SUPPORT GUIDE 3.0
FOR BIOLOGY

SOUTH CAROLINA ACADEMIC STANDARDS AND PERFORMANCE INDICATORS FOR SCIENCE

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INTRODUCTION TO BIOLOGY STANDARDS

Science is a way of understanding the physical universe using observation and experimentation to explain natural phenomena. Science also refers to an organized body of knowledge that includes core ideas to the disciplines and common themes that bridge the disciplines. This document, *South Carolina Academic Standards and Performance Indicators for Science*, contains the academic standards in science for the state's students in kindergarten through grade twelve.

As science educators we must take a 3 dimensional approach in facilitating student learning. By addressing content standards, science and engineering practices and crosscutting concepts, students are able to have relevant and evidence based instruction that can help solve current and future problems. For more information please see: https://www.nap.edu/catalog/13165/a-framework-for-k-12-science-education-practices-crosscutting-concepts.

ACADEMIC STANDARDS

In accordance with the South Carolina Education Accountability Act of 1998 (S.C. Code Ann. § 59-18-110), the purpose of academic standards is to provide the basis for the development of local curricula and statewide assessment. Consensually developed academic standards describe for each grade and high school core area the specific areas of student learning that are considered the most important for proficiency in the discipline at the particular level.

Operating procedures for the review and revision of all South Carolina academic standards were jointly developed by staff at the State Department of Education (SCDE) and the Education Oversight Committee (EOC). According to these procedures, a field review of the first draft of the revised South Carolina science standards was conducted from March through May 2013. Feedback from that review and input from the SCDE and EOC review panels was considered and used to develop these standards.

The academic standards in this document are not sequenced for instruction and do not prescribe classroom activities; materials; or instructional strategies, approaches, or practices. The *South Carolina Academic Standards and Performance Indicators for Science* is not a curriculum.

THE PROFILE OF THE SOUTH CAROLINA GRADUATE

The *2014 South Carolina Academic Standards and Performance Indicators for Science* support the *Profile of the South Carolina Graduate. The Profile of the South Carolina Graduate* has been adopted and approved by the South Carolina Association of School Administrators (SCASA), the South Carolina Chamber of Commerce, the South Carolina Council on Competitiveness, the Education Oversight Committee (EOC), the State Board of Education (SBE), and the South Carolina Department of Education (SCDE) in an effort to identify the knowledge, skills, and characteristics a high school graduate should possess in order to be prepared for success as they enter college or pursue a career. The profile is intended to guide all that is done in support of college- and career-readiness.

Profile of the South Carolina Graduate

World Class Knowledge

- Rigorous standards in language arts and math for career and college readiness
- Multiple languages, science, technology, engineering, mathematics (STEM), arts and social sciences

World Class Skills

- Creativity and innovation
- Critical thinking and problem solving
- Collaboration and teamwork
- Communication, information, media and technology
- Knowing how to learn

Life and Career Characteristics

- Integrity
- Self-direction
- Global perspective
- Perseverance
- Work ethic
- Interpersonal skills

Approved by SCASA Superintendents Roundtable and SC Chamber of Commerce SC Education Oversight Committee, SC State Board of Education, SC Department of Education, SC General Assembly, SC Council on Competitiveness, TransformSC, & SC Arts in Basic Curriculum Steering Committee

SCIENCE AND ENGINEERING PRACTICES

In addition to the academic standards, each grade level or high school course explicitly identifies *Science and Engineering Practice* standards, with indicators that are differentiated across grade levels and core areas. The term "practice" is used instead of the term "skill," to emphasize that scientists and engineers use skill and knowledge simultaneously, not in isolation. These eight science and engineering practices are:

1. Ask questions and define problems
2. Develop and use models
3. Plan and conduct investigations
4. Analyze and interpret data
5. Use mathematical and computational thinking
6. Construct explanations and design solutions
7. Engage in scientific argument from evidence
8. Obtain, evaluate, and communicate information

Students should engage in scientific and engineering practices as a means to learn about the specific topics identified for their grade levels and courses. It is critical that educators understand that the Science and Engineering Practices are ***not*** to be taught in isolation. There should ***not*** be a distinct "Inquiry" unit at the beginning of each school year. Rather, the practices need to be employed ***within the content*** for each grade level or course.

Additionally, an important component of all scientists and engineers' work is communicating their results both by informal and formal speaking and listening, and formal reading and writing. Speaking, listening, reading and writing is important not only for the purpose of sharing results, but because during the processes of reading, speaking, listening and writing, scientists and engineers continue to construct their own knowledge and understanding of meaning and implications of their research. Knowing how one's results connect to previous results and what those connections reveal about the underlying principles is an important part of the scientific discovery process. Therefore, students should similarly be reading, writing, speaking and listening throughout the scientific processes in which they engage.

For additional information regarding the development, use and assessment of the *2014 Academic Standards and Performance Indicators for Science* please see the official document that is posted on the SCDE science web page https://ed.sc.gov/scdoe/assets/file/agency/ccr/Standards-Learning/documents/South_Carolina_Academic_Standards_and_Performance_Indicators_for_Science_2014.pdf.

Support for the guidance, overviews of learning progressions, and explicit details of each SEP can be found in the Science and Engineering Support Document https://ed.sc.gov/scdoe/assets/File/instruction/standards/Science/Support%20Documents/Complete_2014SEPsGuide_SupportDoc2_0.pdf.

Crosscutting Concepts

Seven common threads or themes are presented in *A Framework for K-12 Science Education* (2012). These concepts connect knowledge across the science disciplines (biology, chemistry, physics, earth and space science) and have value to both scientists and engineers because they identify universal properties and processes found in all disciplines. These crosscutting concepts are:

1. Patterns
2. Cause and Effect: Mechanism and Explanation
3. Scale, Proportion, and Quantity
4. Systems and System Models
5. Energy and Matter: Flows, Cycles, and Conservation
6. Structure and Function
7. Stability and Change

These concepts should not to be taught in isolation but reinforced in the context of instruction within the core science content for each grade level or course.

The link http://www.nap.edu/read/13165/chapter/8 provides support from the framework for K-12 Science Education: Practices, Crosscutting Concepts, and Core Ideas (2012) that gives further guidance on each crosscutting concept.

1. **Patterns:** The National Research Council (2012) states that "observed patterns of forms and events guide organization and classification, and they prompt questions about relationships and the factors that influence them" (p. 84).
2. **Cause and Effect: Mechanism and Explanation:** The National Research Council (2012) states that "events have causes, sometimes simple, sometimes multifaceted. A major activity of science is investigating and explaining causal relationships and the mechanisms by which they are mediated. Such mechanisms can then be tested across given contexts and used to predict and explain events in new contexts" (p. 84).
3. **Scale, Proportion, and Quantity:** The National Research Council (2012) states that "in considering phenomena, it is critical to recognize what is relevant at different measures of size, time, and energy and to recognize how changes in scale, proportion, or quantity affect a system's structure or performance" (p. 84).
4. **Systems and Systems Models:** The National Research Council (2012) states that "Defining the system under study—specifying its boundaries and making explicit a model of that system—provides tools for understanding and testing ideas that are applicable throughout science and engineering" (p. 84).
5. **Energy and Matter:** Flows, cycles, and conservation. Tracking fluxes of energy and matter into, out of, and within systems helps one understand the systems' possibilities and limitations.
6. **Structure and Function:** The National Research Council (2012) states that "the way in which an object or living thing is shaped and its substructure determine many of its properties and functions" (p. 84).
7. **Stability and Change:** The National Research Council (2012) states that "For natural and built systems alike, conditions of stability and determinants of rates of change or evolution of a system are critical elements of study" (p. 84).

DECIPHERING THE STANDARDS

Kindergarten
Life Science: Exploring Organisms and the Environment

Standard K.L.2: The student will demonstrate an understanding of the effects of forces on the motion and stability of an object.

K.L.2A. Conceptual Understanding: The environment consists of many types of organisms including plants, animals, and fungi. Organisms depend on the land, water, and air to live and grow. Plants need water and light to make their own food. Fungi and animals cannot make their own food and get energy from other sources. Animals (including humans) use different body parts to obtain food and other resources needed to grow and survive. Organisms live in areas where their needs for air, water, nutrients, and shelter are met.

Performance Indicators: Students who demonstrate this understanding can:

K.L.2A.1 Obtain information to answer questions about different organisms found in the environment (such as plants, animals, or fungi).

Figure 1: Example from the Kindergarten Standards

The code assigned to each performance indicator within the standards is designed to provide information about the content of the indicator. For example, the **K.L.2A.1** indicator decodes as the following:

K: The first part of each indicator denotes the grade or subject. The example indicator is from Kindergarten. The key for grade levels are as follows:

K: Kindergarten
1: First Grade
2: Second Grade
3: Third Grade
4: Fourth Grade
5: Fifth Grade
6: Sixth Grade
7: Seventh Grade
8: Eighth Grade
H.B: High school Biology I
H.B: High School Chemistry I
H.P: High school Physics I
H.E: High School Earth Science

L: After the grade or subject, the content area is denoted by an uppercase letter. The L in the example indicator means that the content covers Life Science. The key for content areas are as follows:
E: Earth Science
EC: Ecology
L: Life Science
P: Physical Science

S: Science and Engineering Practices

2: The number following the content area denotes the specific academic standard. In the example, the 2 in the indicator means that it is within the second academic standard with the Kindergarten science content.

A: After the specific content standard, the conceptual understanding is denoted by an uppercase letter. The conceptual understanding is a statement of the core idea for which students should demonstrate understanding. There may be more than one conceptual understanding per academic standard. The A in the example means that this is the first conceptual understanding for the standard. Additionally, the conceptual understandings are novel to the *2014 South Carolina Academic Standards and Performance Indicators for Science*.

1: The last part of the code denotes the number of the specific performance indicator. Performance indicators are statements of what students can do to demonstrate knowledge of the conceptual understanding. The example discussed is the first performance indicator within the conceptual understanding.

CORE AREAS OF HIGH SCHOOL BIOLOGY

- Cells as a System
- Energy Transfer
- Heredity - Inheritance and Variation of Traits
- Biological Evolution - Unity and Diversity
- Ecosystem Dynamics

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CONTENT SUPPORT GUIDE
FOR HIGH SCHOOL BIOLOGY
SOUTH CAROLINA ACADEMIC STANDARDS AND PERFORMANCE INDICATORS

INTRODUCTION

Local districts, schools and teachers may use this document to construct standards-based science curriculum, allowing them to add or expand topics they feel are important and to organize content to fit their students' needs and match available instructional materials. The support document includes standard, conceptual understanding, performance indicator, science and engineering practices, crosscutting concepts, essential learning experiences, extended learning experiences, assessment guidelines, learning connections, and in some cases note to teacher.

FORMAT OF THE CONTENT SUPPORT GUIDE

The format of this document is designed to be structurally uniformed for each of the academic standards and performance indicators. For each, you will find the following sections--

Standard
- This section provides the standard being explicated.

Conceptual Understanding
- This section provides the overall understanding that the student should possess as related to the standard. Additionally, the conceptual understandings are novel to the *2014 South Carolina Academic Standards and Performance Indicators for Science*.

Performance Indicator
- This section provides a specific set of content with an associated science and engineering practice for which the student must demonstrate mastery.

Science and Engineering Practices (SEPs)
- This section lists the specific science and engineering practice that are paired with the content in the performance indicator. Educators should reference the chapter on this specific science and engineering practice in the *Science and Engineering Practices Support Guide.*
- Educators have the freedom to enhance SEPs addressed during instruction.
- SEPs Support Guide https://ed.sc.gov/scdoe/assets/File/instruction/standards/Science/Support%20Documents/Complete_2014SEPsGuide_SupportDoc2_0.pdf

Crosscutting Concepts (CCCs)
- Cross Cutting Concepts (http://www.nap.edu/read/13165/chapter/8) This link provides support from the Framework for K-12 Science Education: Practices, Crosscutting Concepts, and Core Ideas (2012).
- Educators have the freedom to enhance CCCs addressed during instruction.

Essential Learning Experiences

- This section illustrates the knowledge of the content contained in the performance indicator for which it is fundamental for students to demonstrate mastery.

Note to Teacher

- If necessary or appropriate, this section provides additional instructional guidance.

Extended Learning Experiences

- This section provides educators with topics that will enrich students' knowledge related to topics learned with the explicated performance indicator.

Assessment Guidelines

- This section provides guidelines for educators and assessors to check for student mastery of content utilizing interrelated science and engineering practices.

Learning Connections

- This section provides a list of academic content along with the associated academic standard that students will have received in prior or will experience in future grade levels.

Cells as a System

Standard H.B.2: The student will demonstrate the understanding that the essential functions of life take place within cells or systems of cells.	
H.B.2A. Conceptual Understanding: The essential functions of a cell involve chemical reactions that take place between many different types of molecules (including carbohydrates, lipids, proteins and nucleic acids) and are catalyzed by enzymes.	
Performance Indicator	**H.B.2A.1:** Construct explanations of how the structures of carbohydrates, lipids, proteins, and nucleic acids (including DNA and RNA) are related to their functions in organisms.
Science and Engineering Practice	**H.B.1A.6:** Construct explanations of phenomena using (1) primary or secondary scientific evidence and models, (2) conclusions from scientific investigations, (3) predictions based on observations and measurements, or (4) data communicated in graphs, tables, or diagrams.
Crosscutting Concepts	The following Crosscutting Concepts may be applied to the content of the indicator. For more information see page 6. Cause and Effect

Essential Learning Experiences:
It is essential that students construct explanations of how organic compounds are composed of carbon atoms and how their structures are related to their functions.

