates: monosaccharides
Fats (lipids): glycerol, fatty acids

Previous knowledge: This concept has not been addressed in previous grades.

It is essential for students to understand that all organisms are composed of *organic molecules* which contain carbon atoms. Most organic molecules are made of smaller units that bond to form larger molecules. Energy is stored in the bonds that link these units together. The amount of energy stored in these bonds varies with the type of molecule formed. As a result, not all organic molecules have the same amount of energy available for use by the organism. The energy stored in organic molecules determines its *caloric value*. Proteins, carbohydrates, and fats/lipids are three organic molecules with different structures and different caloric values based on those structures.

- *Proteins* are molecules composed of chains of *amino acids.*
  - Amino acids are molecules that are composed of carbon, hydrogen, oxygen, nitrogen, and sometimes sulfur.
  - There are 20 amino acids that chemically bond in various ways to make proteins. Twelve of these amino acids are made in the body; others must be consumed from foods such as nuts, beans, or meat.
  - Although proteins are more important as a source of building blocks, amino acids may be used by the body as a source of energy (through the process of cellular respiration), but first they must be converted by the body to carbohydrates. This process does not happen as long as there is a carbohydrate or lipid available.
  - As a source of energy, proteins have the same caloric value per gram as carbohydrates.
- *Carbohydrates* (sugars and starches) are molecules composed of carbon, hydrogen, and oxygen.
  - The basic carbohydrates are simple sugars (*monosaccharides*) such as glucose. These simple sugars can bond together to make larger, complex carbohydrate molecules, for example starch or cellulose.
  - Carbohydrates are important because they the main source of energy for the cell.
    - ♦ When carbohydrates are synthesized during the process of photosynthesis, the plants or other photosynthetic organisms use them as a source of energy or they are stored in the cells.
    - ♦ When complex carbohydrates are consumed, the process of digestion breaks the bonds between the larger carbohydrate molecules so that individual simple sugars can be absorbed into the bloodstream through the walls of the intestines.
      - ∗ The bloodstream carries the simple sugars to cells throughout the body where they cross into the cells through the cell membrane.
      - ∗ Once inside the cells, simple sugars are used as fuel in the process of cellular respiration, releasing energy which is stored as ATP.

  - The caloric value of carbohydrates is dependent on the number of carbon-hydrogen bonds. If an organism has a greater supply of carbohydrates than needed for its energy requirements, the extra energy is converted to fats and stored by the body.
- *Lipids*, including *fats*, are organic molecules composed of carbon, hydrogen, and oxygen.
  - Lipid molecules are made of two component molecules (*glycerols* and *fatty acids*) so they are structurally different from carbohydrates. Fats/lipids have more carbon-hydrogen bonds than carbohydrates.
  - Fats are important to organisms for energy when carbohydrates are scarce, but when there is no shortage of food, stored fat accumulates.
    - ♦ When fats are consumed, the molecules are broken down during the process of digestion so that individual glycerol and fatty acid molecules are absorbed into the bloodstream through the walls of the intestines.
    - ♦ The blood stream carries the glycerol and fatty acid molecules to cells throughout the body where the molecules cross into the cells through the cell membrane.
    - ♦ Once inside the cell, glycerols and fatty acids are stored for later use or used as fuel for cellular respiration if there are no carbohydrates available.
    - ♦ The process of cellular respiration releases the energy that is held in the chemical bonds of the glycerol and fatty acid molecules.
- Due to the structure and number of the carbon-hydrogen bonds that hold the different types of molecules (proteins, carbohydrates, or fats) together, fats contain more energy (ATP) per gram than carbohydrates or proteins, which explains why fats have a greater caloric value.

It is not essential for students to understand
- the structures of carbon molecules;
- the chemical formulas for proteins, carbohydrates, or fats;
- the bonding in proteins, carbohydrates, or fats (peptide bonds or the process of hydrolysis);
- the energy value of the molecules mole per mole;
- the mathematical calculations concerning energy values per gram of substance.

Assessment Guidelines:
The objective of this indicator is to *summarize* how the structures of organic molecules (including proteins, carbohydrates, and fats) are related to their relative caloric values; therefore, the primary focus of assessment should be to give major points about the overall structure of the three types of molecules and how the structures determine the amount of energy available.

In addition to *summarize*, assessments may require students to
- *recall* the basic components of each type of organic molecule;
- *compare* the structure and relative caloric value of proteins, carbohydrates, and fats.

Standard B-3: The student will demonstrate an understanding of the flow of energy within and between living systems.

B-3.5 Summarize the functions of proteins, carbohydrates, and fats in the human body.
Taxonomy Level: 2.4-B Understand Conceptual Knowledge

Key Concepts:
Proteins Carbohydrates Fats

Previous knowledge: This concept has not been addressed in previous grades.

It is essential for students to understand that proteins, carbohydrates, and fats have important functions within the human body.

- *Proteins* are involved in almost every function in the human body. For example, they serve as the basis for structures, transport substances, regulate processes, speed up chemical reactions, and control growth.
  - Proteins are more important as a source of building blocks than as a source of energy. Proteins can function as an energy source only if there is a shortage of carbohydrates or lipids.
    - When proteins are consumed, the bonds that hold the amino acids together are broken during the process of digestion so that individual amino acids are absorbed into the bloodstream through the walls of the intestines.
    - The amino acids are carried by the blood stream to cells throughout the body where they cross into the cells through the cell membrane.
    - Once inside the cell, they are used as raw materials to make all of the proteins required by the organism.
  - Because of their structures, proteins serve different functions. For example,
    - Structural proteins are used for support such as connective tissue and keratin that forms hair and finger nails.
    - Transport proteins transport many substances throughout the body such as hemoglobin which transports oxygen from the lungs to the other parts of the body to be used by cells in cellular respiration.
    - Hormone proteins coordinate body activities such as insulin which regulates the amount of sugar in the blood.
    - Contractile proteins help control movement such as proteins in the muscles which help control contraction.
    - Enzymatic proteins accelerate the speed of chemical reactions such as digestive enzymes which break down food in the digestive tract.
- *Carbohydrates* are important as an energy source for all organisms and as a structural molecule in many organisms.
  - Carbohydrates are a primary source of fuel for cellular respiration.
  - Carbohydrates are also used to store energy for short periods of time.
  - The carbon, hydrogen, and oxygen that compose carbohydrates serve as raw materials for the synthesis of other types of small organic molecules, such as amino acids and fatty acids.
  - Some carbohydrates (such as cellulose) are used as structural material in plants.
    - For most animals, foods that contain these carbohydrates are important as fiber which stimulates the digestive system.
- *Fats (lipids)* are important to organisms for energy when carbohydrates are scarce since they are the primary way to store energy.
  - Fats serve a variety of functions in humans, such as providing long-term energy storage, cushioning of vital organs, and insulation for the body.

- ○ Fats also serve as a major component of cell membranes and are one of the raw materials necessary for the production of some vitamins and hormones.

Assessment Guidelines:
The objective of this indicator is to *summarize* the functions of proteins, carbohydrates, and fats in the human body; therefore, the primary focus of assessment should be to give major points about the importance of proteins, carbohydrates, and fats to health of human beings.

In addition to *summarize*, assessments may require students to

- *recall* or *compare* the functions of each organic molecule.

Standard B-3: The student will demonstrate an understanding of the flow of energy within and between living systems.

B-3.6 Illustrate the flow of energy through ecosystems (including food chains, food webs, energy pyramids, number pyramids, and biomass pyramids).
Taxonomy Level: 2.2-B Understand Conceptual Knowledge

Key Concepts:
Food chain, food web
Trophic level: primary producers (autotrophs), primary consumers (heterotrophs)
Types of consumers: herbivore, carnivore, omnivore, detritivore
Ecological pyramids: energy pyramid, number pyramid, biomass pyramid

Previous knowledge: In 5^{th} grade (5-2.4), students identified the roles of organisms as they interact and depend on one another through food chains and food webs in an ecosystem, considering producers and consumers (herbivores, carnivores, omnivores), decomposers (microorganisms, termites, worms, and fungi), predators and prey, and parasites and hosts. In 7^{th} grade (7-4.2), students illustrated energy flow in food chains, food webs, and energy pyramids.

It is essential for students to understand that the flow of energy through ecosystems can be described and illustrated in food chains, food webs, and pyramids (energy, number, and biomass).

Food Chain
A *food chain* is the simplest path that energy takes through an ecosystem. Energy enters an ecosystem from the Sun. Each level in the transfer of energy through an ecosystem is called a *trophic level*. The organisms in each trophic level use some of the energy in the process of cellular respiration, lose energy due to heat loss, and store the rest.

- The first trophic level consists of *primary producers* (green plants or other *autotrophs*).
  - Primary producers capture the Sun's energy during photosynthesis, and it is converted to chemical energy in the form of simple sugars.
  - The autotroph uses some of the simple sugars for energy and some of the simple sugars are converted to organic compounds (carbohydrates, proteins, and fats) as needed for the structure and functions of the organism.
  - Examples of primary producers include land plants and phytoplankton in aquatic environments.
- The second trophic level consists of *primary consumers (heterotrophs).*
  - Primary consumers that eat green plants are called *herbivores*.
  - The herbivore uses some of the organic compounds for energy and some of the organic compounds are converted into the proteins, carbohydrates and fats that are necessary for the structure and functions of the herbivore. Much of the consumed energy is lost as heat.
  - Examples of primary consumers include grasshoppers, rabbits and zooplankton.
- The third trophic level, or any higher trophic level, consists of *consumers*.
  - Consumers that eat primary consumers are called *carnivores*; consumers that eat both producers and primary consumers are called *omnivores*.
  - The carnivores or omnivores use some of the organic compounds for energy and some of the organic compounds are converted into the proteins, carbohydrates and fats that are necessary for their body structures and functions. Much of the consumed energy is lost as heat.
  - Examples of consumers include humans, wolves, frogs, and minnows.
- A heterotroph that decomposes organic material and returns the nutrients to soil, water, and air making the nutrients available to other organisms is called a *detritivore*.

Standard B-3: The student will demonstrate an understanding of the flow of energy within and between living systems.

The energy available for each trophic level in an ecosystem can be illustrated with a food chain diagram. The size of the arrow in a diagram may indicate that the energy is smaller at each trophic level because each organism uses some of the energy for life processes or lost as heat.

Food Web

A *food web* represents many interconnected food chains describing the various paths that energy takes through an ecosystem. The energy available in an ecosystem can be illustrated with a food web diagram.

Ecological Pyramids

Ecological pyramids are models that show how energy flows through ecosystems. Pyramids can show the relative amounts of energy, biomass, or numbers of organisms at each trophic level in an ecosystem. The base of the pyramid represents producers. Each step up represents a different level of consumer. The number of trophic levels in the pyramid is determined by the number of organisms in the food chain or food web.

- An *energy pyramid* represents the energy available for each trophic level in an ecosystem.
  - The energy needs of organisms are greater from level to level in an ecosystem.
  - Therefore, the total amount of energy available at each level decreases in an ecosystem.
  - Each successive level in an ecosystem can support fewer numbers of organisms than the one below. With each level of the pyramid, only 10% of the energy available is used by organisms while there is an energy loss of about 90% to the environment.
- A *number pyramid* represents the number of individual organisms available for energy at each trophic level in an ecosystem. It can be used to examine how the population of a certain species affects another.
  - The autotrophic level is represented at the base of the pyramid. This represents the total number of producers available to support the energy needs of the ecosystem.
  - The total numbers of individual organisms tend to decline as one goes up trophic levels.
- A *biomass pyramid* represents the total mass of living organic matter (biomass) at each trophic level in an ecosystem.
  - Since the number of organisms is reduced in each successive trophic level, the biomass at each trophic level is reduced as well.
  - Even though a biomass pyramid shows the total mass of organisms available at each level, it does not necessarily represent the amount of energy available at each level. For example, the skeleton and beak of a bird will contribute to the total biomass but are not available for energy.

It is not essential for students to understand

- the flow of energy in terms of the laws of thermodynamics or entropy;
- how to calculate the amount of energy available in an energy pyramid or the amount of biomass available in a biomass pyramid;
- the exact proportion of organisms that exists at each trophic level in a numbers pyramid.

Standard B-3: The student will demonstrate an understanding of the flow of energy within and between living systems.

Assessment Guidelines:
The objective of this indicator is to *illustrate* the flow of energy through ecosystems (including food chains, food webs, energy pyramids, number pyramids, and biomass pyramids); therefore, the primary focus of assessment should be to give or use illustrations of food chains, food webs, energy pyramids, numbers pyramids, and biomass pyramids for a given ecosystem showing that the organisms in each trophic level use some of the energy in the process of cellular respiration, lose energy due to heat loss, and store the rest.

In addition to *illustrate*, assessments may require students to
- *interpret* a scientific drawing of a food chain, food web, energy pyramid, numbers pyramid, or biomass pyramid;
- *summarize* the energy flow represented in a food chain, food web, energy pyramid, numbers pyramid or a biomass pyramid for a given ecosystem;
- *compare* different trophic levels in an ecosystem as to energy, numbers of organisms and biomass.

Standard B-4: The student will demonstrate an understanding of the molecular basis of heredity.

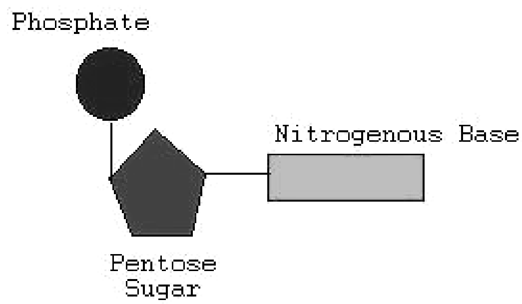
B-4.1 Compare DNA and RNA in terms of structure, nucleotides, and base pairs.
Taxonomy Level: 2.6-B Understand Conceptual Knowledge

Key Concepts:
Nucleic acids: deoxyribonucleic acid (DNA), ribonucleic acid (RNA)
Nucleotides: nitrogenous base, sugar, phosphate group
Complementary bases

Previous knowledge: This concept has not been addressed in previous grades.

It is essential for students to understand that *nucleic acids* are organic molecules that serve as the blueprint for proteins and, through the action of proteins, for all cellular activity.

- There are two types of nucleic acids.
  - *Deoxyribonucleic acid (DNA)*
  - *Ribonucleic acid (RNA)*
- Both DNA and RNA are composed of small units called *nucleotides.* The nucleotides that compose nucleic acids have three parts:
  - A *nitrogenous base*
    - ♦ Cytosine (C)
    - ♦ Guanine (G)
    - ♦ Adenine (A)
    - ♦ Thymine (T) (DNA only)
    - ♦ Uracil (U) (RNA only)
  - A simple (pentose) *sugar*
    - ♦ Deoxyribose (DNA only)
    - ♦ Ribose (RNA only)
  - A *phosphate group*



The basic structure of the two molecules is different.

- DNA consists of two single chains which spiral around an imaginary axis to form a double helix with nitrogenous bases from each strand of DNA chemically bonded through the axis of the helix.
  - When the nitrogenous bases of two strands of DNA chemically bond through the center of the helix, each base can bond to only one type of base. Bases that bond are called *complementary bases.*
    - ♦ Guanine (G) will only bond with Cytosine (C).
    - ♦ Thymine (T) will only bond with Adenine (A).
- RNA consists of a single chain of nucleotides with nitrogenous bases exposed along the side.
  - When the nitrogenous bases of RNA chemically bond to a strand of DNA, each RNA base can bond with only one type of DNA base. Bases that bond are called *complementary bases.*
    - ♦ Guanine (G) will only bond with Cytosine (C).
    - ♦ Uracil (U) will only bond with Adenine (A).

Standard B-4: The student will demonstrate an understanding of the molecular basis of heredity.

It is essential for students to compare the structure of the two types of nucleic acid.

	DNA	**RNA**
Type of base composing nucleotides	Cytosine (C) Adenine (A) Guanine (G) Thymine(T)	Cytosine(C) Adenine (A) Guanine (G) Uracil (U)
Type of sugar composing nucleotides	deoxyribose	ribose
Molecule structure and shape	Double helix	Single chain

It is not essential for students to understand
- the chemical formula for DNA or RNA;
- the difference between pyrimidine bases and purine bases.

Assessment Guidelines:
The objective of this indicator is to *compare* DNA and RNA in terms of structure, nucleotides and base pairs; therefore, the primary focus of assessment should be to detect similarities and differences between structure of DNA and RNA, the nucleotides that compose DNA and RNA, and the bases that bond to form DNA and RNA.

In addition to *compare*, assessments may require students to
- *recognize* the chemical names of the DNA and RNA molecules;
- *identify* the parts of a nucleotide;
- *recognize* the names of the 5 bases and the two sugars that compose the nucleotides that make up all nucleic acids;
- *interpret* an illustration of a nucleotide;
- *interpret* an illustration of a DNA or an RNA molecule.

Standard B-4: The student will demonstrate an understanding of the molecular basis of heredity.

B-4.2 Summarize the relationship among DNA, genes, and chromosomes.
Taxonomy Level: 2.4-B Understand Conceptual Knowledge

Key Concepts:
Chromosome DNA Gene

Previous knowledge: In 7th grade (7-2.5), students summarized how genetic information is passed from parent to offspring by using the terms genes, chromosomes, inherited traits, genotype, phenotype, dominant traits, and recessive traits.

It is essential for students to understand that DNA, genes, and chromosomes compose the molecular basis of heredity.

- A *chromosome* is a structure in the nucleus of a cell consisting essentially of one long thread of DNA that is tightly coiled.
- *DNA*, composed of nucleotides, provides the blueprint for the synthesis of proteins by the arrangement of nitrogenous bases.
  - The code for a particular amino acid (the base unit of proteins) is determined by a sequence of three base pairs on the DNA molecule.
- A *gene* is a specific location on a chromosome, consisting of a segment of DNA, that codes for a particular protein.
  - The particular proteins coded by the DNA on the genes determine the characteristics of an organism.
  - Each chromosome consists of hundreds of genes determining the many proteins for an individual organism.

It is not essential for students to understand the history behind the discovery of DNA.

Assessment Guidelines:
The objective of this indicator is to *summarize* the relationship among DNA, genes, and chromosomes; therefore, the primary focus of assessment should be to give major points about how DNA, genes and chromosomes are related.

In addition to *summarize*, assessments may require students to

- *recall* the basic structure of chromosomes and genes;
- *illustrate* or *interpret* an illustration of the relationship of a chromosome, DNA and genes using words or diagrams.

Standard B-4: The student will demonstrate an understanding of the molecular basis of heredity.

B-4.3 Explain how DNA functions as the code of life and the blueprint for proteins.
Taxonomy Levels: 2.7-B Understand Conceptual Knowledge

Key Concepts:
Genetic code: sex chromosomes, autosomal chromosomes (autosomes)
DNA replication

Previous knowledge: In 7th grade (7-2.5), students summarized how genetic information is passed from parent to offspring by using the terms genes, chromosomes, inherited traits, genotype, phenotype, dominant traits, and recessive traits.

It is essential for students to understand that the DNA, which comprises the organism's chromosomes, is considered the "code of life" (*genetic code*) because it contains the code for each protein that the organism needs.

- The specificity of proteins is determined by the order of the nitrogenous bases found in DNA.
  - In order to construct the specific proteins needed for each specific purpose, cells must have a blueprint that reveals the correct order of amino acids for each protein found in the organism (thousands of proteins).
  - A gene is a segment of DNA that codes for one particular protein.
- Each cell in an organism's body contains a complete set of chromosomes.
  - The number of chromosomes varies with the type of organism. For example, humans have 23 pairs of chromosomes; dogs have 39 pairs; potatoes have 24 pairs.
  - One pair of chromosomes in an organism determines the sex (male, female) of the organism; these are known as *sex chromosomes*. All other chromosomes are known as autosomal chromosomes, or *autosomes*.
  - Cells (except for sex cells) contain one pair of each type of chromosome.
    - ♦ Each pair consists of two chromosomes that have genes for the same proteins.
    - ♦ One chromosome in each pair was inherited from the male parent and the other from the female parent. In this way traits of parents are passed to offspring.
    - ♦ For example, human cells have 46 chromosomes (23 pairs).
- Each chromosome consists of thousands of genes. This is because there are so many unique proteins that each organism needs to produce in order to live and survive.
  - Organisms that are closely related may have genes that code for the same proteins that make the organisms similar. For example, all maple trees have many of the same genes.
  - Each individual organism has unique characteristics and those unique characteristics arise because of the differences in the proteins that the organism produces.
  - Organisms that are not closely related share fewer genes than organisms that are more closely related. For example, red maple trees share more genes with oak trees than with earthworms.

It is essential for students to understand that DNA can function as the code of life for protein synthesis or the process of DNA replication, which ensures that every new cell has identical DNA.

- *DNA replication* is carried out by a series of enzymes. The first enzyme unzips the two strands of DNA that compose the double helix, separating paired bases.
- Each base that is exposed can only bond to its complementary base.
  - Adenine (A) can only bond to thymine (T)
  - Cytosine (C) can only bond to guanine (G)
- Each of the separated strands serves as a template for the attachment of complementary bases, forming a new strand, identical to the one from which it was "unzipped".
- The result is two identical DNA molecules.

Standard B-4: The student will demonstrate an understanding of the molecular basis of heredity.

It is not essential for students to understand

- the specific chromosome numbers for organisms, except for humans;
- the names of the specific enzymes needed for replication.

Assessment Guidelines:

The objective of this indicator is to *explain* how DNA functions as the code of life and the blueprint for proteins, therefore, the primary focus of assessment should be to construct a cause-and-effect model showing how DNA determines the functional and structural proteins produced in an organism. Assessment should include how the process of DNA replication ensures that the entire DNA code is present in every cell of an organism.

In addition to *explain*, assessments may require students to

- *summarize* the role of DNA as the code of life;
- *summarize* the process of DNA replication;
- *infer* why organisms that are similar in structure or function often share many of the same proteins and genes.

Standard B-4: The student will demonstrate an understanding of the molecular basis of heredity.

B-4.4 Summarize the basic processes involved in protein synthesis (including transcription and translation).
Taxonomy Level: 2.4-B Understand Conceptual Knowledge

Key Concepts:
Protein synthesis
Transcription: messenger RNA (mRNA)
Translation: ribosomal RNA (rRNA), codons, transfer RNA (tRNA), anticodon site, peptide bond, stop codon

Previous knowledge: This concept has not been addressed in earlier grades.

It is essential for students to understand that when a particular protein is needed, the cell must make the protein through the process of *protein synthesis.* DNA molecules (which contain the code) do not leave the nucleus of the cell, but protein synthesis must occur in the ribosomes which are located outside of the nucleus in the cytoplasm. Therefore, the code must be carried from the nucleus to the cytoplasm.

Transcription
Transcription is the process by which a portion of the molecule of DNA is copied into a complementary strand of RNA. Through the process of transcription, the DNA code is transferred out of the nucleus to the ribosomes.

- Through a series of chemical signals, the gene for a specific protein is turned on. An enzyme attaches to the exact location on the DNA molecule where the gene is found, causing the two strands of DNA to separate at that location.
- Complementary RNA nucleotide bases bond to the bases on one of the separated DNA strands.

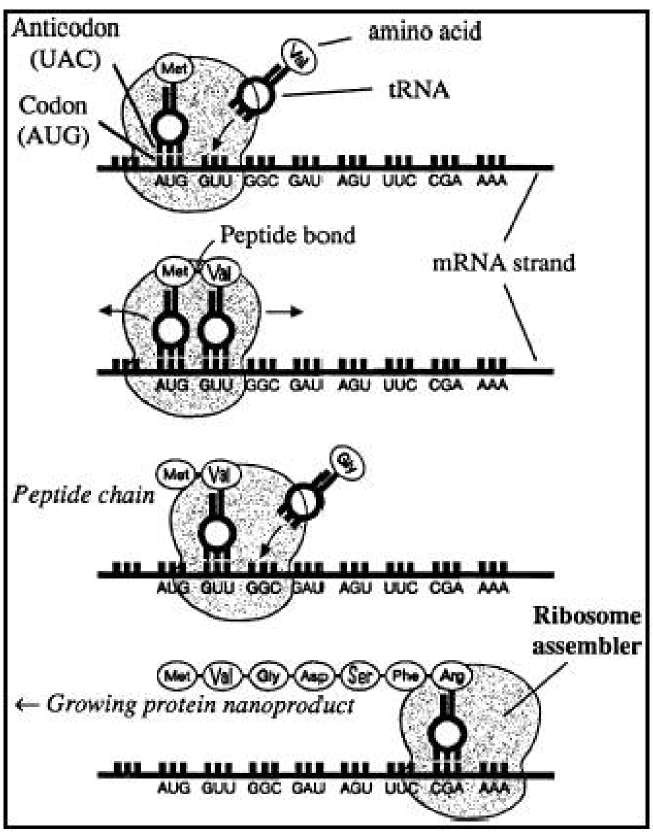
DNA nucleotide bases exposed on the separated strand	RNA nucleotide which bonds
Adenine (A)	Uracil (U)
Thymine (T)	Adenine (A)
Cytosine (C)	Guanine (G)
Guanine (G)	Cytosine (C)

- Nucleotides of RNA bond together, forming a single-stranded molecule of RNA that peels away from the DNA strand and the two DNA strands rejoin. This is called *messenger RNA* (*mRNA*).
- The messenger RNA (mRNA) is formed complementary to one strand of DNA.
- The mRNA strand leaves the nucleus and goes through the nuclear membrane into the cytoplasm of the cell.

Translation
Translation is the process of interpreting the genetic message and building the protein and begins when the mRNA attaches to a ribosome, which contains proteins and *ribosomal RNA (rRNA),* in the cytoplasm.

- The function of ribosomes is to assemble proteins according to the code that the mRNA brings from the DNA.
- Each three-base nucleotide sequence on the mRNA is called a *codon*. Each codon specifies a particular amino acid that will be placed in the chain to build the protein molecule.

  - For example, if the DNA sequence was GAC, then the RNA sequence becomes CUG and the amino acid that is coded is Leucine.
    TEACHER NOTE: mRNA codons for specific amino acids can be found in tables in most textbooks.
  - The sequence of mRNA nucleotides determines the order of the amino acids in the protein chain which, in turn, distinguishes one protein from another in structure and function.
- Another type of RNA, *transfer RNA (tRNA)*, is vital in assembling amino acids into the correct sequence for the required protein by transferring amino acids to the ribosomes when needed. There are twenty different types of tRNA molecules, one for each amino acid.
  - At one end of each tRNA is an *anticodon site*, which has the 3-nucleotide bases complementary to the codon of mRNA.
  - The other end of the tRNA molecule has a specific amino acid attached determined by the anticodon.
- The translation process takes place as follows:
  - The tRNA with its attached amino acid pairs to the codon of the mRNA attached to a ribosome.
  - When a second tRNA with its specific amino acid pairs to the next codon in sequence, the attached amino acid breaks from the first tRNA and attaches to the amino acid of the second tRNA.
  - The ribosome forms a *peptide bond* between the amino acids, and an amino acid chain begins to form.
  - The empty tRNA moves off and picks up another matching amino acid from the cytoplasm in the cell.
  - This sequence is repeated until the ribosome reaches a *stop codon* on the mRNA, which signals the end of protein synthesis.



Standard B-4: The student will demonstrate an understanding of the molecular basis of heredity.

It is not essential for students to

- understand the details of the processes of transcription and translation, other than as described in the essential information as given above;
- understand the termination of transcription, in terms of alteration of the mRNA ends and RNA splicing;
- understand or recognize the enzymes involved in the process of protein synthesis;
- know the amino acid that each codon represents;
- recall the specific codon sequence for any amino acid or names of specific amino acids.

Assessment Guidelines:

The objective of this indicator is to *summarize* the processes involved in protein synthesis, therefore, the primary focus of assessment should be to give major points about the steps in protein synthesis and the roles of each nucleic acid (DNA, mRNA, and tRNA) in the processes of transcription and translation.

In addition to *summarize*, assessments may require students to

- *illustrate* or *interpret* illustrations of the processes of transcription, translation, and protein synthesis;
- *compare* the processes of transcription and translation;
- *sequence* the steps of transcription and translation;
- *explain* the significance of each step to the overall process of protein synthesis.

Standard B-4: The student will demonstrate an understanding of the molecular basis of heredity.

B-4.5 Summarize the characteristics of the phases of meiosis I and II.
Taxonomy Level: 2.4-B Understand Conceptual Knowledge

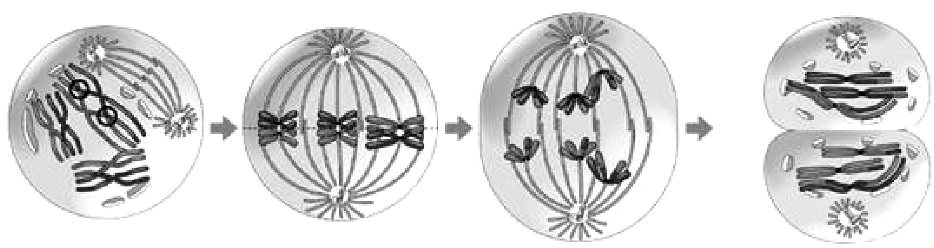
Key Concepts:
Daughter cells: diploid; haploid, gamete, zygote
Meiosis I: interphase, prophase I, tetrad, crossing over; metaphase I; anaphase I; telophase I, cytokinesis
Meiosis II: prophase II, metaphase II, anaphase II, telophase II

Previous knowledge: This concept has not been addressed in earlier grades. Indicator B-2.6 addresses the concept of cell cycle and mitosis.