All organisms are composed of organic molecules.
- Organic molecules 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.

Carbohydrates (sugars and starches) are molecules composed of carbon, hydrogen, and oxygen.
- The basic carbohydrates are simple sugars such as glucose.
- Simple sugars can bond together to make larger, more complex carbohydrate molecules, for example starch, glycogen, or cellulose.
- Carbohydrates are important as an energy source for all organisms.
  - 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. Carbohydrates are used to store energy for short periods of time.
  - When complex carbohydrates are consumed, the process of digestion in animals 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 that is stored in the form of ATP.
    - Carbohydrates provide raw materials and serve as structural molecules in many organisms. 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 in animals.

Lipids are organic molecules with a basic structure composed of carbon, hydrogen, and oxygen that often bond to form fatty acids and glycerols. Lipids have more carbon-hydrogen bonds than carbohydrates, thus contain more energy per gram than carbohydrates or proteins, which explains why fats have a greater caloric value.

- Fats serve a variety of functions such as providing long-term energy storage, cushioning of vital organs, and insulation for the body. Fats are insoluble in water.
- Phospholipids are a major component of cell membranes. They consist of a phosphate group/head and fatty acid tail. The phosphate head is hydrophilic (attracted to water) and the fatty acid tail is hydrophobic (repelled by water).
- Waxes are lipids that form waterproof coatings for plants and animals.
- Steroids can serve as the raw materials necessary for the production of some vitamins, some hormones, and cholesterol. Steroids are types of lipids with a foundational structure consisting of four carbon rings.

Proteins are molecules composed of chains of amino acids. Amino acids are molecules that are composed of carbon, hydrogen, oxygen, nitrogen, and sometimes sulfur.

- Because of the variety of shapes and structures of protein molecules, proteins have a wide variety of functions. Proteins are involved in almost every function in the human body. For example:
    - Contractile proteins help control movement such as proteins in the muscles which help control contraction.
    - Hormone proteins coordinate body activities such as insulin which regulates the amount of sugar in the blood.
    - Enzymatic proteins accelerate the speed of chemical reactions such as digestive enzymes which break down food in the digestive tract. Enzymes are unchanged by the chemical reaction and can be reused.
    - Structural proteins are used for support such as connective tissue and keratin that forms hair and fingernails.
    - Transport proteins move many substances throughout the body. An example is hemoglobin that transports oxygen from the lungs to the other parts of the body to be used by cells in cellular respiration.

Nucleic acids are organic molecules that carry and transmit genetic information.

- 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

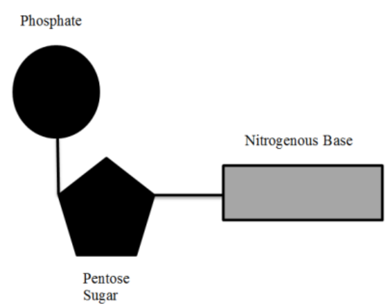


Figure 2. Phosphate group (SCDE, 2018).

The structure of DNA and RNA differs:

- DNA consists of two chains of nucleotides that spiral around an imaginary axis to form a double helix. Nitrogenous bases from each strand of DNA are joined by hydrogen bonds through the axis of the helix.
- Each nitrogenous base is hydrogen bonded to its complementary base:
  - Guanine (G) can only bond with Cytosine (C),
  - Thymine (T) can 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 hydrogen 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) can only bond with Cytosine (C).
    - Uracil (U) can only bond with Adenine (A).

	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

NOTE TO TEACHER: DNA and RNA will be explored in further detail in H.B.4.

Extended Learning Experiences:
The following knowledge and learning experiences are not essential to the success of this learning goal but can be used by teachers to extend the depth and rigor of student engagements. Students could develop and use models to explore

- saturated versus unsaturated fats versus trans fats, and
- hydrolysis and dehydration synthesis reactions (condensation reactions).

Assessment Guidelines:
Students should engage in multiple science and engineering practices when interacting with the content outlined in this performance indicator. For further information please see SEP Support Guide at:
https://ed.sc.gov/scdoe/assets/File/instruction/standards/Science/Support%20Documents/Complete_2014SEPsGuide_SupportDoc2_0.pdf

Learning Connections	**Previous Learning Connections (6-8):** **7.P.2A.4** Construct explanations for how compounds are classified as ionic (metal bonded to nonmetal) or covalent (nonmetals bonded together) using chemical formulas. **Chemistry Learning Connections:** **H.C.3A.6** Construct explanations of how the basic structure of common natural and synthetic polymers is related to their bulk properties.

Cells as a System

Standard H.B.2: The student will demonstrate the understanding that the essential functions of life take place within cells or systems of cells.	
H.B.2A. Conceptual Understanding: The essential functions of a cell involve chemical reactions that take place between many different types of molecules (including carbohydrates, lipids, proteins and nucleic acids) and are catalyzed by enzymes.	
Performance Indicator	**H.B.2A.2:** Plan and conduct investigations to determine how various environmental factors (including temperature and pH) affect enzyme activity and the rate of biochemical reactions.
Science and Engineering Practice	**H.B.1A.3:**Plan and conduct controlled scientific investigations to answer questions, test hypotheses, and develop explanations: (1) formulate scientific questions and testable hypotheses based on credible scientific information, (2) identify materials, procedures, and variables, (3) use appropriate laboratory equipment, technology, and techniques to collect qualitative and quantitative data, and (4) record and represent data in an appropriate form. Use appropriate safety procedures.
Crosscutting Concepts	The following Crosscutting Concepts may be applied to the content of the indicator. For more information see page 6. Cause and Effect Energy and Matter

Essential Learning Experiences:
It is essential that students plan and conduct investigations to determine how temperature and pH affect enzyme activity and the importance of pH control in living systems.

Biochemical reactions allow organisms to grow, develop, reproduce, and adapt. A chemical reaction breaks down some substances and forms other substances.

- 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.

There are several factors that affect the rates of biochemical reactions.

- 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 so that pH homeostasis can be maintained. A small change in pH can disrupt cell processes.
- Enzymes are proteins that 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 examples include but are not limited to digestion, respiration, reproduction, movement and cell regulation.
    - The structure of enzymes can be altered by temperature and pH
    - 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.
    - Each catalyst works best at a specific temperature and pH.
    - Catalysts work by lowering the activation energy of a chemical reaction. A catalyst is not consumed nor altered during a chemical reaction, so, it can be used over and over again.

Extended Learning Experiences:
Students could obtain, communicate and evaluate information regarding--

- 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;
- the term denaturation which is the alteration of proteins.

Assessment Guidelines:
Students should engage in multiple science and engineering practices when interacting with the content outlined in this performance indicator. For further information please see SEP Support Guide at:
https://ed.sc.gov/scdoe/assets/File/instruction/standards/Science/Support%20Documents/Complete_2014SEPsGuide_SupportDoc2_0.pdf

Learning Connections	**Previous Learning Connections (6-8):** **6.E.2A.1** Develop and use models to exemplify the properties of the atmosphere (including the gases, temperature and pressure differences, and altitude changes) and the relative scale in relation to the size of Earth. **6.E.2A.2** Critically analyze scientific arguments based on evidence for and against how different phenomena (natural and human induced) may contribute to the composition of Earth's atmosphere. **Earth Science Learning Connections:** **H.E.5A.1** Develop and use models to describe the thermal structures (including

	the changes in air temperature due to changing altitude in the lower troposphere), the gaseous composition, and the location of the layers of Earth's atmosphere. **H.E.5A.7** Construct scientific arguments to support claims of past changes in climate caused by various factors (such as changes in the atmosphere, variations in solar output, Earth's orbit, changes in the orientation of Earth's axis of rotation, or changes in the biosphere). **H.E.5A.8** Analyze scientific arguments regarding the nature of the relationship between human activities and climate change.

Cells as a System

Standard H.B.2: The student will demonstrate the understanding that the essential functions of life take place within cells or systems of cells.	
H.B.2B. Conceptual Understanding: Organisms and their parts are made of cells. Cells are the structural units of life and have specialized substructures that carry out the essential functions of life. Viruses lack cellular organization and therefore cannot independently carry out all of the essential functions of life.	
Performance Indicator	**H.B.2B.1:** Develop and use models to explain how specialized structures within cells (including the nucleus, chromosomes, cytoskeleton, endoplasmic reticulum, ribosomes and Golgi complex) interact to produce, modify, and transport proteins. Models should compare and contrast how prokaryotic cells meet the same life needs as eukaryotic cells without similar structures.
Science and Engineering Practice	**H.B.1A.2:** Develop, use, and refine models to (1) understand or represent phenomena, processes, and relationships, (2) test devices or solutions, or (3) communicate ideas to others.
Crosscutting Concepts	The following Crosscutting Concepts may be applied to the content of the indicator. For more information see page 6. Systems and System Models Structure and Function

Essential Learning Experiences:
It is essential that students develop and use models to explain the structure and function of organelles and how they interact to produce, modify, and transport proteins. Use models to differentiate between prokaryotic and eukaryotic cells.

Eukaryotic cells have specialized substructures, called organelles, carry out the essential functions of life.

- The nucleus contains the chromosomes which are composed of DNA (deoxyribonucleic acid, a chemical compound that stores and transmits genetic information); and functions in the genetic control of the cell.
  - A chromosome is a structure in the nucleus of a cell consisting essentially of one long thread of DNA that is tightly coiled.
- The cytoskeleton is a network of fibrous proteins that helps the cell with maintaining shape, support, and movement.
- 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.

    - Smooth ER has no ribosomes attached.
- Ribosomes are the sites of protein synthesis; some are located on the ER, others are found in the cytoplasm.
- The Golgi complex collects, packages, and otherwise modifies cell products (for example proteins and lipids) for distribution and use within or outside the cell.
- The vesicles carry proteins from the rough ER to the Golgi apparatus.

Cellular processes are carried out by molecules. Proteins carry out most of the work of cells to perform the essential functions of life. One of the major functions of the cell is the production of proteins. The genetic information in DNA provides instructions for assembling protein molecules. In eukaryotic cells the nucleus, ribosomes, endoplasmic reticulum, vesicles, and the Golgi apparatus interact to produce, modify and transport proteins.

NOTE TO TEACHER: See H.B.2B.2 to compare and contrast prokaryotes and eukaryotes.

Extended Learning Experiences:
Students may develop and use models to:
- understand any additional functions of various organelles stated in the indicator;
- 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); and
- understand the structure or function of any additional organelles.

Assessment Guidelines:
Students should engage in multiple science and engineering practices when interacting with the content outlined in this performance indicator. For further information please see SEP Support Guide at:
https://ed.sc.gov/scdoe/assets/File/instruction/standards/Science/Support%20Documents/Complete_2014SEPsGuide_SupportDoc2_0.pdf

Learning Connections	**Previous Learning Connections (6-8):** **6.L.4A.1** Obtain and communicate information to support claims that living organisms (1) obtain and use resources for energy, (2) respond to stimuli, (3) reproduce, and (4) grow and develop **7.L.3A.1** Obtain and communicate information to support claims that (1) organisms are made of one or more cells, (2) cells are the basic unit of structure and function of organisms, and (3) cells come only from existing cells. **7.L.3A.2** Analyze and interpret data from observations to describe different types of cells and classify cells as plant, animal, protist, or bacteria. **7.L.3A.3** Develop and use models to explain how the relevant structures within cells (including cytoplasm, cell membrane, cell wall, nucleus, mitochondria, chloroplasts, lysosomes, and vacuoles) function to support the life of plant, animal, and bacterial cells.

	Biology Learning Connections: **H.B.2A.1** Construct explanations of how the structures of carbohydrates, lipids, proteins, and nucleic acids (including DNA and RNA) are related to their functions in organisms.

Cells as a System

Standard H.B.2: The student will demonstrate the understanding that the essential functions of life take place within cells or systems of cells.	
H.B.2B. Conceptual Understanding: Organisms and their parts are made of cells. Cells are the structural units of life and have specialized substructures that carry out the essential functions of life. Viruses lack cellular organization and therefore cannot independently carry out all of the essential functions of life.	
Performance Indicator	**H.B.2B.2:** Collect and interpret descriptive data on cell structure to compare and contrast different types of cells (including prokaryotic versus eukaryotic, and animal versus plant versus fungal).
Science and Engineering Practice	**H.B.1A.4:** Analyze and interpret data from informational texts and data collected from investigations using a range of methods (such as tabulation, graphing, or statistical analysis) to (1) reveal patterns and construct meaning, (2) support or refute hypotheses, explanations, claims, or designs, or (3) evaluate the strength of conclusions.
Crosscutting Concepts	The following Crosscutting Concepts may be applied to the content of the indicator. For more information see page 6. Systems and System Models Structure and Function

Essential Learning Experiences:
It is essential that students collect and interpret descriptive data on cell structure to compare and contrast different types of cells.

Prokaryotic and eukaryotic cells share several similarities which include the presence of ribosomes, cytoplasm, genetic material, and a cell membrane.

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 most prokaryotic cells have a singular circular chromosome.
- Eukaryotic cells contain DNA which is organized into linear chromosomes, and the chromosomes are separated from the cytoplasm by a nuclear membrane.

Prokaryotic cells differ from eukaryotic cells in other ways:
- Prokaryotic cells lack most of the other organelles that 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 are generally much smaller than eukaryotic cells.
- Prokaryotes such as bacteria are unicellular organisms.