It is essential for students to understand the process of meiosis and its importance to sexual reproduction just as mitosis is to asexual reproduction (see B-2.6). In order for the offspring produced from sexual reproduction to have cells that are *diploid* (containing two sets of chromosomes, one set from each parent), the egg and sperm cells must be *haploid* (contain only one of each type of chromosome). The division resulting in a reduction in chromosome number is called *meiosis.* Meiosis occurs in two steps:

- *Meiosis I*, in which the chromosome pairs replicate, results in two haploid *daughter cells* with duplicated chromosomes different from the sets in the original diploid cell.
- *Meiosis II*, in which the haploid daughter cells from Meiosis I divide, results in four haploid daughter cells called *gametes*, or sex cells (eggs and sperm), with undoubled chromosomes.

Meiosis I



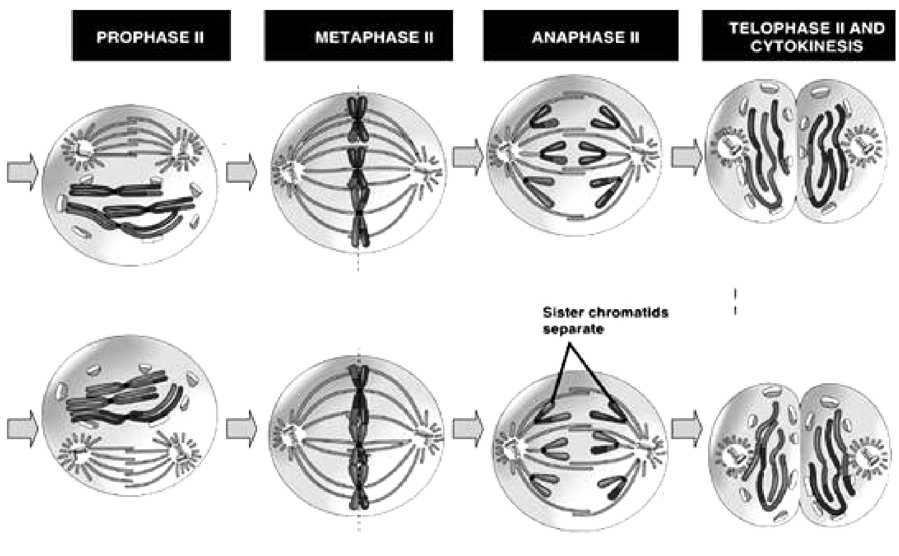
A	B	C	D
prophase I	**metaphase I**	**anaphase I**	**telophase I**

Meiosis I begins with *interphase*, like in mitosis (see B-2.6), in which cells: (1) increase in size, (2) produce RNA, (3) synthesize proteins, and (4) replicate DNA

- *Prophase I* (as in figure "A" above)
  - The nuclear membrane breaks down; centrioles separate from each other and take up positions on the opposite sides of the nucleus and begin to produce spindle fibers.
  - Chromosomes pair up and become visible as a cluster of four chromatids called a *tetrad.*
    - ♦ A *homologous* chromosome pair consists of two chromosomes containing the same type of genes.
      - ∗ the paternal chromosome in the pair contributed by the organism's male parent
      - ∗ the maternal chromosome in the pair contributed by the organism's female parent
    - ♦ Each chromosome consists of two *sister chromatids* attached at a point called the *centromere.*

        - ♦ Because the homologous chromosome pairs are in close proximity, an exchange of chromosome genetic material between pairs often occurs in a process called "*Crossing over.*" (see also B-4.7)
- *Metaphase I* (as in figure "B" above)
    - ○ The chromosomes are attached to the spindle fiber at the centromere and are pulled into the mid-line (or equator) of the cell in pairs.
- *Anaphase I* (as in figure "C" above)
    - ○ The chromosome pairs separate, one chromosome to each side of the cell.
        - ♦ Each daughter cell will receive only one chromosome from each homologous chromosome pair.
        - ♦ Sister chromatids remain attached to each other.
- *Telophase I & Cytokinesis* (as in figure "D" above)
    - ○ Chromosomes gather at the poles, nuclear membrane may form, and the cytoplasm divides.
    - ○ Cytokinesis that occurs at the end of telophase I is the division of the cytoplasm into two individual daughter cells.
- Each of the two daughter cells from meiosis I contains only one chromosome (consisting of two sister chromatids) from each parental pair. Each daughter cell from meiosis I proceeds to undergo meiosis II.

Meiosis II



(E) **(F)** **(G)** **(H)**

- *Prophase II* (as in figure "E" above)
    - ○ Spindle fibers form in each of the daughter cells from meiosis I and attaches to the centromeres of the sister chromatids
    - ○ The chromosomes progress towards the midline of each cell.
    - ○ The nuclear membrane breaks down.
- *Metaphase II* (as in figure "F" above)
    - ○ Chromosomes, made up of two sister chromatids, line up across the center of the cell.
    - ○ Spindle fibers from opposite poles of the cell attach to one of each pair of chromatids.

- *Anaphase II* (as in figure “G” above)
  - The chromosomes separate so that one chromatid from each chromosome goes to each pole.
- *Telophase II* & *Cytokinesis* (as in figure “H” above)
  - Nuclear member forms around each set of chromosomes.
  - The resulting daughter cells are haploid, containing one single chromosome from each pair of chromatids, either from the maternal or paternal contributor.

It is not essential for students to
- recognize any structures other than those listed above;
- explain the process of gametogenesis, the maturing of gametes.

Assessment Guidelines:
The objective of this indicator is to *summarize* the phases of meiosis I and meiosis II, therefore, the primary focus of assessment should be to give major points about each step in the processes and the significance of each step toward the goal of producing haploid daughter cells.

In addition to *summarize*, assessments may require students to
- *illustrate* and *interpret* scientific diagrams of the phases of meiosis;
- *compare* meiosis I to meiosis II with regard to processes and outcomes;
- *compare* haploid cells to diploid cells;
- *compare* mitosis and meiosis with regard to processes and outcomes;
- *explain* the effect of crossing over on the genetic variation in daughter cells.

Standard B-4: The student will demonstrate an understanding of the molecular basis of heredity.

B-4.6 Predict inherited traits by using the principles of Mendelian genetics (including segregation, independent assortment, and dominance).
Taxonomy Level: 2.5-B Understand Conceptual Knowledge

Key Concepts:
Genetics: alleles
Law (Principle) of Dominance: dominant, recessive; homozygous, heterozygous; genotype, phenotype
Law (Principle) of Segregation:
Law (Principle) of Independent Assortment: linked genes
Punnett squares: monohybrid cross, dihybrid cross, F_1 generation, F_2 generation

Previous knowledge: In 7th grade, students summarized how genetic information is passed from parent to offspring by using the terms genes, chromosomes, inherited traits, genotype, phenotype, dominant traits, and recessive traits (7-2.5) and used Punnett squares to predict inherited monohybrid traits (7-2.6).

It is essential for students to understand the principles of Mendelian genetics. *Genetics* is the study of patterns of inheritance and variations in organisms. Genes control each trait of a living thing by controlling the formation of an organism's proteins.

- Since in all cells (except gametes) chromosomes are diploid (exist as a pair of chromosomes), each cell contains two genes for each trait, one on the maternal chromosome and one on the paternal chromosome.
- The two genes may be of the same form or they may be of different forms.
  - These forms produce the different characteristics of each trait. For example, a gene for plant height might occur in a tall form and a short form.
  - The different forms of a gene are called *alleles.*
  - The two alleles are segregated during the process of gamete formation (meiosis II).

Law (Principle) of Dominance

The *law (principle) of dominance* states that some alleles are dominant whereas others are recessive.

- An organism with a dominant allele for a particular trait will always have that trait expressed (seen) in the organism.
- An organism with a recessive allele for a particular trait will only have that trait expressed when the dominant allele is not present.

Since organisms received one gene for a chromosome pair from each parent, organisms can be heterozygous or homozygous for each trait.

- When an organism has two identical alleles for a particular trait that organism is said to be *homozygous* for that trait.
  - The paternal chromosome and the maternal chromosome have the same form of the gene; they are either both dominant or both recessive.
- When an organism has two different alleles for a particular trait that organism is said to be *heterozygous* for that trait.
  - The paternal chromosome and the maternal chromosome have different forms of the gene; one is dominant and one is recessive.

Standard B-4: The student will demonstrate an understanding of the molecular basis of heredity.

The *genotype* (genetic makeup) of an organism reveals the type of alleles that an organism has inherited for a particular trait. The genotype for a particular trait is usually represented by a letter, the capital letter representing the dominant gene and the lower-case letter representing the recessive gene.

- TT represents a homozygous dominant genotype.
- tt represents a homozygous recessive genotype.
- Tt represents a heterozygous genotype.

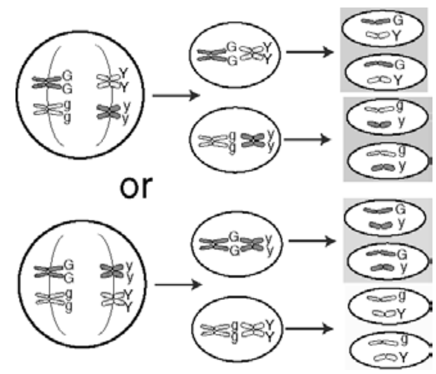
The *phenotype* (physical characteristics) of an organism is a description of the way that a trait is expressed in the organism.

- Organisms with genotypes of TT or Tt would have a phenotype of tall.
- Organisms with a genotype of Tt would have a phenotype of short.

Law (Principle) of Segregation

The *law (principle) of segregation* explains how alleles are separated during meiosis.

- Each gamete receives one of the two alleles that the parent carries for each trait. Each gamete has the same chance of receiving either one of the alleles for each trait.
- During fertilization (when sperm and egg unite), each parent organism donates one copy of each gene to the offspring.



Law (Principle) of Independent Assortment

The *law (principle) of independent assortment* states that the segregation of the alleles of one trait does not affect the segregation of the alleles of another trait.

- Genes on separate chromosomes separate independently during meiosis.
- This law holds true for all genes unless the genes are *linked*. In this case, the genes that do not independently segregate during gamete formation, usually because they are in close proximity on the same chromosome.

The principles of Mendelian genetics can be used to predict the inherited traits of offspring. A *Punnett square* can be used to predict the probable genetic combinations in the offspring that result from different parental allele combinations that are independently assorted.

- A *monohybrid cross* examines the inheritance of one trait. The cross could be homozygous-homozygous, heterozygous-heterozygous, or heterozygous-homozygous.
- The Punnett square example represents the probable outcome of two heterozygous parents with the trait for height: T = dominant tall, t = recessive short (Tt x Tt). The parents are the F_1 *generation*; the resulting offspring possibilities are the F_2 *generation*.

  The square shows the following genotypes are possible:
  - there is a 1:4 ratio (25%) that an offspring will carry two dominant alleles.
  - there is a 1:4 ratio (25%) that an offspring will carry two recessive alleles. there is a 2:4 or 1:2 ratio (50%) that an offspring will carry one dominant allele and one recessive allele.

  The square also shows the following phenotypes are possible:
  - there is a 3:4 ratio (75%) that an offspring will express the tall trait.
  - There is a 1:4 ratio (25%) that an offspring will express the short trait.

	T	t
T	TT	Tt
t	Tt	tt

TEACHER NOTE: It is important to stress the concept that there is only one possible genotype for the offspring, sometimes the process of making a Punnett square overshadows the concept and students think that all offspring are always formed.

Standard B-4: The student will demonstrate an understanding of the molecular basis of heredity.

- A *dihybrid cross* examines the inheritance of two different traits.
- The following Punnett square example represents the probable outcome of two traits of homozygous parents with the traits for shape and color: R = dominant round, r = recessive wrinkled; Y = dominant for yellow, y = recessive green (rryy x RRYY). The parents are the *F_1 generation*; the resulting offspring possibilities are the *F_2 generation*.

	ry	ry	ry	ry
RY	RrYy	RrYy	RrYy	RrYy
RY	RrYy	RrYy	RrYy	RrYy
RY	RrYy	RrYy	RrYy	RrYy
RY	RrYy	RrYy	RrYy	RrYy

  - All of the offspring for this generation would predictably have the same genotype, heterozygous for both traits (RrYy).
  - All of the offspring for this generation would predictably have the same phenotype, round and yellow (16/16 will be round and yellow).

It is not essential for students to understand
- the scientific investigations carried out by Gregor Mendel or other pioneer geneticists, however, the study of the history of genetics adds to the significance of science in the lives of students;
- how to perform testcrosses to solve for unknown genotypes;
- second generation Punnett squares.

Assessment Guidelines:
The objective of this indicator is *predict* inherited traits by using the principles of Mendelian genetics, therefore, the primary focus of assessment should be to determine inherited traits of offspring using the principles of segregation, independent assortment, and dominance.

In addition to *predict*, assessments may require students to
- *identify* traits as homozygous or heterozygous, dominant or recessive;
- *infer* the possible genotypes and phenotypes of offspring;
- *illustrate* monohybrid and dihybrid crosses;
- *summarize* the Mendelian concepts of independent assortment, segregation and dominance;
- *compare* the genotypes and phenotypes of offspring to their parents.

Standard B-4: The student will demonstrate an understanding of the molecular basis of heredity.

B-4.7 Summarize the chromosome theory of inheritance and relate that theory to Gregor Mendel's principles of genetics.
Taxonomy Level: 2.4-B Understand Conceptual Knowledge

Key Concepts:
Chromosome theory of inheritance
Gene linkage, crossing-over
Incomplete dominance, Codominance
Multiple alleles, Polygenic traits
Sex-linked traits, sex-linked genes
Pedigree

Previous knowledge: This concept has not been addressed in earlier grades.

It is essential that students understand that the current *chromosome theory of inheritance* is a basic principle in biology that states genes are located on chromosomes and that the behavior of chromosomes during meiosis accounts for inheritance patterns, which closely parallels predicted Mendelian patterns. The principles of Mendelian genetics (segregation, independent assortment, and dominance) support the chromosome theory of inheritance (see B-4.6). Due to advances in technology since Mendel, inheritance patterns and genetic variations that could not be explained by Mendelian genetics are now understood using the chromosome theory of inheritance. The following are new developments since Mendel's principles of genetics:

Gene Linkage and Crossing-over

- *Gene linkage* simply means that genes that are located on the same chromosome will be inherited together. These genes travel together during gamete *formation* (see B-4.5).
  - This is an exception to the Mendelian principle of independent assortment because linked genes do not segregate independently.
- *Crossing-over* is a process in which alleles in close proximity to each other on homologous chromosomes are exchanged. This results in new combinations of alleles.
  - When chromosomes pair up during meiosis I, sometimes sections of the two chromosomes become crossed. The two crossed sections break off and usually reattach.
  - When the genes are rearranged, new combinations of alleles are formed (see B-4.5).
- Crossing-over explains how linked genes can be separated resulting in greater genetic diversity that could not be explained by Mendel's principles of genetics.

Incomplete Dominance and Codominance

- *Incomplete dominance* is a condition in which one allele is not completely dominant over another. The phenotype expressed is somewhere between the two possible parent phenotypes.
- *Codominance* occurs when both alleles for a gene are expressed completely. The phenotype expressed shows evidence of both alleles being present.
- These conditions go beyond Mendel's principle of dominance.