Plant cells contain almost all the types of organelles that animal cells contain, but plants have three unique structures that are not found in animal cells:
- The cell wall, the central vacuole, and plastids such as chloroplasts.
- Students should understand how these structures are related to the differences between animal and plant functions.

Fungal cells have a cell wall that is made of chitin and other polymers instead of cellulose; they may have several nuclei within a single cell. Fungal cells cannot make their own food through photosynthesis because they lack chloroplasts.

NOTE TO TEACHER: please share different images of fungal cells with students to highlight structural differences within this kingdom (particularly number of nuclei). Show a biological and technological scale comparing eukaryote, prokaryote, and viruses.

Extended Learning Experiences:
Teachers may choose to have students analyze and interpret data regarding:
- differences between eukaryotic and prokaryotic cells beyond what is presented above,
- the evolutionary history of eukaryotic cells (endosymbiosis), and
- differences among prokaryotes (for example some bacteria have two circular chromosomes and others have linear chromosomes).

Assessment Guidelines:
Students should engage in multiple science and engineering practices when interacting with the content outlined in this performance indicator. For further information please see SEP Support Guide at:
https://ed.sc.gov/scdoe/assets/File/instruction/standards/Science/Support%20Documents/Complete_2014SEPsGuide_SupportDoc2_0.pdf

Learning Connections	**Previous Learning Connections (6-8):** **6.L.4A.2** Develop and use models to classify organisms based on the current hierarchical taxonomic structure (including the kingdoms of protists, plants, fungi, and animals). **6.L.5B.2** Analyze and interpret data to explain how the processes of photosynthesis, respiration, and transpiration work together to meet the needs of plants. **7.L.3A.3** Develop and use models to explain how the relevant structures within cells (including cytoplasm, cell membrane, cell wall, nucleus, mitochondria, chloroplasts, lysosomes, and vacuoles) function to support the life of plant, animal, and bacterial cells.

Cells as a System

Standard H.B.2: The student will demonstrate the understanding that the essential functions of life take place within cells or systems of cells.	
H.B.2B. Conceptual Understanding: Organisms and their parts are made of cells. Cells are the structural units of life and have specialized substructures that carry out the essential functions of life. Viruses lack cellular organization and therefore cannot independently carry out all of the essential functions of life.	
Performance Indicator	**H.B.2B.3:** Obtain information to contrast the structure of viruses with that of cells and to explain, in general, why viruses must use living cells to reproduce.
Science and Engineering Practice	**H.B.1A.8:** Obtain and evaluate scientific information to (1) answer questions, (2) explain or describe phenomena, (3) develop models, (4) evaluate hypotheses, explanations, claims, or designs or (5) identify and/or fill gaps in knowledge. Communicate using the conventions and expectations of scientific writing or oral presentations by (1) evaluating grade-appropriate primary or secondary scientific literature, or (2) reporting the results of student experimental investigations.
Crosscutting Concepts	The following Crosscutting Concepts may be applied to the content of the indicator. For more information see page 6. Systems and System Models Structure and Function

Essential Learning Experiences:
It is essential that students obtain information that a virus is a non-living particle made up of a nucleic acid and either a protein or lipid-protein coat. They cause many diseases in living organisms and are useful tools for genetic research.

- Viruses are extraordinarily small; smaller than prokaryotic cells.
- Viruses do not have cytoplasm or organelles and thus cannot carry out cell functions such as metabolism. They cannot grow by dividing.
- To reproduce, viruses must enter a living cell and use that cell's (the host cell's) ribosomes, enzymes, ATP, and other molecules to reproduce.

NOTE TO TEACHER: Viruses were not previously addressed in the 2005 standard. Show a biological and technological scale comparing eukaryote, prokaryote, and viruses.

Extended Learning Experiences:
Students may obtain, communicate and evaluate information regarding:

- viral infection cycles;
- bacteriophages, retroviruses, and prions; and
- diseases caused by viruses.

Assessment Guidelines:
Students should engage in multiple science and engineering practices when interacting with the content outlined in this performance indicator. For further information please see SEP Support Guide at:
https://ed.sc.gov/scdoe/assets/File/instruction/standards/Science/Support%20Documents/Complete_2014SEPsGuide_SupportDoc2_0.pdf

Learning Connections	**Previous Learning Connections (6-8):** **6.L.4A.1** Obtain and communicate information to support claims that living organisms (1) obtain and use resources for energy, (2) respond to stimuli, (3) reproduce, and (4) grow and develop.

Cells as a System

Standard H.B.2: The student will demonstrate the understanding that the essential functions of life take place within cells or systems of cells.	
H.B.2C. Conceptual Understanding: Transport processes which move materials into and out of the cell serve to maintain homeostasis of the cell.	
Performance Indicator	**H.B.2C.1:** Develop and use models to exemplify how the cell membrane serves to maintain homeostasis of the cell through both active and passive transport processes.
Science and Engineering Practice	**H.B.1A.2:** Develop, use, and refine models to (1) understand or represent phenomena, processes, and relationships, (2) test devices or solutions, or (3) communicate ideas to others.
Crosscutting Concepts	The following Crosscutting Concepts may be applied to the content of the indicator. For more information see page 6. Systems and System Models Energy and Matter Stability and Change

Essential Learning Experiences:
It is essential that students develop and use models to exemplify how substances move through cells using both active and passive transport while maintaining homeostasis.

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

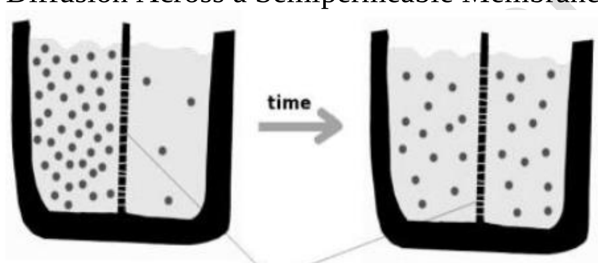
- The cell membrane regulates the passage of material into and out of the cell.
- Materials needed for cellular processes must pass into cells so they can be utilized. For example, oxygen and glucose are continuously needed for the process of cellular respiration.
- Waste materials from cellular processes 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.
- 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 molecules (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 molecules can pass directly through the cell membrane while other molecules cannot.
- Materials can enter or exit through the cell membrane by passive transport or active transport.

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

1. 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); molecules such as oxygen, carbon dioxide and water 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

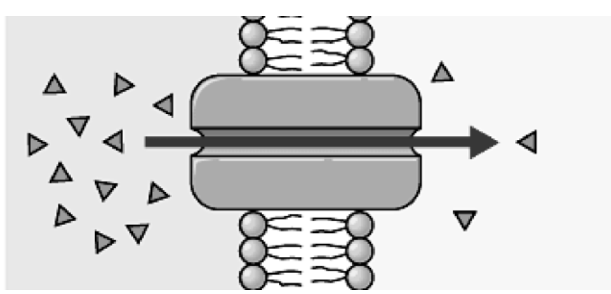


Semipermeable Membrane

Figure 2. Diffusion (SCDE, 2005).

2. Facilitated diffusion is the process by which some molecules 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 molecules have chemical structures that prevent them from passing directly through a cell membrane. The cell membrane is not permeable to these molecules.
- Transport proteins provide access across the cell membrane.
- Glucose is an example of a molecule that passes through the cellular membrane using facilitated diffusion.
- Transport proteins provide access across the cell membrane.



Facilitated Diffusion

Figure 3. (Facilitated Diffusion (SCDE, 2005).

3. 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. The diffusion of water molecules is a passive transport process because it does not require the cell to expend energy.

Active transport is another one way that molecules can move through a cell membrane.

- 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.
- Unlike the process of facilitated diffusion, in active transport, molecules are “pumped” across the cell membrane by transport proteins (carrier 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.

NOTE TO TEACHER: Indicators H.B.2C1-C3 may be utilized collectively to address the larger concept.

Extended Learning Experiences:
Students may analyze and interpret data regarding the:

- structure of the cell membrane,
- role of aquaporins in osmosis,
- specific mechanisms of active transport function (i.e., sodium-potassium pump, proton pump), and
- fluid mosaic model.

Assessment Guidelines
Students should engage in multiple science and engineering practices when interacting with the content outlined in this performance indicator. For further information please see SEP Support Guide at:
https://ed.sc.gov/scdoe/assets/File/instruction/standards/Science/Support%20Documents/Complete_2014SEPsGuide_SupportDoc2_0.pdf

Learning Connections	**Previous Learning Connections (6-8):** **6.L.5B.1:** Construct explanations of how the internal structures of vascular and nonvascular plants transport food and water. **7.L.3A.3:** Develop and use models to explain how the relevant structures within cells (including cytoplasm, cell membrane, cell wall, nucleus, mitochondria, chloroplasts, lysosomes, and vacuoles) function to support the life of plant, animal, and bacterial cells. **Chemistry Learning Connections:** **H.C.5A.1:** Obtain and communicate information to describe how a substance can dissolve in water by dissociation, dispersion, or ionization and how intermolecular forces affect solvation.

Cells as a System

Standard H.B.2: The student will demonstrate the understanding that the essential functions of life take place within cells or systems of cells.	
H.B.2C. Conceptual Understanding: Transport processes which move materials into and out of the cell serve to maintain homeostasis of the cell.	
Performance Indicator	**H.B.2C.2:** Ask scientific questions to define the problems that organisms face in maintaining homeostasis within different environments (including water of varying solute concentrations).
Science and Engineering Practice	**H.B.1A.1:** Ask questions to (1) generate hypotheses for scientific investigations, (2) refine models, explanations, or designs, or (3) extend the results of investigations or challenge scientific arguments or claims.
Crosscutting Concepts	The following Crosscutting Concepts may be applied to the content of the indicator. For more information see page 6. Systems and System Models Energy and Matter Stability and Change

Essential Learning Experiences:
It is essential that students ask scientific questions to define how cells maintain homeostasis within different environments.

Diffusion 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 until they reach equilibrium); substances that are able to pass directly across the cell membrane can diffuse either into a cell or out of a cell.

Osmosis is the facilitated 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.
- 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.

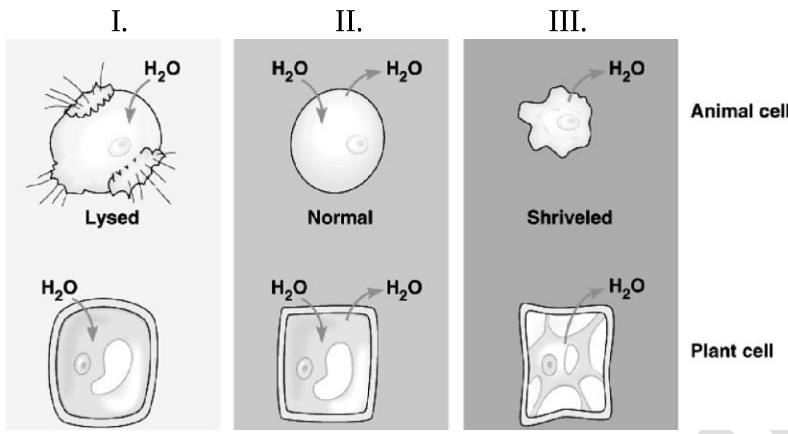


Figure 4. Water (SCDE 2005).

I. Water concentration is greater outside the cell (hypotonic solution) than inside so water moves into the cell.
II. Water concentration is the same inside and outside the cell (isotonic solution)so there is no net movement of water.
III. Water concentration is greater inside the cell than outside so water moves out of the cell (hypertonic solution).

- If the concentration of solute molecules outside of the cell is
  - lower than the concentration inside the cell, the solution is hypotonic.
  - equal to the concentration inside the cell, the solution is isotonic.
  - higher than the concentration inside the cell, the solution is hypertonic.

NOTE TO TEACHER: Indicators H.B.2C1-C3 may be utilized as a collective to address the larger concept.

Extended Learning Experiences:
Students may develop and use models to explain:
- explain the structure of the cell membrane;
- explain the specific mechanisms of active transport function (i.e., sodium-potassium pump, proton pump), and calculate osmotic pressure.

Assessment Guidelines:
Students should engage in multiple science and engineering practices when interacting with the content outlined in this performance indicator. For further information please see SEP Support Guide at:
https://ed.sc.gov/scdoe/assets/File/instruction/standards/Science/Support%20Documents/Complete_2014SEPsGuide_SupportDoc2_0.pdf

Learning Connections	**Previous Learning Connections (6-8):** **6.L.5B.1** Construct explanations of how the internal structures of vascular and nonvascular plants transport food and water. **7.L.3A.3** Develop and use models to explain how the relevant structures within cells (including cytoplasm, cell membrane, cell wall, nucleus, mitochondria, chloroplasts, lysosomes, and vacuoles) function to support the life of plant, animal, and bacterial cells. **Chemistry Learning Connections:** **H.C.5A.1** Obtain and communicate information to describe how a substance can dissolve in water by dissociation, dispersion, or ionization and how intermolecular forces affect solvation.

Cells as a System

Standard H.B.2: The student will demonstrate the understanding that the essential functions of life take place within cells or systems of cells.	
H.B.2C. Conceptual Understanding: Transport processes which move materials into and out of the cell serve to maintain homeostasis of the cell.	
Performance Indicator	**H.B.2C.3:** Analyze and interpret data to explain the movement of molecules (including water) across a membrane.
Science and Engineering Practice	**H.B.1A.4:** Analyze and interpret data from informational texts and data collected from investigations using a range of methods (such as tabulation, graphing, or statistical analysis) to (1) reveal patterns and construct meaning, (2) support or refute hypotheses, explanations, claims, or designs, or (3) evaluate the strength of conclusions.
Crosscutting Concepts	The following Crosscutting Concepts may be applied to the content of the indicator. For more information see page 6. Systems and Systems model Energy and Matter Stability and Change

Essential Learning Experiences:
It is essential for students to analyze and interpret data from an investigation that demonstrates the movement of molecules across a membrane. Students should be able to identify patterns and construct meaning.

NOTE TO TEACHERS: Indicators H.B.2C1-C3 may be utilized as a collective to address the larger concept. See the Essential Knowledge sections for H.B.2C.1-2.

Extended Learning Experiences:
Students may use mathematical and computational thinking to calculate osmotic pressure.

Assessment Guidelines:
Students should engage in multiple science and engineering practices when interacting with the content outlined in this performance indicator. For further information please see SEP Support Guide at:
https://ed.sc.gov/scdoe/assets/File/instruction/standards/Science/Support%20Documents/Complete_2014SEPsGuide_SupportDoc2_0.pdf

Learning Connections	**Previous Learning Connections (6-8):** **6.L.5B.1:** Construct explanations of how the internal structures of vascular and nonvascular plants transport food and water. **7.L.3A.3:** Develop and use models to explain how the relevant structures within cells (including cytoplasm, cell membrane, cell wall, nucleus, mitochondria, chloroplasts, lysosomes, and vacuoles) function to support the life of plant, animal, and bacterial cells. **Chemistry Learning Connections:** **H.C.5A.1:** Obtain and communicate information to describe how a substance can dissolve in water by dissociation, dispersion, or ionization and how intermolecular forces affect solvation.

Cells as a System

Standard H.B.2: The student will demonstrate the understanding that the essential functions of life take place within cells or systems of cells.	
H.B.2D. Conceptual Understanding: The cells of multicellular organisms repeatedly divide to make more cells for growth and repair. During embryonic development, a single cell gives rise to a complex, multicellular organism through the processes of both cell division and differentiation.	
Performance Indicator	**H.B.2D.1** Construct models to explain how the processes of cell division and cell differentiation produce and maintain complex multicellular organisms.
Science and Engineering Practice	**H.B.1A.2** Develop, use, and refine models to (1) understand or represent phenomena, processes, and relationships, (2) test devices or solutions, or (3) communicate ideas to others.
Crosscutting Concepts	The following Crosscutting Concepts may be applied to the content of the indicator. For more information see page 6. Cause and Effect Systems and System Models

Essential Learning Experiences:
It is essential that students construct models to explain how cells divide for growth and repair and how cells become specialized to perform specific function.

- 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 mitotic cell division, but the process of cell division alone could only lead to increasing numbers of identical cells.
- As cell division (cell division is covered in H.B.2D.2) proceeds, the cells not only increase in number but also undergo differentiation, a process through which a cell becomes specialized in order to perform a specific function. Once a cell differentiates, the process is rarely reversed.
- The various types of cells (such as blood, muscle, or epithelial cells) arranged 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.

NOTE TO TEACHER: Stem cells are discussed in H.B.2D.4

Extended Learning Experiences:
Students could construct explanations regarding:
- how the process of transcriptional regulation in a cell produces specific proteins that result in cell differentiation, and
- how a cell's position in an embryo affects determination

Assessment Guidelines:
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https://ed.sc.gov/scdoe/assets/File/instruction/standards/Science/Support%20Documents/Complete_2014SEPsGuide_SupportDoc2_0.pdf

Learning Connections	**Previous Learning Connections (6-8):** **6.L.4A.2:** Develop and use models to classify organisms based on the current hierarchical taxonomic structure (including the kingdoms of protists, plants, fungi, and animals). **7.L.3B.1:** Develop and use models to explain how the structural organizations within multicellular organisms function to serve the needs of the organism.

Cells as a System

Standard H.B.2: The student will demonstrate the understanding that the essential functions of life take place within cells or systems of cells.	
H.B.2D Conceptual Understanding: The cells of multicellular organisms repeatedly divide to make more cells for growth and repair. During embryonic development, a single cell gives rise to a complex, multicellular organism through the processes of both cell division and differentiation.	
Performance Indicator	**H.B.2D.2:** Develop and use models to exemplify the changes that occur in a cell during the cell cycle (including changes in cell size, chromosomes, cell membrane/cell wall, and the number of cells produced) and predict, based on the models, what might happen to a cell that does not progress through the cycle correctly.
Science and Engineering Practice	**H.B.1A.2:** Develop, use, and refine models to (1) understand or represent phenomena, processes, and relationships, (2) test devices or solutions, or (3) communicate ideas to others.
Crosscutting Concepts	The following Crosscutting Concepts may be applied to the content of the indicator. For more information see page 6. Cause and Effect Systems and System Models

Essential Learning Experiences:
It is essential that students develop and use models to exemplify changes and to predict what might happen if the cell does not progress through the cycle correctly.

- The cell cycle is a repeated pattern of growth and division that occurs in eukaryotic cells. This cycle consists of two phases. The first phase represents cell growth while the last phase represents nucleic division (mitosis) and cytoplasmic division (cytokinesis).

Interphase

- Cells spend the majority of the cell cycle in interphase. The purpose of interphase is for cell growth and preparation for mitosis and cytokinesis. 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.

  - During the G2 (gap 2) phase, cells continue to grow and produce the proteins necessary for cell division.

Mitotic Phase (which includes Mitosis and Cytokinesis)

Mitosis

- The purpose of mitosis is the division of the nucleus; making two identical nuclei, each with the same number of chromosomes.
- The result of mitosis is two identical daughter cells. This is a form of asexual reproduction.
- Mitosis, which follows Interphase, is divided into four phases. Each phase is characterized by specific processes involving different structures.
- The characteristics of the phases of mitosis:
  - Prophase
    - Chromosomes condense and are more visible.
    - The nuclear membrane (envelope) disappears.
    - By the end of prophase, the centrosomes (organelles that produce spindle fibers) have separated and have moved to opposite poles of the cell.
    - The formation of the spindle apparatus from the centrosomes.
  - Metaphase (the shortest phase of mitosis)
    - Chromosomes line up across the middle of the cell.
    - Spindle fibers connect the centromere of each sister chromatid to the poles of the cell.

Chromosome composed of two sister chromatids

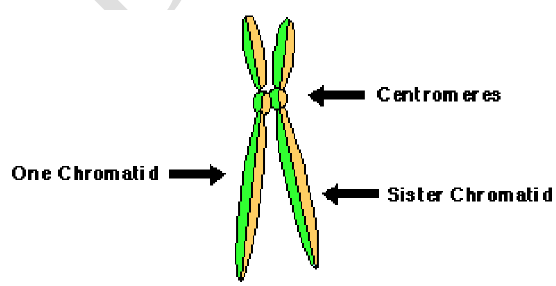
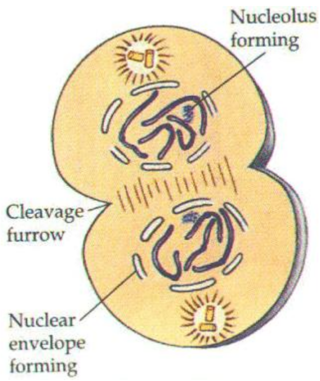


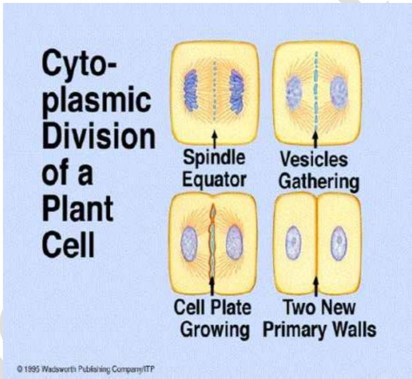
Figure 5. Chromosome (SCDE 2005).

  - Anaphase
    - Sister chromatids separate.
    - Separated chromatids move to opposite poles of the cell.
  - Telophase (the last phase of mitosis)
    - 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 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

Figure 7. Animal Cell (SCDE, 2005).

Figure 8. Plant Cell (SCDE, 2005).

NOTE TO TEACHER: Control of cell division is addressed in indicator H.B.2D.3 and the replication of DNA, the formation of RNA, and protein synthesis is addressed in indicators H.B.4A.2 and H.B.4B.1.

Extended Learning Experiences:
Students can develop and use models to:

- recognize any structures other than those listed in the essential content, and
- understand cell division in prokaryotic cells.

Assessment Guidelines:
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https://ed.sc.gov/scdoe/assets/File/instruction/standards/Science/Support%20Documents/Complete_2014SEPsGuide_SupportDoc2_0.pdf

Learning Connections	**Previous Learning Connections (6-8):** **7.L.3A.1** Obtain and communicate information to support claims that (1) organisms are made of one or more cells, (2) cells are the basic unit of structure and function of organisms, and (3) cells come only from existing cells. **7.L.4A.5** Construct scientific arguments using evidence to support claims for how changes in genes (mutations) may have beneficial, harmful, or neutral effects on organisms.

Cells as a System

Standard H.B.2: The student will demonstrate the understanding that the essential functions of life take place within cells or systems of cells.	
H.B.2D. Conceptual Understanding: The cells of multicellular organisms repeatedly divide to make more cells for growth and repair. During embryonic development, a single cell gives rise to a complex, multicellular organism through the processes of both cell division and differentiation.	
Performance Indicator	**H.B.2D.3:** Construct explanations for how the cell cycle is monitored by check point systems and communicate possible consequences of the continued cycling of abnormal cells.
Science and Engineering Practice	**H.B.1A.6:** Construct explanations of phenomena using (1) primary or secondary scientific evidence and models, (2) conclusions from scientific investigations, (3) predictions based on observations and measurements, or (4) data communicated in graphs, tables, or diagrams.
Crosscutting Concepts	The following Crosscutting Concepts may be applied to the content of the indicator. For more information see page 6. Cause and Effect Systems and System Models

Essential Learning Experiences:
It is essential that students construct explanation on how the cell cycle is monitored and the possible consequences of continued abnormalities.

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.

- Proteins regulate the progress of cell division at certain checkpoints
- 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.
- Other types of control over normal cell division are observed in laboratory settings:
    - When cells are grown on a dish and are in contact with neighbors on all sides, cell division is turned off.
    - When cells are grown in suspension and not in contact with a surface, cell division is turned off.
- If control of the cell cycle is lost, the result may be uncontrolled cell division.

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 when they are very densely packed and/or if the protein(s) that regulate cell division are not functioning properly due to a mutation.

- 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 by mitosis and each daughter cell will be a cancer cell.
  - A benign tumor is a mass of abnormal cells that remains at the original site.
  - A mass of these cells that invades and impairs the functions of one or more organs is called a malignant tumor.

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.

Extended Learning Experiences:
Students may also ask questions to:

- refine cell cycle models with three specific checkpoints,
- refine models to explain chemical control signals and growth factors,
- understand and address the various stages of cancer, and
- understand other terms such as apoptosis and telomeres.

Assessment Guidelines:
Students should engage in multiple science and engineering practices when interacting with the content outlined in this performance indicator. For further information please see SEP Support Guide at:
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Learning Connections	**Previous Learning Connections (6-8):** **7.L.3B.2:** Construct explanations for how systems in the human body (including circulatory, respiratory, digestive, excretory, nervous, and musculoskeletal systems) work together to support the essential life functions of the body.

Cells as a System

Standard H.B.2: The student will demonstrate the understanding that the essential functions of life take place within cells or systems of cells.	
H.B.2D. Conceptual Understanding: The cells of multicellular organisms repeatedly divide to make more cells for growth and repair. During embryonic development, a single cell gives rise to a complex, multicellular organism through the processes of both cell division and differentiation.	
Performance Indicator	**H.B.2D.4:** Construct scientific arguments to support the pros and cons of biotechnical applications of stem cells using examples from both plants and animals.
Science and Engineering Practice	**H.B.1A.7:** Construct and analyze scientific arguments to support claims, explanations, or designs using evidence and valid reasoning from observations, data, or informational texts.
Crosscutting Concepts	The following Crosscutting Concepts may be applied to the content of the indicator. For more information see page 6. Cause and Effect Systems and System Models

Essential Learning Experiences:
It is essential that students construct scientific arguments to support claims on biotechnical applications of stem cells from both plants and animals.

Stem cells are undifferentiated cells that have two important characteristics:
- They are unspecialized cells that are capable of renewing themselves by cell division.
- Under certain natural or experimental conditions they have the ability to differentiate into one or more types of specialized cells.

Plant stem cells
- Virtually all of a plant's tissues are descended from small groups of stem cells located in the actively growing tips of the roots and shoots.
- Plant stem cells have the capacity to grow into any type of plant organ, tissue, or cell.
- Plant stem cells have the capacity for nearly unlimited self-renewal.
- Many important compounds are derived from plants such as medicines, pigments, perfumes, and insecticides. Stem cell technology offers the potential to produce these chemicals under controlled conditions.

Animal stem cells
- Adult stem cells are undifferentiated cells found in certain organs and differentiated tissues with a capacity for both self-renewal and differentiation.

- In 3-5 day old animal embryos stem cells give rise to the entire body of the organism, including all of the many specialized cell types and organs such as the heart, lungs, skin, sperm, eggs, and all other tissues.
- In some adult animal tissues, such as bone marrow, groups of stem cells generate replacements for cells that are lost through normal wear and tear, injury, and disease.

Stem cell research has important uses in biotechnical applications.