Multiple Alleles and Polygenic Traits

- *Multiple alleles* can exist for a particular trait even though only two alleles are inherited. For example, three alleles exist for blood type (A, B, and O), which result in four different blood groups.
- *Polygenic traits* are traits that are controlled by two or more genes. These traits often show a great variety of phenotypes, e.g. skin color.
- Mendel's principles of genetics did not explain that many traits are controlled by more than one gene.

Standard B-4: The student will demonstrate an understanding of the molecular basis of heredity.

Sex-Linked Traits

- *Sex-linked traits* are the result of genes that are carried on either the X or the Y chromosome.
- This is an exception to the Mendel's principle of independent assortment, which does not explain sex-linked traits.
- In organisms that undergo sexual reproduction, one pair of chromosomes (the sex chromosomes) determines the sex of the organism.
  - The pair of sex chromosomes in females consists of two X chromosomes, each carrying the same genes; the pair of sex chromosomes in males consists of one X chromosome and one Y chromosome.
  - During meiosis I, when chromosome pairs separate, each gamete from the female parent receives an X chromosome, but the gametes from the male parent can either receive an X chromosome or a Y chromosome.
- A Punnett square for the cross shows that there is an equal chance of offspring being male (XY) or female (XX).

	X	Y
X	XX	XY
X	XX	XY

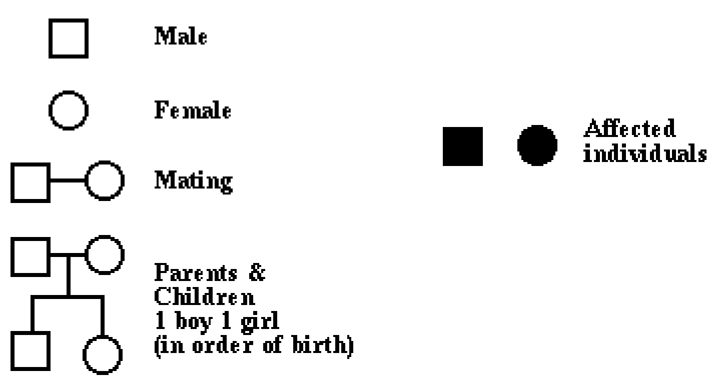
- In humans, the Y chromosome carries very few genes; the X chromosome contains a number of genes that affect many traits. Genes on sex chromosomes are called *sex-linked genes*. Sex-linked genes are expressed differently from an autosomal gene.
  - If a gene is linked on the X chromosome (X-linked),
    - Female offspring will inherit the gene as they do all other chromosomes (X from the father and X from the mother). The principles of dominance will apply.
    - Male offspring will inherit the gene on their X chromosome, but not on the Y chromosome.
    - Since males have one X chromosome, they express the allele whether it is dominant or recessive; there is no second allele to mask the effects of the other allele.
  - For example, the trait for color blindness is located on the X chromosome:
    - X chromosomes carrying a gene for normal vision can be coded X^C
    - X chromosomes carrying a gene for color-blindness can be coded X^c
    - Y chromosomes that all lack this gene can be coded Y
    - Only offspring that have the X^C gene will have normal vision.
  - Hemophilia is also a sex-linked trait.
  - In rare cases, a female can express the sex-linked, recessive trait.

	X^C	Y
X^C	$X^C X^C$	$X^C Y$
X^c	$X^c X^C$	$X^c Y$

Pedigree

A *pedigree* is a chart constructed to show an inheritance pattern (trait, disease, disorder) within a family through multiple generations. Through the use of a pedigree chart and key, the genotype and phenotype of the family members and the genetic characteristics (dominant/recessive, sex-linked) of the trait can be tracked.

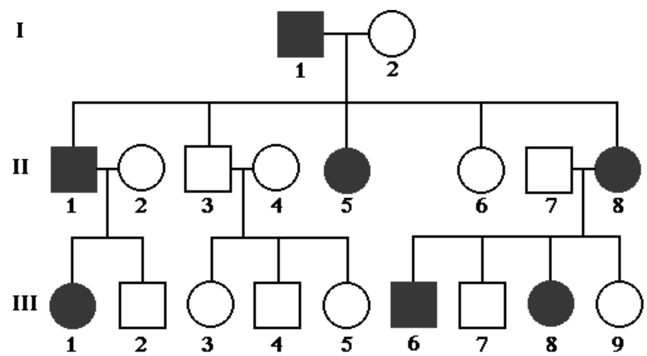
An example of a pedigree key:



Standard B-4: The student will demonstrate an understanding of the molecular basis of heredity.

Pedigree Example I:

(Family with a dominant autosomal genetic trait)



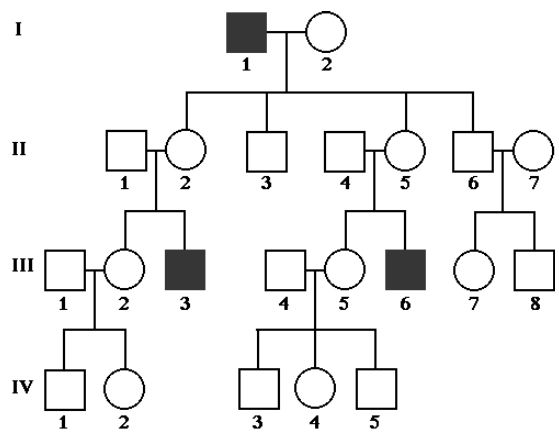
The gene for this particular genetic trait does not occur on the sex chromosomes; it occurs on an autosomal chromosome because both males and females have the trait. This information can be inferred from two facts:

(1) Because the father has the trait, if the trait were sex-linked (on the father's X chromosome), then all females would have the trait. However, because some females do not have the trait, it is not a sex-linked trait.
(2) Individual III-7 who is a male did not inherit the trait from his mother, who has the trait. He received his only X chromosome from his mother.

- This particular gene is a dominant gene because
  - each of the people who have the trait has only one parent who has the trait.
  - if only one parent has the trait and the trait is not sex-linked, then the individuals who have the trait must be heterozygous for the gene.

Pedigree Example II

(Family with a recessive sex-linked genetic trait)



The gene for this particular trait is sex-linked and recessive. This information can be inferred because only males have the trait.

- This is common in X-linked, recessive traits because females who receive the gene for the trait on the X chromosome from their fathers also receive an X chromosome from their mothers which hides the expression of the trait.
- The trait skips a generation.
  - In generation II, all of the offspring receive an X chromosome from their mother.
    - ♦ Because the males only receive the X chromosome from their mother, they do not receive the gene carrying the trait.
    - ♦ Because the females receive an X chromosome from their mother and father, they are heterozygous and do not express the recessive trait, but they are carriers.

- In generation III, the offspring of all of the females from generation II have a 50/50 chance of passing a trait-carrying gene to their children.
  - ♦ If the males receive the trait-carrying gene, they will express the trait.
  - ♦ If the females receive the trait-carrying gene, they will again be carriers.

It is not essential for students to understand X-chromosome inactivation (which occurs during embryonic development) or the Barr body.

Assessment Guidelines:
The objective of this indicator is to *summarize* the chromosome theory of inheritance and relate that theory to Gregor Mendel's principles of genetics; therefore, the primary focus of assessment should be to give major points about the modern chromosomal theory that relates to and expands upon Mendelian genetics.

In addition to *summarize*, assessments may require students to

- *explain* the effect of gene linkage and crossing over on the genetic variety of offspring;
- *compare* incomplete dominance and codominance;
- *compare* multiple alleles and polygenic traits;
- *exemplify* the ways that sex-linked traits are passed to offspring;
- *interpret* a pedigree with regard to the nature of specific traits within a family.

Standard B-4: The student will demonstrate an understanding of the molecular basis of heredity.

B-4.8 Compare the consequences of mutations in body cells with those in gametes.
Taxonomy Level: 2.6-B Understand Conceptual Knowledge

Key Concepts:
Mutation: mutagen, mutant cell, gene mutation, chromosomal mutation, nondisjunction
Beneficial mutations

Previous knowledge: This concept has not been addressed in earlier grades.

It is essential that students understand that a *mutation* is the alteration of an organism's DNA. Mutations can range from a change in one base pair to the insertion or deletion of large segments of DNA. Mutations can result from a malfunction during the process of meiosis or from exposure to a physical or a chemical agent, a *mutagen.*

Most mutations are automatically repaired by the organism's enzymes and therefore have no effect. However, when the mutation is not repaired, the resulting altered chromosome or gene structure is then passed to all subsequent daughter cells of the *mutant cell*, which may have adverse or beneficial effects on the cell, the organism, and future generations.

- If the mutant cell is a body cell (somatic cell), the daughter cells can be affected by the altered DNA, but the mutation will not be passed to the offspring of the organism.
  - Body cell mutations can contribute to the aging process or the development of many types of cancer.
- If the mutant cell is a gamete (sex cell), the altered DNA will be transmitted to the embryo and may be passed to subsequent generations. Gamete cell mutations can result in *genetic disorders*.
  - If the mutation affects a single gene, it is known as a *gene mutation*.
    - ♦ For example, the genetic basis of sickle-cell disease is the mutation of a single base pair in the gene that codes for one of the proteins of hemoglobin.
    - ♦ Other examples of genetic disorders are Tay-Sachs disease, Huntington's disease, cystic fibrosis, or albinism.
  - If the mutation affects a group of genes or an entire chromosome, it is know as a *chromosomal mutation.*
    - ♦ *Nondisjunction* results in an abnormal number of chromosomes, usually occurring during meiosis.
      - ∗ Examples of abnormalities in humans due to nondisjunction of sex chromosomes are Klinefelter's syndrome (male) and Turner's syndrome (female).
      - ∗ Examples of abnormalities in humans due to nondisjunction of autosomal chromosomes include Down syndrome.

In some cases mutations are beneficial to organisms. *Beneficial mutations* are changes that may be useful to organisms in different or changing environments. These mutations result in phenotypes that are favored by natural selection and increase in a population.

It is not essential for students to understand
- the exact mechanism of the various mutations;
- the exact characteristics of the nondisjunction mutation abnormalities listed above;
- the mechanism through which somatic mutations can cause various cancers.

Standard B-4: The student will demonstrate an understanding of the molecular basis of heredity.

Assessment Guidelines:
The objective of this indicator is to *compare* the consequences of mutations in body cells with those in gametes, therefore, the primary focus of assessment should be to detect similarities and differences between the mutations that occur in sex cells to those in somatic cells.

In addition to *compare*, assessments may require students to
- *recall* the causes of mutations;
- *classify* mutations as resulting from sex cell or somatic cell alterations;
- *classify* mutations as genetic or chromosomal;
- *exemplify* genetic or chromosomal disorders;
- *explain* the effect that various mutations have on the cell, the organism, and future generations.

Standard B-4: The student will demonstrate an understanding of the molecular basis of heredity.

B-4.9 Exemplify ways that introduce new genetic characteristics into an organism or a population by applying the principles of modern genetics.
Taxonomy Level: 2.2-B Understand Conceptual Knowledge

Key Concepts:
Genetic engineering: gene map, genome, cloning, gene therapy, stem cells
Selective breeding: inbreeding, hybridization

Previous knowledge: This concept has not been addressed in earlier grades.

It is essential for students to understand that the knowledge of genes and chromosomes enables the manipulation of the genotypes and phenotypes of organisms rather than allowing them to be left to natural processes.

Genetic Engineering
Genetic engineering is the process of replacing specific genes in an organism in order to ensure that the organism expresses a desired trait. Genetic engineering is accomplished by taking specific genes from one organism and placing them into another organism.

- Genetic engineering can only occur when scientists know exactly where particular genes for particular traits occur on specific chromosomes.
    - A *gene map* shows the relative location of each known gene on a chromosome.
    - *Genome* refers to all the genetic material in an organism. The Human Genome Project that mapped the DNA sequence of human genes is useful in identifying genes for specific traits.
- In *cloning*, an identical copy of a gene or an entire organism is produced. This may occur naturally or may be engineered. Cloning brings benefits such as organ transplants or saving endangered species, but it may also result in an organism with genetic disorders or health problems.
- In *gene therapy*, scientists insert a normal gene into an absent or abnormal gene. Once inserted the normal gene begins to produce the correct protein or enzyme, eliminating the cause of the disorder. However, gene therapy has had limited success because the host often rejects the injected genetic material.
- *Stem cells* are undifferentiated cells that have the potential to become specialized in structure or function. Although primarily found in embryos, they are also found all over the adult human body (for example bone marrow) but may be harder to isolate. Therapy using stem cells can replace tissue that is deficient due to disease or damage.
- Results of genetic engineering may include:
    - The development of plants that manufacture natural insecticides, are higher in protein, or spoil more slowly.
    - The development of animals that are bigger, are faster growing, or are resistant to disease.
    - The development of bacteria that produce hormones such as human insulin or human growth hormone.
    - In humans, it is theoretically possible to transplant copies of normal genes into the cells of people suffering from genetically carried diseases such a Tay-Sachs disease, cystic fibrosis, and sickle-cell anemia.

Standard B-4: The student will demonstrate an understanding of the molecular basis of heredity.

Selective Breeding

Selective breeding is the method of artificially selecting and breeding only organisms with a desired trait to produce the next generation. Almost all domesticated animals and most crop plants are the result of selective breeding.

- The process works because in order for the parents to show strong expression for the trait, they must carry at least one gene for the trait.
  - Once the breeder has successfully produced offspring with the desired set of characteristics, *inbreeding* (crossing individuals who are closely related) continues.
  - Over several generations, the gene for the trait will become more and more prevalent in the offspring.
  - The drawback to this method is that recessive gene defects often show up more frequently after several generations of inbreeding.
- *Hybridization*, which is another form of selective breeding, is the choosing and breeding organisms that show strong expression for two different traits in order to produce offspring that express both traits. This occurs often between two different (but similar) species. The offspring are often hardier than either of the parents.

It is not essential for students to understand the molecular processes of genetic engineering (recombinant DNA, gel electrophoresis), cell transformation, and DNA fingerprinting.

Assessment Guidelines:

The objective of this indicator is to *exemplify* ways that introduce new genetic characteristics into an organism or a population by applying the principles of modern genetics; therefore, the primary focus of assessment should be to give or use examples that show the ways the genetic makeup of an organism can be engineered or selected.

In addition to *exemplify*, assessments may require students to

- *recognize* types of genetic engineering and selective breeding;
- *summarize* the purposes of the various types of genetic engineering and selective breeding;
- *compare* selective breeding and hybridization;
- *summarize* the benefits and drawbacks of the various types of genetic engineering and selective breeding.

Standard B-5: The student will demonstrate an understanding of biological evolution and the diversity of life.

B-5.1 Summarize the process of natural selection.
Taxonomy Level: 2.4-B Understand Conceptual Knowledge

Key Concepts:
Biological evolution: microevolution, macroevolution
Natural selection
Overproduction of offspring
Variation: inherited traits
Adaptation: fitness, survival of the fittest
Descent with modification

Previous knowledge: In 6th grade (6-3.2), students summarized the basic functions of the structures of animals that allow them to defend themselves, to move, and to obtain resources. In 8th grade (8-2.1), students explained how biological adaptations of populations enhance their survival in a particular environment. The principles of natural selection related to biological evolution have not been addressed in previous grades.