- Scientists use stem cells to study normal growth, development, and differentiation. This research can help to identify the causes of cancer and birth defects that result from abnormal development.
- Human embryonic stem cells are derived from a 5-day old embryo.
  - They have the capacity for long-term self-renewal in laboratory culture.
  - They can develop into any type of specialized cell in the body.
- Stem cells are currently used to screen new medicines for safety in humans.
- Cell-based regenerative therapies are treatments in which stem cells are induced to differentiate into specific cell types required to repair damaged or destroyed cells or tissues.
  - The demand for organs and tissues needed for transplantation is greater than the supply.
  - Stem cells offer a renewable source of replacement cells and tissues such as:
    - bone tissue from bone marrow cells,
    - spinal cord after injury,
    - cells of the pancreas that produce insulin to treat diabetes.

The pros and cons of human embryonic and adult stem cells for cell-based therapies include:

- the number of types of cells they can become.
  - Embryonic stem cells can become all of the types of cells in the body (see extended knowledge).
  - Adult stem cells are thought to be limited to the types of cells in the tissue of origin.
- growth in laboratory culture.
  - Embryonic stem cells can be grown in culture and can divide indefinitely producing large numbers of cells for research.
  - Adult stem cells are difficult to isolate from the original tissue and are difficult to grow in culture.
- potential for rejection by the human immune system.
  - It is unknown how the immune system might react to embryonic stem cells.
  - Scientists think that adult stem cells are less likely to be rejected by the immune system because a patient's own cells can be used.

Extended Learning Experiences:
Students may obtain, communicate and evaluate information regarding:

- induced pluripotent stem cells (iPS cells),
- the role of embryonic cell layers (ecto, meso and endoderm) in stem cell generation, and
- the use of current stem cell technology in both plants and animals.

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Learning Connections	**Previous Learning Connections (6-8):** **7.L.4A.6:** Construct scientific arguments using evidence to support claims concerning the advantages and disadvantages of the use of technology (such as selective breeding, genetic engineering, or biomedical research) in influencing the transfer of genetic information.

Energy Transfer

Standard H.B.3: The student will demonstrate the understanding that all essential processes within organisms require energy which in most ecosystems is ultimately derived from the Sun and transferred into chemical energy by the photosynthetic organisms of that ecosystem	
H.B.3.A. Conceptual Understanding: Cells transform energy that organisms need to perform essential life functions through a complex sequence of reactions in which chemical energy is transferred from one system of interacting molecules to another.	
Performance Indicator	**H.B.3.A.1:** Develop and use models to explain how chemical reactions among ATP, ADP, and inorganic phosphate act to transfer chemical energy within cells.
Science and Engineering Practice	**H.B.1A.2:** Develop, use, and refine models to (1) understand or represent phenomena, processes, and relationships, (2) test devices or solutions, or (3) communicate ideas to others.
Crosscutting Concepts	The following Crosscutting Concepts may be applied to the content of the indicator. For more information see page 6. Cause and Effect Systems and System Energy and Matter

Essential Learning Experiences:
It is essential that students develop and use models to explain the chemical reactions in ATP-ADP cycle of storage and release of energy.

How life processes require a constant supply of energy. Cells use energy that is stored in the bonds of certain organic molecules. Adenosine triphosphate (ATP) is a molecule that transfers energy from the breakdown of food molecules to cell processes.
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

The ATP-ADP cycle

- The energy stored in ATP is released when a phosphate group is removed from the molecule. ATP has three phosphate groups, but the bond holding the third phosphate groups is very easily broken.

- When the phosphate is removed, ATP becomes ADP—adenosine diphosphate, a phosphate is released into the cytoplasm and energy is released.
- ADP is a lower energy molecule than ATP, but can be converted to ATP by the addition of a phosphate group.

ATP → ADP + phosphate + energy available for cell processes

- To supply the cell with energy, ADP is continually converted to ATP by the addition of a phosphate during the process of cellular respiration. ATP carries much more energy than ADP.
- As the cell requires more energy, it uses energy from the breakdown of food molecules to attach a free phosphate group to an ADP molecule in order to make ATP.

ADP + phosphate + energy from breakdown of food molecules → ATP

ATP is consumed in the cell by energy-requiring processes and can be generated by energy-releasing processes. In this way ATP transfers energy between separate biochemical reactions in the cell. ATP is the main energy source for the majority of cellular functions. This includes the synthesis of organic molecules, including DNA and, and proteins. ATP also plays a critical role in the transport of organic molecules across cell membranes, for example during exocytosis and endocytosis (See H.B.2C.)

Extended Learning Experiences:
Students could also develop and use models to:

- compare exergonic (energy-yielding) and endergonic (energy-requiring) reactions,
- illustrate oxidation-reduction reactions, and
- explain how electrons are involved in energy transfer (this background helps students to understand how electron transport chains in photosynthesis and cellular respiration work).

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Learning Connections	**Previous Learning Connections (6-8):** **6.P.3A.1:** Analyze and interpret data to describe the properties and compare sources of different forms of energy (including mechanical, electrical, chemical, radiant, and thermal).

Energy Transfer

<table>
<tr><td colspan="2">Standard H.B.3: The student will demonstrate the understanding that all essential processes within organisms require energy which in most ecosystems is ultimately derived from the Sun and transferred into chemical energy by the photosynthetic organisms of that ecosystem.</td></tr>
<tr><td colspan="2">H.B.3.A. Conceptual Understanding: Cells transform energy that organisms need to perform essential life functions through a complex sequence of reactions in which chemical energy is transferred from one system of interacting molecules to another.</td></tr>
<tr><td>Performance Indicator</td><td>H.B.3A.2: <u>Develop and revise models</u> to describe how photosynthesis transforms light energy into stored chemical energy.</td></tr>
<tr><td>Science and Engineering Practice</td><td>H.B.1A.2: <u>Develop, use, and refine models</u> to (1) understand or represent phenomena, processes, and relationships, (2) test devices or solutions, or (3) communicate ideas to others.</td></tr>
<tr><td>Crosscutting Concepts</td><td>The following Crosscutting Concepts may be applied to the content of the indicator. For more information see page 6.

Cause and Effect
Systems and System
Energy and Matter</td></tr>
</table>

Essential Learning Experiences:
<u>It is essential</u> for students to develop and revise models to describe how the process of photosynthesis transforms light/solar energy into chemical energy.

All organisms need a constant source of energy to survive. The ultimate source of energy for most life on Earth is the Sun. Photosynthesis, which occurs in the chloroplast, is the overall process by which solar energy (sunlight) is used to chemically convert water and carbon dioxide into chemical energy stored in simple sugars (such as glucose). This process occurs in two stages.

- The first stage is called the light-dependent reactions because they require solar energy.
- Sugars are not made during the light-dependent reactions.
- During the light-dependent reactions, solar energy is absorbed by chloroplasts and two energy-storing molecules (ATP and NADPH) are produced.
- The solar energy is used to split water molecules that results in the release of oxygen as a waste product. The splitting of water molecules allows for the temporary transfer of the solar energy to electrons released by the broken bonds. This energy is used to make ATP and NADPH.
- The second stage is called the Calvin cycle or the light-independent reactions because they do not require solar energy.

- During the Calvin cycle (light-independent reactions), carbon dioxide from the atmosphere and energy carried by ATP and NADPH is used to make simple sugars (such as glucose). These simple sugars store chemical energy.

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.
- The reactants, water and carbon dioxide are input during different stages of the process. Of the reactants water is used during the light-dependent reactions and carbon dioxide is used during the Calvin cycle.
- Each of the products (oxygen and glucose) is an output of different stages of the process. Oxygen is released during the light-dependent reactions and glucose is formed during the Calvin cycle.
- Solar energy is needed to split the water molecules.

Extended Learning Experiences:
Students could construct explanations regarding:
- environmental factors that affect photosynthesis (such as light intensity, temperature and carbon dioxide concentration);
- 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);
- the synthesis of ATP by Chemiosmosis; alternative pathways (CAM and C_4) for carbon fixation.

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Learning Connections	**Previous Learning Connections (6-8):** **6.L.4A.2:** Develop and use models to classify organisms based on the current hierarchical taxonomic structure (including the kingdoms of protists, plants, fungi, and animals). **6.L.5B.2:** Analyze and interpret data to explain how the processes of photosynthesis, respiration, and transpiration work together to meet the needs

	of plants. **6.P.3A.1:** Analyze and interpret data to describe the properties and compare sources of different forms of energy (including mechanical, electrical, chemical, radiant, and thermal). **7.L.3A.2:** Analyze and interpret data from observations to describe different types of cells and classify cells as plant, animal, protist, or bacteria. **Chemistry Learning Connections:** **H.C.6A.1:** Develop and use models to predict the products of chemical reactions (1) based upon movements of ions; (2) based upon movements of protons; and (3) based upon movements of electrons.

Energy Transfer

Standard H.B.3: The student will demonstrate the understanding that all essential processes within organisms require energy which in most ecosystems is ultimately derived from the Sun and transferred into chemical energy by the photosynthetic organisms of that ecosystem.	
H.B.3.A. Conceptual Understanding: Cells transform energy that organisms need to perform essential life functions through a complex sequence of reactions in which chemical energy is transferred from one system of interacting molecules to another.	
Performance Indicator	**H.B.3A.3:** Construct scientific arguments to support claims that chemical elements in the sugar molecules produced by photosynthesis may interact with other elements to form amino acids, lipids, nucleic acids or other large organic molecules.
Science and Engineering Practice	**H.B.1A.7:** Construct and analyze scientific arguments to support claims, explanations, or designs using evidence and valid reasoning from observations, data, or informational texts.
Crosscutting Concepts	The following Crosscutting Concepts may be applied to the content of the indicator. For more information see page 6. Cause and Effect Systems and System Models Energy and Matter

Essential Learning Experiences:
It is essential that students construct scientific arguments to support claims on how the chemical components of sugar interact with other elements to form amino acids, lipids, nucleic acids or other large organic molecules.

- Photosynthesis is the overall process by which solar energy (sunlight) is used to chemically convert water and carbon dioxide into chemical energy stored in simple sugars (such as glucose).

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

- The simple sugars produced by the fixation of atmospheric carbon (from carbon dioxide) are mostly recycled to keep the Calvin cycle (light-independent reactions) going. Some of these sugars, however, are converted to form other carbohydrates such as glucose, starch and cellulose.

- Glucose can be used by the cell for energy to make ATP during cellular respiration or it can be converted into starch or cellulose. The sugars produced by photosynthesis also provide carbon skeletons that can interact with elements such as nitrogen, sulfur, and phosphorus to make other organic molecules such as amino acids, lipids or nucleic acids (See H.B.2A.1).

Extended Learning Experiences:
Students may develop and use chemical formulas as models of specific organic molecules other than those listed in the photosynthesis equation.

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Learning Connections	**Previous Learning Connection (6-8):** **6.L.4A.2:** Develop and use models to classify organisms based on the current hierarchical taxonomic structure (including the kingdoms of protists, plants, fungi, and animals). **6.L.5B.2:** Analyze and interpret data to explain how the processes of photosynthesis, respiration, and transpiration work together to meet the needs of plants. (Chloroplasts) **6.P.3A.1:** Analyze and interpret data to describe the properties and compare sources of different forms of energy (including mechanical, electrical, chemical, radiant, and thermal). **7.P.2B.5:** Develop and use models to explain how chemical reactions are supported by the law of conservation of matter. **7.L.3A.2:** Analyze and interpret data from observations to describe different types of cells and classify cells as plant, animal, protist, or bacteria. **Chemistry Learning Connections:** **H.C.3A.6** Construct explanations of how the basic structure of common natural and synthetic polymers is related to their bulk properties. **H.C.6A.1** Develop and use models to predict the products of chemical reactions (1) based upon movements of ions; (2) based upon movements of protons; and (3) based upon movements of electrons.

Energy Transfer

Standard H.B.3: The student will demonstrate the understanding that all essential processes within organisms require energy which in most ecosystems is ultimately derived from the Sun and transferred into chemical energy by the photosynthetic organisms of that ecosystem.	
H.B.3.A. Conceptual Understanding: Cells transform energy that organisms need to perform essential life functions through a complex sequence of reactions in which chemical energy is transferred from one system of interacting molecules to another.	
Performance Indicator	**H.B.3A.4:** Develop models of the major inputs and outputs of cellular respiration (aerobic and anaerobic) to exemplify the chemical process in which the bonds of molecules are broken, the bonds of new compounds are formed and a net transfer of energy results.
Science and Engineering Practice	**H.B.1A.2:** Develop, use, and refine models to (1) understand or represent phenomena, processes, and relationships, (2) test devices or solutions, or (3) communicate ideas to others.
Crosscutting Concepts	The following Crosscutting Concepts may be applied to the content of the indicator. For more information see page 6. Cause and Effect Systems and System Models Energy and Matter

Essential Learning Experiences:
It is essential that students develop models to explain the inputs and outputs of cellular respiration and communicate how stored energy from food molecules are broken down to produce ATP molecules in the presence or absence of oxygen.

The ultimate goal of cellular respiration is to convert the chemical energy in food 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, including carbohydrates, fats/lipids, and proteins can be broken down into smaller molecules and then used as a source of energy to produce ATP molecules.

To transfer the energy stored in glucose to the ATP molecule, a cell must break down glucose slowly in a series of steps 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 with a net gain of two ATP molecules.

- Glycolysis is a series of reactions using enzymes that takes place in the cytoplasm and does not need oxygen.

Glucose → pyruvic acid + ATP (small amount)

- If oxygen is available, the two-stage process of aerobic respiration occurs, primarily in the mitochondria of the cell.
  - The first stage of aerobic respiration is called the Krebs cycle.
    - The pyruvic acid, produced by glycolysis, travels to the mitochondria where it is broken down in a cycle of chemical reactions, from which carbon dioxide and energy (used to form a small number of ATP molecules) are released.

pyruvic acid → carbon dioxide + ATP (small amount)

  - The second stage of aerobic respiration is the electron transport chain.
    - The electron transport chain is a series of chemical reactions in which energy is transferred to form a large number of ATP molecules.
    - At the end of the chain oxygen enters the process and is combined with hydrogen to form water.

<u>It is essential</u> for students to understand that the process of 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.

$$C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 6H_2O + \text{energy (ATP)}$$

- 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 cellular respiration. Glucose is an input of glycolysis and oxygen is an input of the electron transport chain of aerobic respiration.
- Each of the products (carbon dioxide and water) is formed during different stages of the process. Carbon dioxide is released from the Krebs cycle and water is released at the end of the electron transport chain.
- Up to 38 molecules of ATP are made from the breakdown of one glucose molecule: 2 from glycolysis and up to 36 from aerobic respiration.
- Most of the energy released by cellular respiration, that is not used to make ATP, is released in the form of heat.

If no oxygen is available, cells can obtain energy through the process of anaerobic respiration. Fermentation is an anaerobic process that allows glycolysis (which is also anaerobic) to continue making ATP in the absence of oxygen.

- Fermentation is not an efficient process and results in the formation of far fewer ATP molecules than aerobic respiration.
- Two fermentation processes that occur in many organisms are:

- Lactic acid fermentation occurs, for example, in muscle tissues during rapid and vigorous exercise when muscle cells may be depleted of oxygen. Lactic acid fermentation is also used by bacteria in the production of food products such as yogurt and sauerkraut.
- The pyruvic acid formed during glycolysis is broken down to lactic acid, and in the process energy is released, which can be used in glycolysis to make ATP.

Glucose → Pyruvic acid → Lactic acid + energy

- Once oxygen becomes available again, muscle cells return to using aerobic respiration.
- Alcohol fermentation occurs in many yeast species.
- In this process, pyruvic acid formed during glycolysis is broken down to produce alcohol and carbon dioxide, and in the process energy is released can be used by glycolysis to make ATP.

Glucose → Pyruvic acid → alcohol + carbon dioxide + energy

NOTE TO TEACHER: The structure of ATP molecules and a deeper treatment of its function are addressed in H.B.3A.3.
Pyruvic acid is a pyruvate molecule that has combined with a hydrogen ion. Many texts use the terms interchangeably.
Lactic acid is lactate that has acquired a hydrogen ion. Many texts use the two interchangeably.
Teachers may want to compare the processes of photosynthesis and aerobic respiration. Diagrams that compare and contrast the heterotroph and autotroph cycle could be used.

Extended Learning Experiences:
Students may develop and use models to explain:

- the specific chemical reactions of cellular respiration;
- the role of excited electrons or the mechanism of the electron transport chain in the process of respiration;
- the location of the electron transport chain (cristae);
- the role of ATP Synthase in the movement of H+ ion;
- the role of NADH in respiration or fermentation and
- muscle cells and liver cells are responsible for the breakdown of accumulated lactic acid.

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Learning Connections	**Previous Learning Connections (6-8):** **6.L.4A.2:** Develop and use models to classify organisms based on the current hierarchical taxonomic structure (including the kingdoms of protists, plants, fungi, and animals). **6.L.5B.2:** Analyze and interpret data to explain how the processes of photosynthesis, respiration, and transpiration work together to meet the needs of plants. **6.P.3A.1:** Analyze and interpret data to describe the properties and compare sources of different forms of energy (including mechanical, electrical, chemical, radiant, and thermal). **7.P.2B.5:** Develop and use models to explain how chemical reactions are supported by the law of conservation of matter. **7.L.3A.3:** Develop and use models to explain how the relevant structures within cells (including cytoplasm, cell membrane, cell wall, nucleus, mitochondria, chloroplasts, lysosomes, and vacuoles) function to support the life of plant, animal, and bacterial cells. **Chemistry Learning Connections:** **H.C.6A.1:** Develop and use models to predict the products of chemical reactions (1) based upon movements of ions; (2) based upon movements of protons; and (3) based upon movements of electrons

Energy Transfer

Standard H.B.3: The student will demonstrate the understanding that all essential processes within organisms require energy which in most ecosystems is ultimately derived from the Sun and transferred into chemical energy by the photosynthetic organisms of that ecosystem.	
H.B.3.A. Conceptual Understanding: Cells transform energy that organisms need to perform essential life functions through a complex sequence of reactions in which chemical energy is transferred from one system of interacting molecules to another.	
Performance Indicator	**H.B.3A.5:** Plan and conduct scientific investigations or computer simulations to determine the relationship between variables that affect the processes of fermentation and/or cellular respiration in living organisms and interpret the data in terms of real-world phenomena.
Science and Engineering Practice	**H.B.1A.3:** Plan and conduct controlled scientific investigations to answer questions, test hypotheses, and develop explanations: (1) formulate scientific questions and testable hypotheses based on credible scientific information, (2) identify materials, procedures, and variables, (3) use appropriate laboratory equipment, technology, and techniques to collect qualitative and quantitative data, and (4) record and represent data in an appropriate form. Use appropriate safety procedures.
Crosscutting Concepts	The following Crosscutting Concepts may be applied to the content of the indicator. For more information see page 6. Cause and Effect Systems and System Models Energy and Matter

Essential Learning Experiences:
It is essential that students plan and conduct scientific investigations or computer simulations to determine the relationship between aerobic and anaerobic respiration.

- Factors that may affect the processes of fermentation or cellular respiration include the presence or absence of oxygen, the amount or type of food molecules available (for example the concentration of sugar), temperature, or type of organism. Organisms that may be investigated include yeast and small aquatic snails.

NOTE TO TEACHER: see H.B.3A.4

Extended Learning Experiences:
Students may also obtain, communicate and evaluate information regarding:
- examples of fermentation in bacteria;

- 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; and
- the role of NADH in respiration or fermentation.

Assessment Guidelines:
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Learning Connections	**Previous Learning Connections (6-8):** **6.L.4A.2:** Develop and use models to classify organisms based on the current hierarchical taxonomic structure (including the kingdoms of protists, plants, fungi, and animals). **6.L.5B.2:** Analyze and interpret data to explain how the processes of photosynthesis, respiration, and transpiration work together to meet the needs of plants. **6.P.3A.1:** Analyze and interpret data to describe the properties and compare sources of different forms of energy (including mechanical, electrical, chemical, radiant, and thermal). **7.P.2B.5:** Develop and use models to explain how chemical reactions are supported by the law of conservation of matter. **7.L.3A.3** Develop and use models to explain how the relevant structures within cells (including cytoplasm, cell membrane, cell wall, nucleus, mitochondria, chloroplasts, lysosomes, and vacuoles) function to support the life of plant, animal, and bacterial cells. **Chemistry Learning Connections:** **H.C.6A.1** Develop and use models to predict the products of chemical reactions (1) based upon movements of ions; (2) based upon movements of protons; and (3) based upon movements of electrons.

Heredity – Inheritance and Variation of Traits

Standard H.B.4. The student will demonstrate an understanding of the specific mechanisms by which characteristics or traits are transferred from one generation to the next via genes.	
H.B.4A. Conceptual Understanding: Each chromosome consists of a single DNA molecule. Each gene on the chromosome is a particular segment of DNA. The chemical structure of DNA provides a mechanism that ensures that information is preserved and transferred to subsequent generations.	
Performance Indicator	**H.B.4A.1** <u>Develop and use models</u> at different scales to explain the relationship between DNA, genes, and chromosomes in coding the instructions for characteristic traits transferred from parent to offspring.
Science and Engineering Practice	**H.B.1A.2** <u>Develop, use, and refine models</u> to (1) understand or represent phenomena, processes, and relationships, (2) test devices or solutions, or (3) communicate ideas to others.
Crosscutting Concepts	The following Crosscutting Concepts may be applied to the content of the indicator. For more information see page 6. Cause and Effect Scale, Proportion, and Quantity Systems and System Models Structure and Function

Essential Learning Experiences:
<u>It is essential</u> that students develop and use models at different scales to explain the relationship between DNA, genes, and chromosomes in composing the molecular basis of heredity.

A chromosome is a structure in the nucleus of a cell that consists of one long molecule of *DNA* that is condensed and tightly coiled around associated proteins. Each chromosome consists of hundreds of genes that code for proteins or RNA molecules.

- 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; and 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 autosomes. Cells (except for sex cells) contain one pair of each type of chromosome.
- Each pair of chromosomes has genes that code 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.

A gene is a specific location on a chromosome, consisting of a segment of DNA that codes for a particular protein or RNA molecule that has a function in an organism.

- Genes are cellular units of information that determine how organisms inherit characteristics from their parents.
- The particular protein or RNA molecules coded by each gene determine the characteristics of an organism.

DNA, which comprises an organism's chromosomes, is considered the "code of life" (genetic code) because it contains the instructions for building each protein that an organism needs.

- DNA provides the blueprint for the synthesis of proteins via the sequence of nucleotides that make up the DNA strand.
- Each individual organism has unique characteristics that arise because of the differences in the nucleotide sequences found in the organism's DNA.
- Organisms that are closely related share more genes (with similar nucleotide sequences) than organisms that are less closely related.
- For example red maple trees have many of the same genes as other red maple trees. Furthermore, red maple trees have more genes in common with oak trees than with earthworms.

Extended Learning Experiences:
Students may also construct explanations of

- the structural and functional relationships between histones and chromosomes along with coding vs. non-coding sequences of the human genome, and
- the role of introns and exons in post-transcriptional modifications.

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https://ed.sc.gov/scdoe/assets/File/instruction/standards/Science/Support%20Documents/Complete_2014SEPsGuide_SupportDoc2_0.pdf

Learning Connections	**Previous Learning Connections (6-8):** **7.L.4A.1:** Obtain and communicate information about the relationship between genes and chromosomes to construct explanations of their relationship to inherited characteristics. **7.L.4A.2:** Construct explanations for how genetic information is transferred from parent to offspring in organisms that reproduce sexually. **7.L.4A.3:** Develop and use models (Punnett squares) to describe and predict patterns of the inheritance of single genetic traits from parent to offspring (including dominant and recessive traits, incomplete dominance, and codominance). **7.L.4A.4:** Use mathematical and computational thinking to predict the probability of phenotypes and genotypes based on patterns of inheritance.

	7.L.4A.5: Construct scientific arguments using evidence to support claims for how changes in genes (mutations) may have beneficial, harmful, or neutral effects on organisms. **7.L.4A.6:** Construct scientific arguments using evidence to support claims concerning the advantages and disadvantages of the use of technology (such as selective breeding, genetic engineering, or biomedical research) in influencing the transfer of genetic information.

Heredity – Inheritance and Variation of Traits

Standard H.B.4. The student will demonstrate an understanding of the specific mechanisms by which characteristics or traits are transferred from one generation to the next via genes.	
H.B.4A. Conceptual Understanding: Each chromosome consists of a single DNA molecule. Each gene on the chromosome is a particular segment of DNA. The chemical structure of DNA provides a mechanism that ensures that information is preserved and transferred to subsequent generations.	
Performance Indicator	**H.B.4A.2** Develop and use models to explain how genetic information (DNA) is copied for transmission to subsequent generations of cells (mitosis).
Science and Engineering Practice	**H.B.1A.2** Develop, use, and refine models to (1) understand or represent phenomena, processes, and relationships, (2) test devices or solutions, or (3) communicate ideas to others.
Crosscutting Concepts	The following Crosscutting Concepts may be applied to the content of the indicator. For more information see page 6. Cause and Effect Scale, Proportion, and Quantity Systems and System Models Structure and Function

Essential Learning Experiences:
It is essential for students to develop and use models to explain how DNA replication during mitosis transmits identical information to the new cells.

The process of DNA replication ensures that every new cell that results from mitotic division has identical DNA. Enzymes facilitate the replication process:

- 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.
- 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.

NOTE TO TEACHER: See H.B.2A.1 and H.B.2D.2

Extended Learning Experiences:
Students may obtain, communicate, and evaluate information regarding
- the chemical formula for DNA or RNA,
- the difference between pyrimidine bases and purine bases, and
- the enzymes involved in replication.

Assessment Guidelines:
Students should engage in multiple science and engineering practices when interacting with the content outlined in this performance indicator. For further information please see SEP Support Guide at:
https://ed.sc.gov/scdoe/assets/File/instruction/standards/Science/Support%20Documents/Complete_2014SEPsGuide_SupportDoc2_0.pdf

<table>
<tr>
<td>Learning Connections</td>
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7.L.4A.3 Develop and use models (Punnett squares) to describe and predict patterns of the inheritance of single genetic traits from parent to offspring (including dominant and recessive traits, incomplete dominance, and codominance).
7.L.4A.4 Use mathematical and computational thinking to predict the probability of phenotypes and genotypes based on patterns of inheritance.
7.L.4A.5 Construct scientific arguments using evidence to support claims for how changes in genes (mutations) may have beneficial, harmful, or neutral effects on organisms.
7.L.4A.6 Construct scientific arguments using evidence to support claims concerning the advantages and disadvantages of the use of technology (such as selective breeding, genetic engineering, or biomedical research) in influencing the transfer of genetic information.