It is essential for students to understand that *biological evolution* describes all of the changes that have transformed life on Earth from the earliest beginnings to the diversity of organisms in the world today. Biological evolution is the unifying theme of biology. Biological evolution can occur on a small scale affecting a single population (*microevolution*) or on a large scale affecting changes in species across populations (*macroevolution*).

One way to explain how biological evolution occurs is through natural selection. *Natural selection* occurs because the individual members of a population have different traits which allow them to interact with the environment either more or less effectively than the other members of the population. Natural selection results in changes in the inherited traits of a population over time. These changes often increase a species' fitness in its environment. There are four main principles to natural selection.

Overproduction of Offspring

- The ability of a population to have many offspring raises the chance that some will survive but also increases the competition for resources.

Variation

- Within every population, variation exists within the *inherited traits* of the individuals.
- Variation exists in the phenotypes (body structures and characteristics) of the individuals within every population.
- An organism's phenotype may influence its ability to find, obtain, or utilize its resources (food, water, shelter, and oxygen) and also might affect the organism's ability to reproduce.
- Phenotypic variation is controlled by the organism's genotype and the environment.
    - Those individuals with phenotypes that do not interact well with the environment are more likely to either die or produce fewer offspring than those that can interact well with the environment.

Standard B-5: The student will demonstrate an understanding of biological evolution and the diversity of life.

Adaptation

- The process of *adaptation* leads to the increase in frequency of a particular structure, physiological process, or behavior in a population of organisms that makes the organisms better able to survive and reproduce.
  - With every generation, organisms with specific beneficial inherited traits (that arose in a previous generation due to genetic variation) become more prevalent.
  - As each generation progresses, those organisms that carry genes that hinder their ability to meet day to day needs become less and less prevalent in the population.
    - Organisms that have a harder time finding, obtaining, or utilizing, food, water, shelter, or oxygen will be less healthy and more likely to die before they reproduce or produce less viable or fewer offspring.
  - In this manner, the gene pool of a population can change over time.
- The concept of *fitness* is used to measure how a particular trait contributes to reproductive success in a given environment and results from adaptations.
  - Natural selection has sometimes been popularized under the term *survival of the fittest*.

Descent with modification

- As the environment of a population changes, the entire process of natural selection can yield populations with new phenotypes adapted to new conditions.
- Natural selection can produce populations that have different structures, live in different niches or habitats from their ancestors. Each successive living species will have descended, with adaptations or other modifications, from previous generations.
- More individuals will have the successful traits in successive generations, as long as those traits are beneficial to the environmental conditions of the organism.

It is not essential for students to understand the history of the study of natural selection, though understanding the contributions made by various scientists makes the study of science more relevant to students. Students do not need to compare or understand directional, stabilizing, and disruptive natural selection.

Assessment Guidelines:

The objective of this indicator is to *summarize* the process of natural selection; therefore, the primary focus of assessment should be to generalize major points about the principles of natural selection.

In addition to *summarize,* assessments may require students to

- *infer* the fate of a particular species given a scenario of environmental change;
- *compare* microevolution and macroevolution;
- *explain* how changes in the environment may result in the appearance or disappearance of particular traits.

Standard B-5: The student will demonstrate an understanding of biological evolution and the diversity of life.

B-5.2 Explain how genetic processes result in the continuity of life-forms over time.
Taxonomy Level: 2.7-B Understand Conceptual Knowledge

Key Concepts:
Common genetic structures: nucleic acids, proteins
Passing genetic information: sexual reproduction, asexual reproduction

Previous knowledge: In 6th grade, students summarized the characteristics that all organisms share (including… the ability to reproduce) (6-2.1) and differentiated between the processes of sexual and asexual reproduction of flowering plants (6-2.6). In 8th grade (8-2.5), students illustrated the vast diversity of life that has been present on Earth over time by using the geologic time scale.

It is essential for students to understand that the continuity of life-forms on Earth is based on an organism's success in passing genes to the next generation. Many organisms that lived long ago resemble those still alive today because the same genetic processes have passed along the genetic material of life. Based on scientific evidence, most scientists attribute the continuity of life-forms over time to the genetic processes that all organisms share.

- All life that has ever existed on Earth, share at least the same two structures:
  (1) Nucleic acids (RNA or DNA) that carry the code for the synthesis of the organism's proteins (see B-4.1)
  (2) Proteins (composed of the same twenty amino acids in all life forms on Earth)
- The process by which nucleic acids code for proteins (transcription and translation) is the same in all life forms on Earth. The same sequences of nucleotides code for the same specific amino acids. (see B-4.4)

All organisms have reliable means of passing genetic information to offspring through reproduction. The reproductive processes of organisms, whether sexual or asexual, result in offspring receiving essentially the same genetic information as the parent or parents, though there may be some genetic variability.

Sexual Reproduction
Sexual reproduction uses the process of meiosis to create gametes. (see B-4.5) Fertilization results in the embryo receiving alleles from each parent for each trait. The new individual will express a combination of traits allowing for variation within the offspring. (see B-4.7)

- Genetic variability may also be due to gene shuffling, crossing-over, recombination of DNA, or mutations. (see B-4.7 and B-4.8) When gametes are produced, each parent's alleles may be arranged in new ways in the offspring.
- Genetic changes or variability result in the transcription and translation of new or different proteins that will result in changes in the phenotype of an individual organism.
- Reproduction that results in allele combinations producing traits that improve an individual's chance of survival ensures the continuity of that life form over time.

Asexual Reproduction
Asexual reproduction involves only one parent that produces the offspring that are for the most part genetically identical to that parent.

- Genetic variability can only occur through mutations in the DNA passed from parent to offspring, which is another way these organisms achieve variations as the populations continue over time.

- This may be accomplished by cell division: binary fission (reproduction of single-celled organisms) or mitosis (reproduction in multi-celled organisms).
- Examples of asexual reproduction are budding, fragmentation, and vegetative propagation.
- The asexual reproduction rate is much higher than sexual reproduction and produces many offspring that are suited to continuing life in the present environment.
- Asexual reproduction may have a disadvantage in changing conditions because genetically identical offspring respond to the environment in the same way. If a population lacks traits that enable them to survive and reproduce, the entire population could die off.

The genetic view of evolution includes the transfer of the genetic material through these processes of reproduction. The continuity of a species is contingent upon these genetic processes. If an organism can reproduce both sexually and asexually, they have an adaptive advantage for survival.

It is not essential for students to recall
- the specific type of reproduction for various groups of organisms;
- the specific organisms that appeared or lived at specific geologic time periods.

Assessment Guidelines:
The objective of this indicator is to *explain* how genetic processes result in the continuity of life-forms over time; therefore, the primary focus of assessment should be to construct a cause-and-effect model showing how sexual and asexual reproduction allows for the continuity of life-forms through the passing on of genetic material.

In addition to *explain*, assessments may require students to
- *recall* the similarities between organisms that live today with those that lived in the past;
- *exemplify* how genetic variability results in the continuity of life-forms;
- *compare* the results of sexual and asexual reproduction;
- *summarize* how sexual and asexual reproduction ensure that genetic material is passed to offspring allowing for the continuity of life-forms.

Standard B-5: The student will demonstrate an understanding of biological evolution and the diversity of life.

B-5.3 Explain how diversity within a species increases the chances of its survival.
Taxonomy Level: 2.7-B Understand Conceptual Knowledge

Key Concepts:
Species
Gene pool

Previous knowledge: In 6^{th} grade, students recognized the hierarchical structure to classification (including…species) (6-2.2) and illustrated animal behavioral responses (including … courtship) to environmental stimuli (6-3.5). In 8^{th} grade (8-2.1), students explained how biological adaptations of populations enhance their survival in a particular environment.

It is essential for students to understand that a *species* is a group of organisms that share similar characteristics and can interbreed with one another to produce fertile offspring.

- Species that interbreed share a common *gene pool* (all genes, including all the different alleles, of all of the individuals in a population).
- Because of the shared gene pool, a genetic change that occurs in one individual can spread through the population as that individual and its offspring mate with other individuals.
- If the genetic change increases fitness, it will eventually be found in many individuals in the population.

Within a species there is a variability of phenotypic traits leading to diversity among the organisms of the species. The greater the diversity, the greater the chances are for that species to survive during environmental changes.

If an environment changes, organisms that have phenotypes which are well-suited to the new environment will be able to survive and reproduce at higher rates than those with less favorable phenotypes. Therefore, the alleles associated with favorable phenotypes increase in frequency and become more common and increase the chances of survival of the species.

- Favorable traits (such as coloration or odors in plants and animals, competitive strength, courting behaviors) in male and female organisms will enhance their reproductive success. Non-random mating results in the gene pool of a population that can change over time and a species that can become increasingly adapted to its environment.
- Organisms with inherited traits that are beneficial to survival in its environment become more prevalent. For example, resistance of the organism to diseases or ability of the organism to obtain nutrients from a wide variety of foods or from new foods.
- Organisms with inherited traits that are detrimental to survival in its environment become less prevalent.

It is not essential for students to understand how dispersion can limit the distribution of organisms. Students do not need to address long- or short-term environmental changes in the context of this indicator.

Standard B-5: The student will demonstrate an understanding of biological evolution and the diversity of life.

Assessment Guidelines:
The objective of this indicator is to *explain* how diversity within a species increases the chances of its survival; therefore, the primary focus of assessment should be to construct a cause-and-effect model showing how variability in species ensures reproductive success and adaptation to its environment.

In addition to *explain*, assessments may require students to

- *summarize* the ways that diversity affects a species chances of survival;
- *exemplify* favorable traits that ensure reproductive success or species survival;
- *infer* the fate of a particular species in the face of a specific environmental change based on the degree of diversity of its members;
- *compare* the chances of two species to survive in the face of a specific environmental change based on the degree of diversity among the members of each group.

Standard B-5: The student will demonstrate an understanding of biological evolution and the diversity of life.

B-5.4 Explain how genetic variability and environmental factors lead to biological evolution.
Taxonomy Level: 2.7-B Understand Conceptual Knowledge

Key Concepts:
Genetic variability: genetic drift, gene flow, non-random mating, mutations, natural selection
Genetic equilibrium: Hardy-Weinberg principle
Speciation
Patterns of evolution: gradualism, punctuated equilibrium, adaptive radiation/divergent evolution, convergent evolution (analogous structures), coevolution, extinction (gradual, mass)

Previous knowledge: In 8th grade, students explained how Earth's history has been influenced by catastrophes (including the impact of an asteroid or comet, climatic changes, and volcanic activity) that have affected the conditions on Earth and the diversity of its life-forms (8-2.3) and summarized the factors, both natural and man-made that can contribute to the extinction of a species (8-2.7).

It is essential for students to understand that genetic variation is random and ensures that each new generation results in individuals with unique genotypes and phenotypes. This *genetic variability* leads to biological evolution.

Factors that influence genetic variability within a population may be:
- *Genetic drift* is the random change in the frequency of alleles of a population over time. Due to chance, rare alleles in a population will decrease in frequency and become eliminated; other alleles will increase in frequency and become fixed. The phenotypic changes may be more apparent in smaller populations than in larger ones.
- *Gene flow* is the movement of genes into or out of a population. This occurs during the movement of individuals between populations (such as migration) thus increasing the genetic variability of the receiving population.
- *Non-random mating* limits the frequency of the expression of certain alleles. (see B-5.3)
- *Mutations* increase the frequencies and types of allele changes within the population. (see B-5.2)
- *Natural selection* allows for the most favorable phenotypes to survive and thus be passed on to future generations. (see B-5.1)

When there is no change in the allele frequencies within a species, the population is said to be in *genetic equilibrium*. This concept is known as the *Hardy-Weinberg principle*. Five conditions that are required to maintain genetic equilibrium are:
- The population must be very large, no genetic drift occurs
- There must be no movement into or out of a population
- There must be random mating
- There must be no mutations within the gene pool
- There must be no natural selection

Speciation is the process of forming of a new species (or other taxonomic groups) by biological evolution from a preexisting species.
- New species usually form when organisms in the population are isolated or separated so that the new population is prevented from reproducing with the original population, and its gene pools cease to blend.
- Once isolation (reproductive or temporal, behavioral, geographic) occurs, genetic variation and natural selection increase the differences between the separated populations.

- As different traits are favored in the two populations (original and new) because of isolation, the gene pools gradually become so different that they are no longer able to reproduce. At this point the two groups are by definition different species.

It is also essential for students to understand that environmental factors (such as catastrophic events, climatic changes, continental drift) can also lead to biological evolution. Results from environmental factors may affect biological evolution on a grand scale over many generations (macroevolution). Some *patterns of evolution* are:

Gradualism

- Gradual changes of a species in a particular way over long periods of time, such as a gradual trend toward larger or smaller body size.

Punctuated equilibrium

- Periods of abrupt changes in a species after long periods of little change within the species over time, such as sudden change in species size or shape due to environmental factors.

Adaptive radiation/Divergent evolution

- In adaptive radiation (divergent evolution), a number of different species diverge (split-off) from a common ancestor.
- This occurs when, over many generations, organisms (whose ancestors were all of the same species) evolve a variety of characteristics which allow them to survive in different niches.

Convergent evolution

- In convergent evolution, evolution among different groups of organisms living in similar environments produces species that are similar in appearance and behavior.
- Convergent evolution has produced many of the *analogous structures* in organisms today. Analogous structures are similar in appearance and function, but have different evolutionary origins.

Coevolution

- With coevolution, when two or more species living in close proximity change in response to each other. The evolution of one species may affect the evolution of the other.

Extinction

- Extinction is the elimination of a species often occurring when a species as a whole cannot adapt to a change in its environment. This elimination can be gradual or rapid.
- *Gradual extinction* usually occurs at a slow rate and may be due to other organisms, changes in climate, or natural disasters. Speciation and gradual extinction occur at approximately the same rate.
- *Mass extinction* usually occurs when a catastrophic event changes the environment very suddenly (such as a massive volcanic eruption, or a meteor hitting the earth causing massive climatic changes). It is often impossible for a species to adapt to rapid and extreme environmental changes.

It is not essential for students to

- know specific types of genetic drift;
- make calculations using the Hardy-Weinberg equation;
- recall the historical development of the theory of evolution.

Standard B-5: The student will demonstrate an understanding of biological evolution and the diversity of life.

Assessment Guidelines:
The objective of this indicator is to *explain* how genetic variability and environmental factors lead to biological evolution; therefore, the primary focus of assessment should be to construct a cause-and-effect model showing how the factors influencing genetic variability, speciation, and processes of evolution due to environmental changes can lead to the evolution of a species over time.

In addition to *explain,* assessments may require students to
- *summarize* the factors influencing genetic variability in a population;
- *summarize* the Hardy-Weinberg principle;
- *explain* the process of speciation;
- *summarize* the patterns of macroevolution;
- *compare* gradual and mass extinction.

Standard B-5: The student will demonstrate an understanding of biological evolution and the diversity of life.

B-5.5 Exemplify scientific evidence in the fields of anatomy, embryology, biochemistry, and paleontology that underlies the theory of biological evolution.
Taxonomy Level: 2.2-B Understand Conceptual Knowledge

Key Concepts:
Anatomy - Homologous structures, vestigial organs
Embryology
Biochemistry
Paleontology – fossil record

Previous knowledge: In 8th grade, students summarized how scientists study Earth's past environment and diverse life-forms by examining different type of fossils (including molds, casts, petrified fossils, preserved and carbonized remains of plants and animals, and trace fossils) (8-2.2), illustrated the vast diversity of life that has been present on Earth over time by using the geologic time scale (8-2.5) and inferred the relative age of rocks and fossils from index fossils and the ordering of the rock layers (8-2.6).

It is essential for students to understand how scientific studies in the fields of anatomy, embryology, biochemistry, and paleontology have contributed scientific evidence for the theory of evolution.

Field of Anatomy
The field of *anatomy* (the study of the structures of organisms) provides one type of data for the support of biological evolution.

- Scientists study homologous structures as one form of evidence to determine the possible relationship between the evolutionary paths of two species. (see B-5.4)
    - Organisms which have diverged from a common ancestor often have *homologous structures* (similar characteristics resulting from common ancestry). The greater the numbers of shared structures between two species, the more closely the species are related.
    - Many species have *vestigial organs* (structures with little or no function to the organism) that are remnants of structures that had important functions in ancestors of the species. The vestigial organs of one species are often homologous with structures in related species where the structure has remained functional.
- Also, the study of the anatomy of species located in different geographical locations reveals that species living in different locations under similar ecological conditions developed similar structures and behaviors.
- If a species encountered a different ecosystem due to a change in geographical location, favorable anatomical traits become established. A new species evolves with a shared common ancestor from the original population.

Field of Embryology
The field of *embryology* (the study of the embryonic development of organisms) provides another type of data for the support of biological evolution by comparing the anatomies of embryos (an early stage—pre-birth, pre-hatching, or pre-germination—of organism development).

- Sometimes similarities in patterns of development or structures that are not obvious in adult organisms become evident when embryonic development is observed.
- The embryos of vertebrates are very similar in appearance early in development but may grow into different structures in the adult form.

- These similar structures of these embryos may suggest that these species evolved from common ancestors.

Field of Biochemistry
The field of *biochemistry* (the study of the chemical processes in organisms) studies genes and proteins to provide support for biological evolution.

- The more similar the DNA and amino acid sequences in proteins of two species, the more likely they are to have diverged from a common ancestor.
- Biochemistry provides evidence of evolutionary relationships among species when anatomical structures may be hard to use. For example,
  - when species are so closely related that they do not appear to be different, or
  - when species are so diverse that they share few similar structures.

Field of Paleontology
Paleontology (the study of prehistoric life) is another tool that scientists use to provide support for biological evolution.

- The fossil record provides valid evidence of life forms and environments along a timeline and supports evolutionary relationships by showing the similarities between current species and ancient species.
- Comparing current and ancient species shows a pattern of gradual change from the past to the present.
- Examining the fossil record of Earth reveals a history that tells a story of the types of organisms that have lived on Earth (including those that are extinct) and the relative ages of those fossils.
- The fossil record is not complete because most organisms do not form fossils. Many of the gaps in the fossil record have been filled in as more fossils have been discovered.
- The older the fossils, the less resemblance there is to modern species.

It is not essential for students to

- understand Haeckel's embryos or the early history of embryology;
- understand the various ways that DNA and RNA change rates are used to determine the relationship between the evolutionary paths of two species;
- explain processes of relative, absolute, or radiometric dating;
- classify fossils;
- explain how fossils are formed or the geologic time scale;
- explain how life began or the origin of heredity.

Assessment Guidelines:
The objective of this indicator is to *exemplify* scientific evidence in the fields of anatomy, embryology, biochemistry, and paleontology that underlies the theory of biological evolution; therefore, the primary focus of assessment should be to give or use examples of how these scientific fields provide evidence that supports the change in species over time.

In addition to *exemplify,* assessments may require students to

- *identify* fields of science that provide evidence for biological evolution;
- *illustrate* evidence for biological evolution using pictures, diagrams, or words;
- *infer* relationships among organisms based on evidence from each field of science listed;
- *summarize* the ways that each field of science listed provides evidence for evolutionary relationships.

Standard B-5: The student will demonstrate an understanding of biological evolution and the diversity of life.

B-5.6 Summarize ways that scientists use data from a variety of sources to investigate and critically analyze aspects of evolutionary theory.
Taxonomy Level: 2.4-B Understand Conceptual Knowledge

Key Concepts:
Phylogeny: convergence
Sources of evolutionary data – anatomy, embryology, paleontology, biochemistry
Transitional fossils

Previous knowledge: In 6th grade (6-2.2), students recognized the hierarchical structure of the classification (taxonomy) of organisms. In 8th grade (8-2.6), students inferred the relative age of rocks and fossils from index fossils and the ordering of the rock layers. The concept of scientists investigating and analyzing evolutionary data has not been addressed in previous grades.

It is essential for students to understand that scientists study data to trace the *phylogeny* (evolutionary history) of a species or a group of related species. Based on this study of data, an evolutionary theory has been developed that states all forms of life on Earth are related because the ancestry of organisms can be traced back to a common origin. Evidence of the shared history is found in all aspects of living and fossil organisms (physical features, structures of proteins, sequences found in RNA and DNA). Scientists must use multiple sources of evidence in drawing conclusions concerning the evolutionary relationship among groups of organisms. For example:

Field of Anatomy:
- Phylogenies can be constructed by assuming that anatomical differences increase with time. The greater the anatomical similarity, the more recently a pair of species shares a common ancestor.
  - The accumulation of evolutionary differences over time is called divergence. (see B-5.7)
  - Anatomical structures that share a common evolutionary history but not necessarily the same function are termed homologous. (see B-5.5)
- Evolutionary biologists make observations on as many anatomical structures as possible to construct phylogenies.
- Sometimes individual structures may suggest evolutionary relationships that differ from the bulk of the evidence. This may result from *convergence*, structures becoming more similar with time.
  - Convergence occurs when organisms with different evolutionary histories adapt to similar environments.
  - Anatomical structures that have different evolutionary origins but similar functions are said to be analogous. (see B-5.4)

Field of Embryology:
- Characters of embryonic development allow scientists to reconstruct the phylogenies of highly divergent taxa, such as phyla and classes, that may have evolved so many anatomical differences that they are difficult to compare otherwise.
- One mechanism by which evolution may have proceeded is by selection for successive new stages at the end of embryonic development. If this has been the case, ontogeny (growth and development of an individual organism) will recapitulate phylogeny.

Standard B-5: The student will demonstrate an understanding of biological evolution and the diversity of life.

Field of Paleontology:

- The fossil record provides information regarding the dates and order of divergence for phylogenies.
- *Transitional fossils* (fossils that show links in traits between groups of organisms used to document intermediate stages in the evolution of a species) confirm evolutionary relationships.
- The primary challenge for using the fossil record as a map of evolutionary history is that the record is incomplete.
    - Even though millions of fossils have been discovered by scientists, many environmental conditions must be met in order for a fossil to form, and the chance of all of these conditions coming together at one time is rare.
    - The fossil record favors the preservation of species that existed for a long time, were abundant and widespread, and had hard shells or skeletons.
    - Gaps do not indicate weakness in the evolutionary theory, but rather point out opportunities for additional research. Fossils that allow scientists to fill gaps in the record are continually being discovered.

Field of Biochemistry:

- Phylogenies can be constructed by assuming that differences in DNA, proteins, and other molecules increase over time. The greater the overall genetic similarity, the more recently a pair of species shares a common ancestor.
- The time since a pair of species has diverged can be estimated under the assumptions of a "molecular clock."
- Even though a comparison of the DNA sequences of two species provides some of the most reliable evidence, there are challenges inherent in this approach as well.
    - Because genes evolve at different rates, it may be difficult for scientists to identify the molecules that yield information about the group of organisms at the scale under study.
    - Insertions and deletions result in homologous genes of different lengths, which may introduce difficulties in aligning them for comparison. (see B-4.8)
    - Different assumptions about the details of molecular evolution can yield different phylogenetic trees. (see B-5.7)
    - Natural selection can cause convergence in molecules, just as it causes convergence in anatomical structures. (see B-5.1)

Students should also understand that one piece of evidence does not ensure an accurate picture of the history of the evolution of a particular group of organisms, but as scientists collect many pieces of evidence from many fields, the reliability of a particular hypothesis becomes greater and greater. The more evidence scientists can gather from different fields of science, the more reliable their information becomes in regards to evolutionary relationships. The evolutionary theory is a well-tested explanation that accounts for a wide range of observations made by scientists in many fields of science. No scientist suggests that all evolutionary processes are understood; many unanswered questions remain to be studied and analyzed.

Standard B-5: The student will demonstrate an understanding of biological evolution and the diversity of life.

It is not essential for students to

- make judgments concerning the evolution of organisms based on scientific evidence as most of the science that is essential for this process is beyond the scope of this course (it is only essential that students understand why it is imperative for scientists to use a wide variety of evidence when they determine a phylogenetic relationship);
- understand how scientists use pseudogenes or homeobox genes in determining evolutionary relationships.

Assessment Guidelines:

The objective of this indicator is to *summarize* ways that scientists use data from a variety of sources to investigate and critically analyze aspects of evolutionary theory; therefore, the primary focus of assessment should be to give major points about how scientists in the fields of anatomy, embryology, paleontology, and biochemistry have used data to develop a picture of the process of evolutionary theory.

In addition to *summarize,* assessments may require students to

- *compare* the evidence within the fields that scientists use to critically analyze evolutionary ancestry;
- *recall* the evidence that analogous and homologous structures provide for evolutionary relationships;
- *infer* how the fossil record has challenged scientists in paleontology;
- *explain* how biochemists use DNA evidence to show evolutionary relationship.

Standard B-5: The student will demonstrate an understanding of biological evolution and the diversity of life.

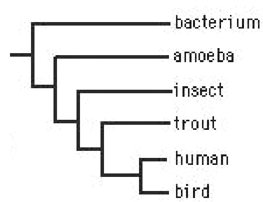
B-5.7 Use a phylogenetic tree to identify the evolutionary relationships among different groups of organisms.
Taxonomy Level: 3.2-B Apply Conceptual Knowledge

Key Concepts:
Phylogenetic tree: taxa

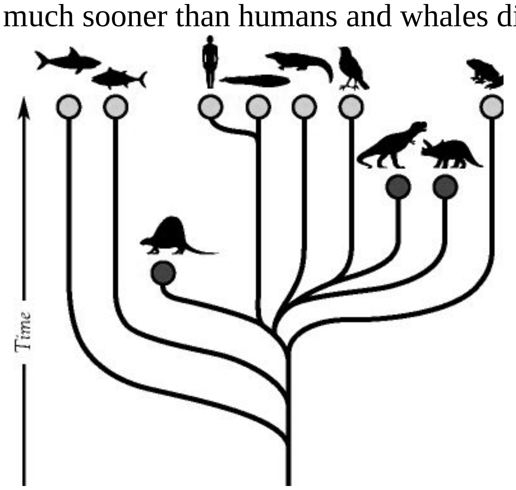
Previous knowledge: In 6th grade (6-2.2), students recognized the hierarchical structure to classification (taxonomy) of organisms (including the seven major levels or categories of living things—kingdom, phylum, class, order, family, genus, and species).

It is essential for students to understand that a *phylogenetic tree* is a scientific diagram that biologists use to represent the phylogeny (evolutionary history of a species) of organisms. It classifies organisms into major *taxa* (groups) based on evolutionary relationships. Phylogenetic trees are used to classify species in the order in which they descended from a common ancestor using physical characteristics. Speciation could be thought of as a branching of a family tree then extinction is like the loss of one of the branches.

- Some phylogenetic trees only express the order of divergence of a species. They do not attempt to show relative or absolute time frames.



- Some phylogenetic trees indicate an estimated time of divergence. The tree below shows the relative time that species diverged.
  - The branch between humans and whales is almost at the top of the line, while the branch between birds and tyrannosaurs happens about midway up the line, indicating that birds and tyrannosaurs diverged much sooner than humans and whales diverged.



From phylogenetic trees, the following information can be determined:
- Which groups are most closely related?
- Which groups are least closely related?
- Which group diverged first (longest ago) in the lineage?

Standard B-5: The student will demonstrate an understanding of biological evolution and the diversity of life.

One of the main challenges that biologists concerned with biodiversity have recently face is in classifying organisms because species are becoming extinct at an increasing pace. As knowledge of biodiversity increases, revisions to taxonomic systems are continually being proposed. Biologists regularly revise the many branches of the phylogenetic tree to reflect current hypotheses of the evolutionary relationships between groups. The most recent classification scheme includes

- three domains (Bacteria, Archaea, and Eukarya)
- six kingdoms (Eubacteria, Archaebacteria, Protista, Fungi, Plantae, and Animalia).

TEACHER NOTE: A different way of classifying organisms is by using a cladogram, which represents a hypothesis using derived characteristics to determine evolutionary relationships.

It is not essential for students to know

- types of characters used in constructing phylogenies (morphological, biochemical/ molecular);
- other concepts for determining species classification (typological, biological);
- molecular cladistics.

Assessment Guidelines:

The objective of this indicator is to *use* a phylogenetic tree to identify the evolutionary relationships among different groups of organisms; therefore, the primary focus of assessment should be to apply procedural knowledge of a phylogenetic tree to determine the evolutionary relationships among species.

In addition to *use*, assessments may require students to

- *interpret* data from a phylogenetic tree;
- *classify* organisms according to evolutionary relationships based on a phylogenetic tree;
- *summarize* information provided by a phylogenetic tree;
- *infer* the evolutionary relationships among groups represented on a phylogenetic tree;
- *explain* why organisms would be placed at various positions on a phylogenetic tree based on given scientific data.

Standard B-6: The student will demonstrate an understanding of the interrelationships among organisms and the biotic and abiotic components of their environments.

B-6.1 Explain how the interrelationships among organisms (including predation, competition, parasitism, mutualism, and commensalism) generate stability within ecosystems.

Taxonomy Level: 2.7-B Understand Conceptual Knowledge

Key Concepts:
Ecosystem: stable ecosystem
Predation: predator, prey
Competition: niche
Symbiotic relationships: parasitism, mutualism, commensalism

Previous knowledge: In 5th grade (5-2.4), students identified the roles of organisms as they interact and depend on one another through food chains and food webs in an ecosystem, considering producers and consumers (herbivores, carnivores, omnivores), decomposers (microorganisms, termites, worms, and fungi), predators and prey, and parasites and hosts. In 7th grade (7-4.1), students summarized the characteristics of the levels of organization within ecosystems (including populations, communities, habitats, niches, and biomes).