Chemistry Learning Connections:
H.C.3A.6 Construct explanations of how the basic structure of common natural and synthetic polymers is related to their bulk properties.</td>
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Heredity – Inheritance and Variation of Traits

Standard H.B.4. The student will demonstrate an understanding of the specific mechanisms by which characteristics or traits are transferred from one generation to the next via genes.	
H.B.4B. Conceptual Understanding: In order for information stored in DNA to direct cellular processes, a gene needs to be transcribed from DNA to RNA and then must be translated by the cellular machinery into a protein or an RNA molecule. The protein and RNA products from these processes determine cellular activities and the unique characteristics of an individual. Modern techniques in biotechnology can manipulate DNA to solve human problems.	
Performance Indicator	**H.B.4B.1** Develop and use models to describe how the structure of DNA determines the structure of resulting proteins or RNA molecules that carry out the essential functions of life.
Science and Engineering Practice	**H.B.1A.2** Develop, use, and refine models to (1) understand or represent phenomena, processes, and relationships, (2) test devices or solutions, or (3) communicate ideas to others.
Crosscutting Concepts	The following Crosscutting Concepts may be applied to the content of the indicator. For more information see page 6. Cause and Effect Scale, Proportion, and Quantity Systems and System Models Structure and Function

Essential Learning Experiences:
It is essential for students to develop and use models to describe how the structure of DNA determines the structure of the proteins essential for life function.

When a particular protein is needed, the cell must make the protein through the process of transcription and translation. DNA molecules (which contain the code) do not leave the nucleus of the cell. Protein synthesis occurs on ribosomes located outside of the nucleus. Therefore, the code must be carried from the nucleus to the cytoplasm.

Transcription is the process by which a portion of the molecule of DNA is copied into a complementary strand of RNA. The process of transcription takes place as follows:

- An enzyme attaches to the DNA molecule at the gene of interest.
- The two strands of DNA separate at that location.
- Complementary RNA nucleotides bond to the nitrogenous bases on one of the separated DNA strands.
- The chain of RNA nucleotides forms a single-stranded molecule of RNA by using the DNA strand as a template.

- When a stop codon is reached, the RNA strand separates from the DNA molecule, leaves the nucleus and goes through the nuclear membrane into the cytoplasm.
- The two DNA strands rejoin.

Translation is the process by which the genetic message, carried by the mRNA, is used to assemble a protein.

- The mRNA attaches to a ribosome, which contains proteins and ribosomal RNA (rRNA). The function of ribosomes is to assemble proteins according to the genetic message (Refer to H.B.2B.1).
- Each three-base nucleotide sequence on the mRNA is called a codon. Each codon specifies a particular amino acid that will be used to build the protein molecule. For example, if the DNA sequence was GAC, then the RNA sequence becomes CUG (transcription) and the amino acid that is coded is Leucine (translation).(Refer to H.B.2A.1)
- Another type of RNA, transfer RNA (tRNA), brings amino acids to the ribosome in the order specified by the codon sequence on the mRNA. At one end of each tRNA is the anticodon, a region that consists of three nucleotide bases that are complementary to the codon of mRNA. The other end of the tRNA molecule binds to the specific amino acid that is determined by the mRNA codon.
- The translation process takes place as follows:
    - The anticodon of the tRNA, with its attached amino acid, pairs to the codon of the mRNA, which is 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 is bonded 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.

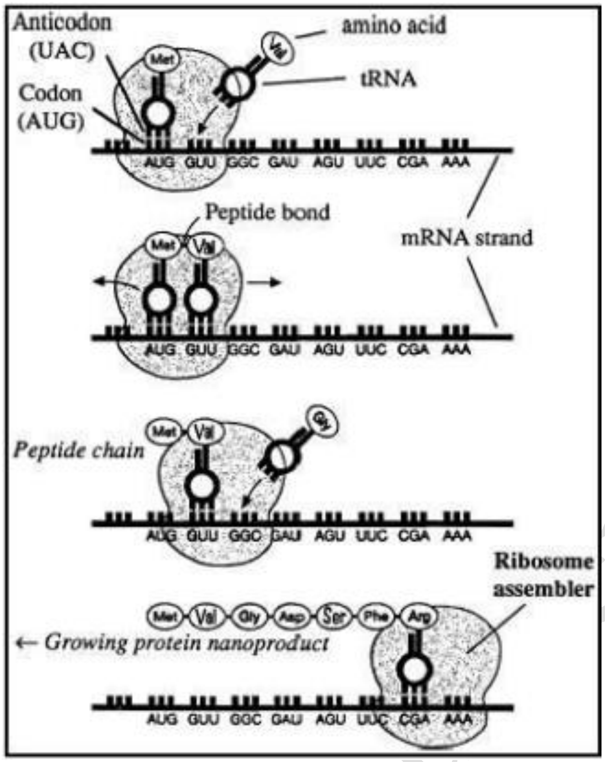

Figure 9. Protein (SCDE, 2005).

RNA plays an important role in protein synthesis but it can also have other functions in the cell.

- mRNA is essential to the process of transcription, tRNA is essential to the process of translation, and rRNA makes up the ribosomes in which translation takes place.

NOTE TO TEACHER: mRNA codons for specific amino acids (the genetic code) can be found in tables in most textbooks. Students should be expected to use several styles (i.e. wheel and square) but not necessarily memorize these tables.

Extended Learning Experiences:
Students may also develop and use models to illustrate:

- the termination of transcription, in terms of alteration of the mRNA ends and RNA splicing,
- the processing of mRNA in regard to introns and exons,
- the enzymes involved in the process of protein synthesis,
- the lac operon in relation to lactose intolerance,
- the functions and types of RNA(new forms and functions of RNAs continue to be discovered).
    - RNA may function as an enzyme in biochemical reactions.
    - In eukaryotes, there are kinds of RNA that help regulate gene expression and modify yet other types of RNA.

- In prokaryotes, RNA is involved in a wide range of processes, from determining the ability to cause disease to regulation of bacterial growth.

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Learning Connections	**Previous Learning Connections (6-8):** **7.L.4A.1** Obtain and communicate information about the relationship between genes and chromosomes to construct explanations of their relationship to inherited characteristics. **7.L.4A.2** Construct explanations for how genetic information is transferred from parent to offspring in organisms that reproduce sexually. **7.L.4A.3** Develop and use models (Punnett squares) to describe and predict patterns of the inheritance of single genetic traits from parent to offspring (including dominant and recessive traits, incomplete dominance, and codominance). **7.L.4A.4** Use mathematical and computational thinking to predict the probability of phenotypes and genotypes based on patterns of inheritance. **7.L.4A.5** Construct scientific arguments using evidence to support claims for how changes in genes (mutations) may have beneficial, harmful, or neutral effects on organisms. **7.L.4A.6** Construct scientific arguments using evidence to support claims concerning the advantages and disadvantages of the use of technology (such as selective breeding, genetic engineering, or biomedical research) in influencing the transfer of genetic information.

Heredity – Inheritance and Variation of Traits

Standard H.B.4. The student will demonstrate an understanding of the specific mechanisms by which characteristics or traits are transferred from one generation to the next via genes.	
H.B.4B. Conceptual Understanding: In order for information stored in DNA to direct cellular processes, a gene needs to be transcribed from DNA to RNA and then must be translated by the cellular machinery into a protein or an RNA molecule. The protein and RNA products from these processes determine cellular activities and the unique characteristics of an individual. Modern techniques in biotechnology can manipulate DNA to solve human problems.	
Performance Indicator	Obtain, evaluate and communicate information on how biotechnology (including gel electrophoresis, plasmid-based transformation and DNA fingerprinting) may be used in the fields of medicine, agriculture, and forensic science.
Science and Engineering Practice	Obtain and evaluate scientific information to (1) answer questions, (2) explain or describe phenomena, (3) develop models, (4) evaluate hypotheses, explanations, claims, or designs or (5) identify and/or fill gaps in knowledge. Communicate using the conventions and expectations of scientific writing or oral presentations by (1) evaluating grade-appropriate primary or secondary scientific literature, or (2) reporting the results of student experimental investigations.
Crosscutting Concepts	The following Crosscutting Concepts may be applied to the content of the indicator. For more information see page 6. Cause and Effect Scale, Proportion, and Quantity Systems and System Models Structure and Function

Essential Learning Experiences:
It is essential that students obtain, evaluate and communicate information on how biotechnology applications may be used in the fields of medicine, agriculture, and forensic science.

Biotechnology utilizes biological processes, organisms, cells or cellular components to develop new technologies. New tools and products developed by biotechnologists are useful in research, agriculture, industry and the medicine.

Genetic Engineering is the deliberate modification of the characteristics of an organism by manipulating its genetic material.

- The goal is to add one or more new traits that are not already found in that organism.
- Genetic engineering is accomplished by taking specific genes from one organism and placing them into another organism.

- Genetic engineering is possible because the genetic code is shared by all organisms.
- Examples of genetically engineered products currently on the market include human insulin produced by genetically modified bacteria, plants with resistance to some insects, plants that can tolerate herbicides.
- An organism that is generated through genetic engineering is considered to be a genetically modified organism (GMO).

Techniques used to manipulate DNA

- Restriction enzymes are used to cut DNA at precise locations.
    - Because it is a very long molecule, DNA needs to be cut into smaller pieces to facilitate studying and working with it.
    - Restriction enzymes are enzymes that cut DNA at particular nucleotide sequences.
    - Each of the many restriction enzymes cuts DNA at a different restriction site.
- Gel electrophoresis is used to separate segments of DNA according to length.
    - After DNA has been cut with a restriction enzyme, the pieces must be separated from one another.
    - For gel electrophoresis, an electric current is applied to a small tray containing a flat slab of gelatin. One end of gel is positively charged and the other is negatively charged.
    - A solution of cut-up DNA is placed in the negative end of the gel. Because DNA has a negative charge, the segments are pulled to the positive end of the gel. Small pieces move through the gel faster than large pieces.
    - A dye is used to be able to see the DNA on the gel slab. Clumps of DNA made up of a certain length segment appear on the gel as bands or lines.
    - Scientists can use the pattern of bands to identify the location of a gene or in DNA fingerprinting.
- DNA fingerprinting
    - A genome is the complete genetic material contained within an individual organism.
    - Except for in identical twins, every person's genome (DNA sequence) is unique.
    - The specific patterns of bands produced by gel electrophoresis create a DNA fingerprint.
    - Because the probability of two individuals having the same DNA fingerprint is extremely small, it provides compelling forensic evidence and can also provide evidence of family relationships.
- Bacterial plasmids are used to create recombinant DNA
    - Recombinant DNA is DNA that contains genes from more than one organism.
    - A bacterial plasmid is a tiny ring of DNA carried in the cytoplasm. They are separate from the bacteria's chromosome and replicate on their own inside the cell.
    - A restriction enzyme is used to cut a desired gene from a strand of "foreign" DNA (i.e. from a different organism than the bacteria from which the plasmid was taken). An example of a desired gene is the human DNA sequence that codes for the protein hormone insulin.

- The circular bacterial plasmid is cut with the same restriction enzyme.
- The piece of foreign DNA, with the desired gene, is attached to the open ends of the plasmid DNA. The plasmid and the foreign DNA are bonded together to form recombinant DNA.
- In the insulin example, the plasmid could be reintroduced into bacterial cells, which would then multiply rapidly and produce insulin in large amounts and at low cost.

Extended Learning Experiences:
Students may obtain, communicate, and evaluate information regarding the biological:
- function of restriction enzymes in bacteria,
- polymerase chain reaction,
- restriction maps, and
- comparisons between genetic engineering and selective breeding.

Assessment Guidelines:
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Learning Connections	**Previous Learning Connections (6-8):** **7.L.4A.6** Construct scientific arguments using evidence to support claims concerning the advantages and disadvantages of the use of technology (such as selective breeding, genetic engineering, or biomedical research) in influencing the transfer of genetic information.

Heredity – Inheritance and Variation of Traits

Standard H.B.4. The student will demonstrate an understanding of the specific mechanisms by which characteristics or traits are transferred from one generation to the next via genes.	
H.B.4C. Conceptual Understanding: Sex cells are formed by a process of cell division in which the number of chromosomes per cell is halved after replication. With the exception of sex chromosomes, for each chromosome in the body cells of a multicellular organism, there is a second similar, but not identical, chromosome. Although these pairs of similar chromosomes can carry the same genes, they may have slightly different alleles. During meiosis the pairs of similar chromosomes may cross and trade pieces. One chromosome from each pair is randomly passed on to form sex cells resulting in a multitude of possible genetic combinations. The cell produced during fertilization has one set of chromosomes from each parent.	
Performance Indicator	**H.B.4C.1** Develop and use models of sex cell formation (meiosis) to explain why the DNA of the daughter cells is different from the DNA of the parent cell.
Science and Engineering Practice	**H.B.1A.2** Develop, use, and refine models to (1) understand or represent phenomena, processes, and relationships, (2) test devices or solutions, or (3) communicate ideas to others.
Crosscutting Concepts	The following Crosscutting Concepts may be applied to the content of the indicator. For more information see page 6. Cause and Effect Scale, Proportion, and Quantity Systems and System Models Structure and Function

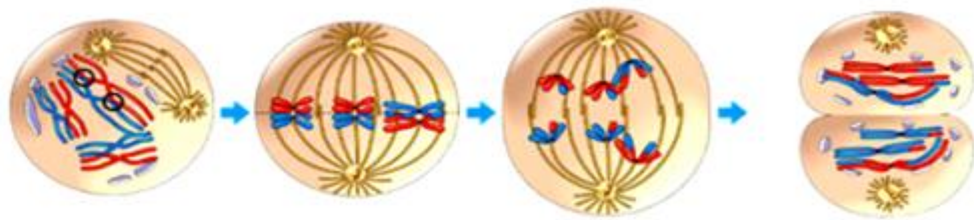
Essential Learning Experiences:
It is essential for students to develop and use models to explain how meiosis produces non-identical daughter cells due to fertilization, crossing-over, and independent assortment.