It is essential for students to understand that an *ecosystem* is defined as a community (all the organisms in a given area) and the abiotic factors (such as water, soil, or climate) that affect them. A *stable ecosystem* is one where

- the population numbers of each organism fluctuate at a predictable rate.
- the supply of resources in the physical environment fluctuates at a predictable rate.
- energy flows through the ecosystem at a fairly constant rate over time.

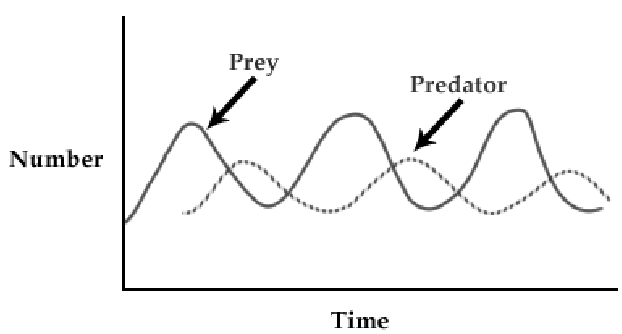
These fluctuations in populations and resources ultimately result in a stable ecosystem.

Organisms in an ecosystem constantly interact. The interactions among the organisms generate stability within ecosystems.

Predation

Predation is an interaction between species in which one species (the *predator*) eats the other (the *prey*). This interaction helps regulate the population within an ecosystem thereby causing it to become stable. Fluctuations in predator–prey populations are predictable. At some point the prey population grows so numerous that they are easy to find.

- A graph of predator–prey density over time shows how the cycle of fluctuations results in a stable ecosystem.
  - ○ As the prey population increases, the predator population increases.
  - ○ As the predator population increases, the prey population decreases.



Standard B-6: The student will demonstrate an understanding of the interrelationships among organisms and the biotic and abiotic components of their environments.

Competition

Competition is a relationship that occurs when two or more organisms need the same resource at the same time.

- Competition can be among the members of the same or different species and usually occurs with organisms that share the same niche.
  - An ecological *niche* refers to the role of an organism in its environment including type of food it eats, how it obtains its food and how it interacts with other organisms.
  - Two species with identical ecological niches cannot coexist in the same habitat.
- Competition usually results in a decrease in the population of a species less adapted to compete for a particular resource.

Symbiotic Relationships

A *symbiotic relationship* exists between organisms of two different species that live together in direct contact. The balance of the ecosystem is adapted to the symbiotic relationship. If the population of one or other of the symbiotic organisms becomes unbalanced, the populations of both organisms will fluctuate in an uncharacteristic manner. Symbiotic relationships include parasitism, mutualism, and commensalism.

Parasitism is a symbiotic relationship in which one organism (the parasite) benefits at the expense of the other organism (the host). In general, the parasite does not kill the host.

- Some parasites live within the host, such as tape worms, heartworms, or bacteria.
- Some parasites feed on the external surface of a host, such as aphids, fleas, or mistletoe.
- The parasite-host populations that have survived have been those where neither has a devastating effect on the other.
- Parasitism that results in the rapid death of the host is devastating to both the parasite and the host populations. It is important that the host survive and thrive long enough for the parasite to reproduce and spread.

Mutualism is a symbiotic relationship in which both organisms benefit. Because the two organisms work closely together, they help each other survive. For example,

- bacteria, which have the ability to digest wood, live within the digestive tracts of termites;
- plant roots provide food for fungi that break down nutrients the plant needs.

Commensalism is a symbiotic relationship in which one organism benefits and the organism is not affected. For example,

- barnacles that attach to whales are dispersed to different environments where they can obtain food and reproduce;
- burdock seeds that attach to organisms and are carried to locations where they can germinate.

It is not essential for students to understand adaptations that have resulted from symbiotic relationships.

Standard B-6: The student will demonstrate an understanding of the interrelationships among organisms and the biotic and abiotic components of their environments.

Assessment Guidelines:

The objective of this indicator is to *explain* how the interrelationships among organisms generate stability within ecosystems; therefore, the primary focus of assessment should be to construct a cause-and-effect model showing how predation, competition, parasitism, mutualism, and commensalism affect the stability of an ecosystem.

In addition to *explain*, assessments may require students to

- *summarize* how a stable ecosystem is obtained;
- *identify* or *illustrate* the roles of various organisms in an ecosystem (predator, prey, parasite, host) using pictures, diagrams, or words;
- *interpret* a graph of predator/prey numbers over time;
- *explain* how the numbers of various organisms fluctuate in an ecosystem to maintain stability;
- *exemplify* biological relationships;
- *explain* how a significant change in the numbers of a particular organism will affect the stability of the ecosystem;
- *classify* a symbiotic relationship as mutualism, parasitism, or commensalism;
- *summarize* each of the types of biological relationships;
- *compare* how various types of biological relationships affect the organisms involved.

Standard B-6: The student will demonstrate an understanding of the interrelationships among organisms and the biotic and abiotic components of their environments.

B-6.2 Explain how populations are affected by limiting factors (including density-dependent, density-independent, abiotic, and biotic factors).
Taxonomy Level: 2.7-B Understand Conceptual Knowledge

Key Concepts:
Population: population density
Limiting factors: density-dependent, density-independent, abiotic, biotic

Previous knowledge: In 5th grade (5-2.5) students explained how limiting factors (including food, water, space, and shelter) affect populations in ecosystems. In 7th grade, students explained the interaction among changes in the environment due to…limiting factors (including climate and the availability of food and water, space, and shelter) (7-4.3) and summarized the characteristics of the levels of organization within ecosystems (including populations…) (7-4.1).

It is essential for students to understand that a *population* is a group of organisms belonging to the same species that live in a particular area. Populations can be described based on their size, density, or distribution. *Population density* measures the number of individual organisms living in a defined space. Regulation of a population is affected by limiting factors that include density-dependent, density-independent, abiotic and biotic factors.

Density-dependent
Limiting factors that are density-dependent are those that operate more strongly on large populations than on small ones. Density-dependent limiting factors include competition, predation, parasitism, and disease. These limiting factors are triggered by increases in population density (crowding).

Density-independent
Limiting factors that are density-independent are those that occur regardless of how large the population is and reduce the size of all populations in the area in which they occur by the same proportion. Density-independent factors are mostly abiotic (such as weather changes), human activities (such as pollution), and natural disasters (such as fires).

Abiotic and biotic factors
Limiting factors can change within an ecosystem and may affect a population.

- *Abiotic factors* may be chemical or physical. Some examples are water, nitrogen, oxygen, salinity, pH, soil nutrients and composition, temperature, amount of sunlight, and precipitation.
- *Biotic factors* include all of the living components of an ecosystem. Some examples are bacteria, fungi, plants, and animals.

A change in an abiotic or biotic factor may decrease the size of a population if it cannot acclimate or adapt to or migrate from the change. A change may increase the size of a population if that change enhances its ability to survive, flourish or reproduce.

It is not essential for students to understand

- the biogeographic factors that affect the biodiversity of communities or the population densities of those communities;
- the control of internal conditions of organisms;
- how to calculate population growth patterns or population density.

Standard B-6: The student will demonstrate an understanding of the interrelationships among organisms and the biotic and abiotic components of their environments.

Assessment Guidelines:
The objective of this indicator is to *explain* how populations are affected by limiting factors; therefore, the primary focus of assessment should be to construct cause-and-effect models of how each limiting factor (including density-dependent, density-independent, abiotic, and biotic factors) can affect a population in an ecosystem and in turn, the entire ecosystem.

In addition to *explain*, assessments may require students to

- *summarize* how limiting factors (as listed in the indicator) affect population size;
- *exemplify* or *classify* each type of limiting factor (as listed in the indicator);
- *compare* density-dependent limiting factors to density-independent limiting factors and biotic limiting factors to abiotic limiting factors;
- *infer* the result of a change in a limiting factor on the size of a population.

Standard B-6: The student will demonstrate an understanding of the interrelationships among organisms and the biotic and abiotic components of their environments.

B-6.3 Illustrate the processes of succession in ecosystems.
Taxonomy Level: 2.2-B Understand Conceptual Knowledge

Key Concepts:
Ecological succession
Primary succession: pioneer species, climax community
Secondary succession

Previous knowledge: In 7th grade, students summarized the characteristics of the levels of organization within ecosystems (including populations, communities, habitats, niches, and biomes) (7-4.1), explained the interaction among changes in the environment due to natural hazards (including landslides, wildfires, and floods), changes in populations, and limiting factors (including climate and the availability of food and water, space, and shelter) (7-4.3), and explained the effects of soil quality on the characteristics of an ecosystem (7-4.4).

It is essential for students to understand that *ecological succession* is the series of changes in an ecosystem when one community is replaced by another community as a result of changes in abiotic and biotic factors. There are two types of succession, primary and secondary.

Primary succession occurs in an area that has not previously been inhabited: for example, bare rock surfaces from recent volcanic lava flows, rock faces that have been scraped clean by glaciers, or a city street.

- The beginning of primary succession depends on the presence of unique organisms that can grow without soil and also facilitate the process of soil formation.
    - Lichens (mutualistic relationships between fungi and algae) and some mosses, which break down rock into smaller pieces, are among the most important *pioneer species* (the first organisms) in the process of primary succession. At this stage of succession there are the fewest habitats for organisms in the ecosystem.
    - Once there is enough soil and nutrients, small plants, such as small flowers, ferns, and shrubs, grow. These plants break down the rock further, and provide more soil.
    - Then seeds of other plants and small trees are able to germinate and grow.
    - Over time more species grow and die. Their decomposed bodies add nutrients to the soil and larger plant species are able to populate the area.
- As the species of plants change, the species of animals that are able to inhabit the area also change. The organisms in each stage may alter the ecosystem in ways that hinder their own survival but make it more favorable for future organisms. In this way, one community replaces another over time.
- Eventually a mature community (*climax community*) results where there is little change in the composition of species and perpetuates itself as long as no disturbances occur.
    - The climax community of a particular area is determined by the limiting factors of the area. (see B-6.2)
- As scientists have studied changes in ecosystems, they have found that the processes of succession are always changing ecosystems.

Secondary succession begins in an area where there was a preexisting community and well-formed soil: for example, abandoned farmland, vacant lots, clear-cut forest areas, or open areas produced by forest fires.

- It is similar to primary succession in the later stages, after soil has already formed.
- Something halts the succession, such as a fire, a hurricane or human activities, and destroys the established community but the soil remains intact.
- When the disturbance is over, the ecosystem interacts to restore the original condition of the community.

It is also essential for students to understand that succession is a continual process.

- Some stages (and the organisms that compose the communities that characterize these stages) may last for a short period of time, while others may last for hundreds of years.
- Any disturbance to the ecosystem will affect the rate of succession in a particular area. Usually secondary succession occurs faster than primary succession because soil is already present.
  - When disturbances are frequent or intense, the area will be mostly characterized by the species that are present in the early stages of succession.
  - When disturbances are moderate, the area will be composed of habitats in different stages of succession.
- The process of succession occurs in all ecosystems (i.e., forest succession, pond succession, coral reef or marine succession and desert succession).

It is not essential for students to understand

- how the rate of disturbance in an area is related to species diversity;
- characteristics of specific biomes.

Assessment Guidelines:

The objective of this indicator is to *illustrate* the processes of succession in ecosystems; therefore, the primary focus of assessment should be to give or use illustrations that show how one biological community replaces another community.

In addition to *explain*, assessments may require students to

- *identify* communities that characterize the stages of succession;
- *explain* the environmental conditions that are necessary for pioneer species to survive;
- *infer* what type of organisms will be present in a given area in the future based on the a description of the area's current species;
- *exemplify* the conditions for primary and secondary succession;
- *summarize* the processes of primary and secondary succession.

Standard B-6: The student will demonstrate an understanding of the interrelationships among organisms and the biotic and abiotic components of their environments.

B-6.4 Exemplify the role of organisms in the geochemical cycles (including the cycles of carbon, nitrogen, and water).
Taxonomy Level: 2.2-B Understand Conceptual Knowledge

Key Concepts:
Geochemical cycles
Carbon cycle
Nitrogen cycle: elemental nitrogen, nitrogen fixation, denitrifying bacteria
Water cycle (hydrologic cycle)

Previous knowledge: In 6th grade (6-4.2), students summarized the interrelationships among the dynamic processes of the water cycle (including precipitation, evaporation, transpiration, condensation, surface-water flow, and groundwater flow). In 7th grade, students summarized how the location and movement of water on Earth's surface through groundwater zones and surface-water drainage basins, called watersheds, are important to ecosystems and to human activities (7-4.5).

It is essential for students to understand the role of organisms in the *geochemical cycles* (the movement of a particular form of matter through the living and nonliving parts of an ecosystem) since Earth is a closed system and must continually cycle its essential matter. Matter changes form but is neither created nor destroyed; it is used over and over again in a continuous cycle. Organisms are an important part of this cycling system. Matter placed into biological systems is always transferred and transformed. Matter, including carbon, nitrogen, and water, gets cycled in and out of ecosystems.

Carbon Cycle

- Carbon is one of the major components of the biochemical compounds of living organisms (proteins, carbohydrates, lipids, nucleic acids).
- Carbon is found in the atmosphere and also in many minerals and rocks, fossil fuels (natural gas, petroleum, and coal) and in the organic materials that compose soil and aquatic sediments.
- Organisms play a major role in recycling carbon from one form to another in the following processes:
  - Photosynthesis: Photosynthetic organisms take in carbon dioxide from the atmosphere and convert it to simple sugars. (see B-3.1)
  - Respiration: Organisms break down glucose and carbon is released into the atmosphere as carbon dioxide. (see B-3.2)
  - Decomposition: When organisms die, decomposers break down carbon compounds which both enrich the soil or aquatic sediments and are eventually released into the atmosphere as carbon dioxide.
  - Conversion of biochemical compounds: Organisms store carbon as carbohydrates, proteins, lipids, and nucleic acids in their bodies. For example, when animals eat plants and animals, some of the compounds are used for energy; others are converted to compounds that are suited for the predator's body (see B-3.6), other compounds, (such as methane and other gases) are released to the atmosphere.
- Other methods of releasing stored carbon may be:
  - Combustion: When wood or fossil fuels (which were formed from once living organisms) are burned, carbon dioxide is released into the atmosphere.

- ○ Weathering of carbonate rocks: Bones and shells fall to the bottom of oceans or lakes and are incorporated into sedimentary rocks such as calcium carbonate. When sedimentary rocks weather and decompose, carbon is released into the ocean and eventually into the atmosphere.

Nitrogen Cycle

- Nitrogen is the critical component of amino acids which are needed to build proteins in organisms.
- Nitrogen is found in the atmosphere as *elemental nitrogen* (N_2), in living organisms (in the form of proteins and nucleic acids), or in organic materials that compose soil and aquatic sediments.
- Organisms play a major role in recycling nitrogen from one form to another in the following processes:
  - ○ Nitrogen-fixation: Nitrogen-fixing bacteria, which are found in the soil, root nodules of plants, or aquatic ecosystems, are capable of converting elemental nitrogen found in the air or dissolved in water into the forms that are available for use by plants (*nitrogen fixation*).
  - ○ Intake of nitrogen into the organisms: Plants take in the nitrogen through their root systems in the form of ammonia or nitrate and in this way, nitrogen can enter the food chain. (see B-3.6)
  - ○ Decomposition: When an organism dies or from animal waste products, decomposers return nitrogen to the soil.
  - ○ Denitrification: *Denitrifying bacteria* break down the nitrogen compounds in the soil and release elemental nitrogen, N_2, into the atmosphere.

Water Cycle (Hydrologic cycle)

- Water is a necessary substance for the life processes of all living organisms.
- Water is found in the atmosphere, on the surface of Earth and underground, and in living organisms.
- The water cycle, also called the *hydrologic cycle*, is driven by the Sun's heat energy, which causes water to evaporate from water reservoirs (the ocean, lakes, ponds, rivers) on Earth and also from organisms.
- Organisms play a role in recycling water from one form to another in water cycle. For example,
  - ○ Intake of water into the organisms: Organisms take in water and use it to perform life functions (such as photosynthesis or transport of nutrients).
  - ○ Transpiration: Plants release water back into the atmosphere through the process of transpiration (the evaporative loss of water from plants).
  - ○ Respiration: All organisms metabolize food for energy and produce water as a by-product of respiration.
  - ○ Elimination: Most organisms need water to assist with the elimination of waste products.

It is not essential for students to

- recall or interpret the chemical reactions which occur in the cycles or recall the percentages of each resource occurring in each reservoir;
- understand the oxygen or phosphorus cycles.

Standard B-6: The student will demonstrate an understanding of the interrelationships among organisms and the biotic and abiotic components of their environments.

Assessment Guidelines

The objective of this indicator is to *exemplify* the role of organisms in geochemical cycles; therefore, the primary focus of assessment should be to give examples of the ways that organisms are involved in nutrient cycles, such as the nitrogen cycle, the carbon cycle, and the water cycle.

In addition to *exemplify*, assessments may require students to

- *summarize* the ways that organisms are a vital part of each cycle (carbon, nitrogen, and water) in various ecosystems;
- *interpret* a diagram, description, or illustration of an ecosystem in order to describe how various organisms play a major role in the cycling of nutrients;
- *explain* the role of various organisms on the carbon, nitrogen, and water cycles.

Standard B-6: The student will demonstrate an understanding of the interrelationships among organisms and the biotic and abiotic components of their environments.

B-6.5 Explain how ecosystems maintain themselves through naturally occurring processes (including maintaining the quality of the atmosphere, generating soils, controlling the hydrologic cycle, disposing of wastes, and recycling nutrients).
Taxonomy Level: 2.7 B Understand Conceptual Knowledge

Key Concepts:
Atmosphere: ozone layer, greenhouse effect, sink
Geosphere: soil erosion, deposition
Hydrologic cycle

Previous knowledge: In 6th grade (6-4.2), students summarized the interrelationships among the dynamic processes of the water cycle (including precipitation, evaporation, transpiration, condensation, surface-water flow, and groundwater flow). In 7th grade, students summarized how the location and movement of water on Earth's surface through groundwater zones and surface-water drainage basins, called watersheds, are important to ecosystems and to human activities (7-4.5).

It is essential for students to understand that there are naturally occurring Earth processes that help ecosystems maintain the materials necessary for the organisms in the ecosystem. The portion of Earth that is inhabited by life (the biosphere) is interconnected with other Earth systems: the atmosphere, the hydrosphere, and the geosphere. All of these systems must interact efficiently in order for an ecosystem to maintain itself.

Maintaining the Quality of the Atmosphere
The composition of Earth's *atmosphere* is mostly the result of the life processes of the organisms which inhabit Earth (past and present).

- Plants and other photosynthetic organisms need to produce enough oxygen for themselves and all other organisms on Earth to maintain a balance of atmospheric carbon dioxide and oxygen.
- The oxygen that is produced through the process of photosynthesis is also responsible for the *ozone layer* in the atmosphere and prevents much of the Sun's ultraviolet radiation from reaching Earth's surface and protects the biosphere from the harmful radiation.
- The normal cycling of oxygen and carbon dioxide occurs as plants produce more oxygen through photosynthesis than they consume through respiration, while animals use this oxygen in cellular respiration and release carbon dioxide used by the plants in photosynthesis.
- Nitrogen is maintained in the atmosphere through the nitrogen cycle. (see B-6.4)
- Water is maintained in the atmosphere through the water cycle. (see B-6.4)
    - o As water vapor condenses in the atmosphere, impurities (such as dust and particulates) are removed from the atmosphere and fall to Earth with precipitation. In this manner, the air is cleaned after a rain or snow fall.

The *greenhouse effect* is the normal warming effect when gases trap heat in the atmosphere.

- Greenhouse gases (such as carbon dioxide, oxygen, methane, and water vapor) trap heat energy and maintain Earth's temperature range.
- Greenhouse gases do not allow heat to pass through very well. Therefore, the heat that Earth releases stays trapped under the atmosphere.
- The amount of carbon dioxide in the atmosphere cycles in response to the degree to which plants and other photosynthetic organisms cover Earth and absorb carbon dioxide.

Amount of CO_2 in the atmosphere	Greenhouse effect	Average Global Temperature	Plant cover on Earth	Rate of photosynthesis	Amount of CO_2 absorbed by plants	Amount of CO_2 in the atmosphere
higher	increases	increases	increases	increases	increases	decreases
lower	decreases	decreases	decreases	decreases	decreases	increases

- The amount of carbon dioxide in the atmosphere also cycles in response to the degree to which oceans cover Earth. The salt water of oceans acts as a *sink* for carbon dioxide, absorbing what plants do not use and converting it to various salts such as calcium carbonate.

Generating Soils

As part of the *geosphere*, the soils on Earth are constantly being generated and eroded.

- All soils are composed of four distinct components – inorganic minerals, organic matter, water, and air.
- As the weathering of inorganic materials from wind, water, and ice and the decaying of organic materials continue, the process of soil generation continues.
- *Soil erosion* and *deposition* are natural processes that move soil from one location to another due to water, wind, ice and other agents.
- In most areas, the presence of plants allows the process of soil production to be consistent with the process of soil erosion so that the overall amount of soil remains constant.
- The presence of soil in an ecosystem allows for succession to take place. (see B-6.3)

Controlling the Hydrologic Cycle:

The *hydrologic cycle* is maintained by the energy of the Sun and the effect of weather. (see B-6.4)
The hydrologic cycle purifies water in several ways:

- Evaporated water is pure water containing no impurities.
- As water seeps down through the soil and rock it is physically filtered of impurities.
- As water flow slows, heavier particles of sediment settle out, leaving purified water to travel toward the oceans.

Disposing of Waste & Recycling Nutrients

- Waste materials from organisms are decomposed by bacteria or other organisms in the soil or in aquatic ecosystems. (see B-6.4)
- Nutrients are cycled through an ecosystem from organisms to the environment and back through series of specific processes known as geochemical cycles. (see B-6.4)

It is not essential for students to

- understand the processes involved in other geochemical cycles (other than the carbon, nitrogen, and water cycles) though it is important that students realize that there are cycles for every nutrient that is present in living organisms;
- recognize the chemical reactions that characterize the geochemical cycles;
- recognize the names and characteristics of various types of soils.

Standard B-6: The student will demonstrate an understanding of the interrelationships among organisms and the biotic and abiotic components of their environments.

Assessment Guidelines:

The objective of this indicator is to *explain* how ecosystems maintain themselves through naturally occurring processes, therefore, the primary focus of assessment should be to construct a cause-and-effect model showing how the natural processes including maintaining the quality of the atmosphere, generating soils, controlling the hydrologic cycle, disposing of wastes, and recycling nutrients of Earth maintain the environment.

In addition to *explain*, assessments may require students to

- *summarize* how various aspects of an ecosystem are naturally maintained (quality of the atmosphere, generation of soils, controlling of the water cycle, disposing of wastes, and the recycling of nutrients.);
- *interpret* diagrams, charts, tables, and graphs in order to describe how naturally occurring processes maintain balance in an ecosystem;
- *exemplify* various naturally occurring processes that ensure the quality of the atmosphere, the generation of soils, the control of the water cycle, the disposal of wastes, and the recycling of nutrients.

Standard B-6: The student will demonstrate an understanding of the interrelationships among organisms and the biotic and abiotic components of their environments.

B-6.6 Explain how human activities (including population growth, technology, and consumption of resources) affect the physical and chemical cycles and processes of Earth.

Taxonomy Level: 2.7-B Understand Conceptual Knowledge

Key Concepts:
Carrying capacity
Sustainability: population growth, technology, consumption of resources
Technology: agricultural, industrial, alternative energy
Resources: renewable, nonrenewable

Previous knowledge: In 5th grade (5-3.6), students explained how human activity (including conservation efforts and pollution) has affected the land and the oceans of Earth. In 7th grade (7-4.6), students classified resources as renewable or nonrenewable and explained the implications of their depletion and the importance of conservation.

It is essential for students to understand that humans play a role in ecosystems and geochemical cycles. People depend on the resources and geochemical cycles of Earth to provide clean water, breathable air, and soil that is capable of supporting crops. Human activities, including population growth, technology, and consumption of resources, can affect the cycles and processes of Earth.

- The *carrying capacity* of an environment is defined as the maximum population size that can be supported by the available resources.
- Various factors (such as energy, water, oxygen, nutrients) determine the carrying capacity of Earth for the human population.

In order to meet the needs of humans to survive indefinitely (*sustainability*), there needs to be a balance between Earth's resources and carrying capacity, the needs of humans, and the needs of other species on Earth. Factors that affect the sustainability of humans include:

Population Growth

- Population growth world-wide has grown exponentially. Based on current trends, scientists predict that the population will continue to grow at a rapid rate.
- The natural slowing of population growth as it nears Earth's carrying capacity is due to an increase in the death rate and a decrease in the birth rate as a result of:
  - Food and water shortages
  - Pollution of the environment
  - Spread of diseases
- An increasing population can have an effect on the amount of available clean water.
  - If clean water is being depleted at a greater rate than it can be purified, it is not considered renewable in our lifetime.
- An increasing population can have an effect on the amount of waste that is produced.
  - Although there are mechanisms in place to control the disposal of some waste products, more waste is produced than can be managed effectively.
  - Some waste products require complicated and costly means for removal once they are introduced into the environment.
- An increasing population can have an effect on the amount of available fertile soil for agriculture (food resources).
  - Soil is often lost when land is cleared, making the land unsuitable for agriculture.

- Worldwide demand for land (for agriculture or habitation) has led to deforestation.
    - As forests are cut down, there are fewer trees to absorb atmospheric carbon dioxide. The increase in atmospheric carbon dioxide contributes to global warming by preventing heat from radiating back into space. (see B-6.5)
    - Deforestation can increase the rate of erosion (both wind and water) and decrease the rate of soil generation. (see B-6.5)
- Human population growth has depleted the amount of fertile soil, clean water and available land in many areas of the world. When these resources become scarce, many natural processes (such as the water cycle, the carbon cycle, the nitrogen cycle, and the physical process of soil regeneration) are affected.

Technology

Different types of technology have applied scientific knowledge in order to either find solutions to problems or develop products to help meet the needs of humans. Although technology has benefited humankind, it has also contributed to the pollution of the air, water, and land. For sustainability, humans depend on technology to now provide cleaner energy sources, safer ways to deal with waste, and better methods for cleaning up pollution. Technological advances in agriculture, industry, and energy can have a positive or negative impact on Earth.

Agricultural technology

- Advances in agricultural methodology, tools, and biotechnology have improved the ability to grow crops to sustain a growing world population.
- Sustainable agricultural practices can help conserve fertile soil and reduce soil erosion.
- Farm machinery (such as tractors and combines) consumes nonrenewable resources and can contribute to erosion and air pollution.
- The addition of substances (such as fertilizers, pesticides, fungicides, livestock waste) to the environment can alter the composition of soil and can have a positive or negative effect on the water, carbon or nitrogen cycles.

Industrial technology

- Advances in industrial technology have changed the world and have lead to developments in communication, transportation, and industry.
- The development of certain chemicals, such as CFCs (chlorofluorohydrocarbons), contributes to the depletion of the ozone layer, which results in increased ultraviolet rays reaching Earth. CFCs are used in producing foam packing materials, for cleaning electrical components, and refrigeration chemicals (Freon).
- Technological advances have revolutionized the communication industry; however, the disposal of outdated or damaged equipment is becoming an increasing concern.
- The burning of fossil fuels for industry and transportation increases sustainability of the growing human population; however, it also:
    - increases the greenhouse gases released in the atmosphere (mainly carbon dioxide), which increases global temperatures (global warming) that affect sea levels, climate and atmospheric composition (see B-6.5)
    - produces acid rain (pollutants in the air combining with water to cause the normal water pH to be lowered)
        - Acid rain decreases the pH of the soil and can leach nutrients from soils or destroy plant life.

- ♦ Acid rain changes the pH of aquatic ecosystems and therefore affects the types of organisms that can survive there.

Alternative energy technology

- Using natural renewable energy sources (such as wind, water, geothermal, or solar energy) decreases the burning of fossil fuels, which increases the quality of the atmosphere and the cycles involved.
- Using nuclear energy technology provides an alternative energy source that does not impact the atmosphere. However, the waste produced from nuclear energy use is becoming an increasing concern.

Consumption of Resources

- As the population increases and technology expands, the demand for Earth resources also increases. However, there is a limited supply of these resources available to sustain the human population.
- Some resources (such as food, clean water, and timber) are considered *renewable resources,* those that can be produced at roughly the same rate that they are consumed.
  - Renewable resources have factors that limit their production, for example the amount of grain that can be produced is limited by the amount of land available for farming, fertility of the land, productivity of the grain, or availability of clean water.
- Other resources, such as fossil fuels, are *nonrenewable resources*, those that cannot be produced at the same rate that they are consumed. For example,
  - The demand for minerals, metals, and ores increases because these strategic materials are vital to industry but are decreasing in availability.
  - Minerals are regarded as nonrenewable because mineral deposits that can be extracted economically are formed so slowly by geological processes that their formation as a means of replacing what we are using is of no practical use to us.
- Sustainable use of resources can be accomplished by reducing consumption, reusing products rather than disposing of them, or recycling waste to protect the environment.

It is not essential for students to know the chemicals involved in acid rain or human impact and threats to biodiversity (biological magnification, eutrophication, extinction rates).

Assessment Guidelines:
The objective of this indicator is to *explain* how human activities affect the physical and chemical cycles and processes of Earth; therefore, the primary focus of assessment should be to construct cause-and-effect models of how human population growth, technology, and consumption of resources can influence the geochemical cycles and processes of Earth.

In addition to *explain*, assessments may require students to

- *interpret* diagrams, charts, tables, and graphs in order to describe how human activities affect the geochemical cycles and process of Earth;
- *summarize* how various human activities affect the geochemical cycles and processes of Earth;
- *illustrate* ways that the geochemical cycles and processes of Earth have been altered by human activities;
- *infer* the future effect of human activities on the geochemical cycles and processes of Earth based on current trends.