The process of meiosis is essential to sexual reproduction just as mitosis is to asexual reproduction (see H.B.2D.2). Sexual reproduction requires the fusion of gametes or sex cells (fertilization). 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 (gametes) must be haploid (contain only one of each type of chromosome). The cellular division resulting in a reduction in chromosome number is called meiosis.

Meiosis occurs in two steps:

- Meiosis I, in which the homologous chromosome pairs separate, results in two haploid daughter cells with duplicated chromosomes different from the sets in the original diploid cell.

Meiosis I



Prophase I | Metaphase I | Anaphase I | Telophase I & Cytokinesis

Figure 10. Meiosis I (SCDE, 2005)

- Meiosis II, in which the duplicated chromosomes from Meiosis I separate, resulting in four haploid daughter cells called gametes, or sex cells (eggs and sperm), with single (unduplicated) chromosomes.

Interphase precedes Meiosis I. (For information on Interphase see H.B.2D.2)

- Prophase I
  - The nuclear membrane breaks down during prophase I.
  - The duplicated chromosomes condense and homologous chromosomes pair up. A homologous chromosome pair consists of two chromosomes containing the same type of genes. One chromosome in the pair is contributed by the organism's male parent, the other chromosome in the pair is contributed by the organism's female parent.
  - As in mitosis, each duplicated chromosome consists of two identical sister chromatids attached at a point called the centromere.
  - Because the homologous chromosome pairs very close to one another, an exchange of chromosome genetic material between pairs occurs in a process called crossing over.
  - Crossing over causes the daughter cells to have different gene combinations from the original parent cell.
- Metaphase I
  - The paired homologous chromosomes are aligned along the equator of the cell with one chromosome of a pair on one side and one chromosome of a pair on the other side.
  - Each pair is randomly oriented in terms of whether the paternal or maternal chromosome is on a given side of the equator.
  - The result is that 23 chromosomes, some from the mother and some from the father, are lined up on each side of the equator. This arrangement is called independent assortment and also causes the daughter cells to have DNA that is different from the original parent cell.

- Anaphase I
    - The homologous chromosome pairs separate and move to opposite poles 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
    - Chromosomes gather at the poles and cytokinesis begins.
    - Cytokinesis occurs at the end of telophase I; the chromosomes uncoil and the nuclear membrane reforms
    - Each of the two daughter cells at the end of meiosis I contain only one chromosome (consisting of two sister chromatids) from each parental pair, and are therefore haploid.
    - Each daughter cell from meiosis I undergoes meiosis II.

It is important to emphasize that there is no duplication of DNA between meiosis I and meiosis II.

Meiosis II

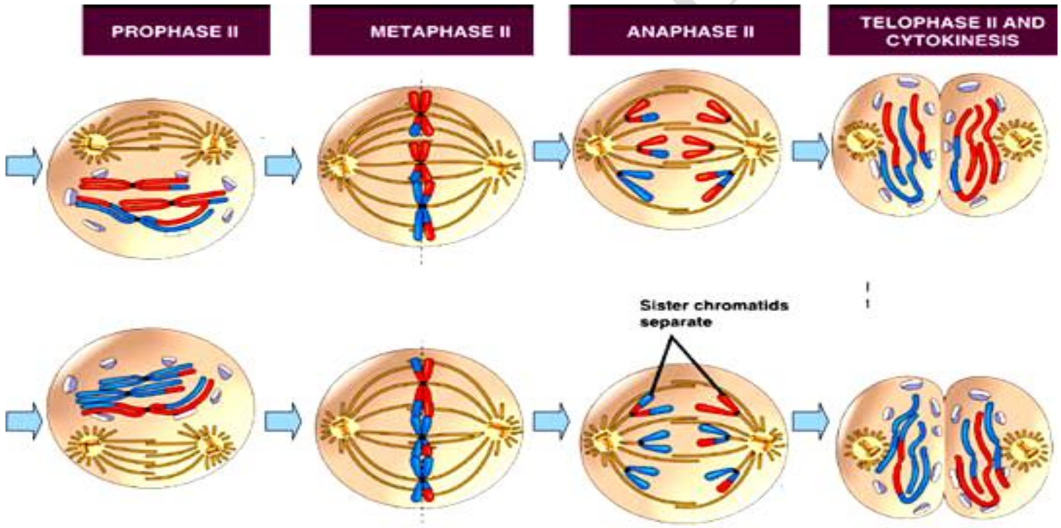


Image 11. Meiosis II (SCDE, 2005).

- Prophase II
    - The nuclear membrane breaks down.
- Metaphase II
    - Chromosomes, made up of two sister chromatids, line up across the center of the cell.
- Anaphase II
    - The chromosomes separate so that one chromatid from each chromosome goes to each pole.

- Telophase II & Cytokinesis
    - The nuclear membrane reforms around each set of chromosomes.
    - The cell undergoes cytokinesis.
    - The four resulting daughter cells are still haploid (as they were at the end of meiosis I) because meiosis II is almost identical to mitosis.

- The DNA of the daughter cells produced by meiosis is different from that of the parent cells due to three sources of genetic diversity provided by sexual reproduction and meios

1. Fertilization combines the genetic material of two genetically unique individuals (the two parents.
2. Crossing-over produces new combinations of genes.
3. Independent assortment allows for the possibility of about 8 million different combinations of chromosome.

NOTE TO TEACHER: Please connect meiosis to diversity.

Extended Learning Experiences:
Students may also develop and use models to explain the process of gametogenesis (including oogenesis and spermatogenesis).

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Learning Connections	**Previous Learning Connections (6-8):** **7.L.4A.1** Obtain and communicate information about the relationship between genes and chromosomes to construct explanations of their relationship to inherited characteristics. **7.L.4A.2** Construct explanations for how genetic information is transferred from parent to offspring in organisms that reproduce sexually.

Heredity – Inheritance and Variation of Traits

Standard H.B.4. The student will demonstrate an understanding of the specific mechanisms by which characteristics or traits are transferred from one generation to the next via genes.	
H.B.4C. Conceptual Understanding: Sex cells are formed by a process of cell division in which the number of chromosomes per cell is halved after replication. With the exception of sex chromosomes, for each chromosome in the body cells of a multicellular organism, there is a second similar, but not identical, chromosome. Although these pairs of similar chromosomes can carry the same genes, they may have slightly different alleles. During meiosis the pairs of similar chromosomes may cross and trade pieces. One chromosome from each pair is randomly passed on to form sex cells resulting in a multitude of possible genetic combinations. The cell produced during fertilization has one set of chromosomes from each parent.	
Performance Indicator	**H.B.4C.2** Analyze data on the variation of traits among individual organisms within a population to explain the patterns in the data in the context of transmission of genetic information.
Science and Engineering Practice	**H.B.1A.4** Analyze and interpret data from informational texts and data collected from investigations using a range of methods (such as tabulation, graphing, or statistical analysis) to (1) reveal patterns and construct meaning, (2) support or refute hypotheses, explanations, claims, or designs, or (3) evaluate the strength of conclusions.
Crosscutting Concepts	The following Crosscutting Concepts may be applied to the content of the indicator. For more information see page 6. Cause and Effect Scale, Proportion, and Quantity Systems and System Models Structure and Function

Essential Learning Experiences:
It is essential for students to analyze and interpret data collected from investigations and informational texts to study the patterns of variation of traits and to explain or make claims on how genes and traits are inherited.

Many inherited traits result from modes of inheritance that differ from a strict dominant and recessive pattern. Phenotypes can result from alleles with a range of dominance; from the combined effects of more than one gene, or from genes that have more than two alleles within a population.
Scientists study the patterns of trait (phenotypic) variation within families and populations in order to determine how genes are inherited.

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.

Sex-Linked Traits

- Sex-linked traits are the result of genes that are carried on sex chromosomes.
- For example, in humans and most other mammals the X and Y chromosomes determine the sex of the organism.
    - Sex chromosomes in females consist of two X chromosomes.
    - Sex chromosomes in males consist 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 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 can 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 lack this gene) can be coded Y
    - Only offspring that have the X^C gene will have normal vision.

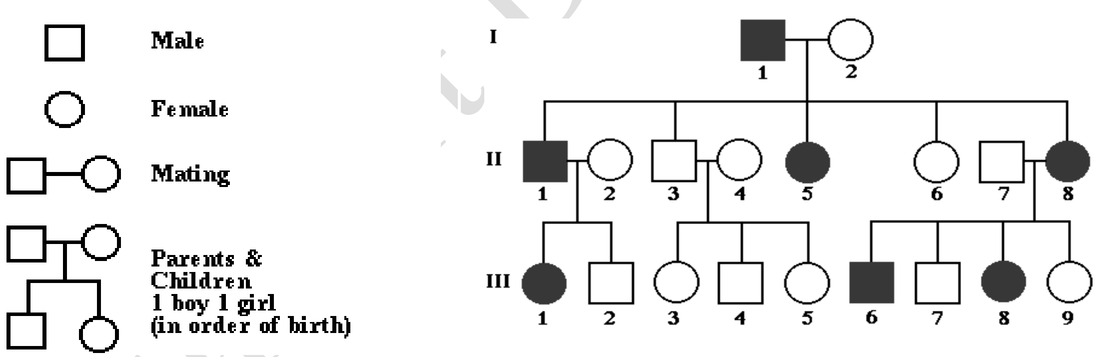
	X^C	Y
X^C	X^CX^C	X^CY
X^c	X^cX^C	X^cY

- Hemophilia is a disease caused by a sex-linked gene.
- A female can express the sex-linked recessive gene only if it is present on both copies of the X chromosome.

Pedigrees

- A pedigree is a chart constructed to show an inheritance pattern (trait, disease, disorder) within a family over multiple generations. Each generation is represented by the Roman numeral. Each individual in each generation is numbered from left to right. Squares represent males and circles represent females. Through the use of a pedigree chart and key, the genotype and phenotype of the family members and the genetic inheritance patterns (dominant/recessive, sex-linked) of traits can be tracked.

Pedigree Example I: Family with an autosomal dominant genetic trait:



Pedigree Key:

Image 12. Pedigree (SCDE, 2005).

- The gene for this particular genetic trait does not occur on the sex chromosomes; it occurs on an autosomal chromosome. This information can be inferred from two facts:
    1. Both males and females have the trait.
    2. Individual III-7 who is a male did not inherit the trait from his affected mother. 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 an autosomal recessive genetic trait

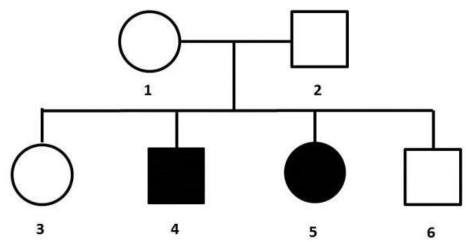


Image 13. Small pedigree (SCDE, 2005).

- The gene for this particular trait is autosomal recessive. This information can be inferred because:
    - affected children are born to unaffected parents,
    - and affected children include both males and females equally.
- We can deduce that the parents (individuals 1 and 2) must be heterozygotes as they have both affected and non-affected children. Often, rare recessive alleles will be found mostly in heterozygotes and not in homozygotes.
    - Matings between relatives (inbreeding) has a greater risk for producing homozygotes with rare recessive alleles than do matings with non-relatives.

Pedigree Example III: Family with a recessive sex-linked genetic trait

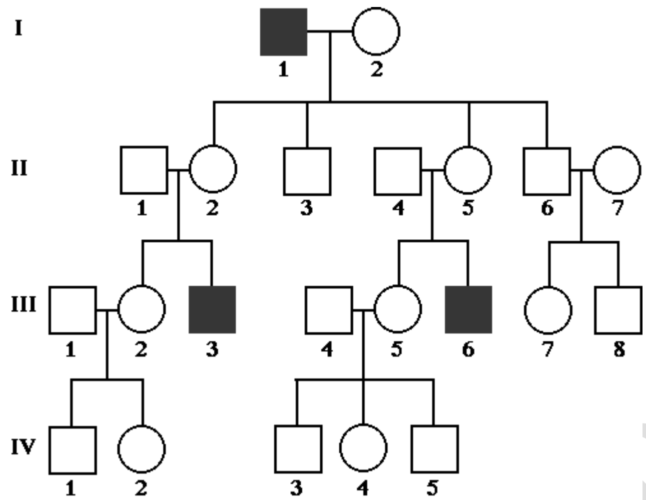


Image 14. Pedigree II (SCDE, 2005).

- 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.

NOTE TO TEACHERS: Teachers should review the vocabulary and notation of basic Mendelian genetics: dominant, recessive, heterozygous, homozygous, genotype, phenotype (7.L.4A). Teachers might also review how to set up a basic monohybrid Punnett square, but it is not recommended that students spend a lot of time working Punnett square problems. Rather, lessons should emphasize inheritance patterns represented by Punnett squares.
With X-linked inheritance; many more males than females are affected.

Extended Learning Experiences:
Some traits are affected by the environment.

- Biological sex and blood type are not affected by the environment.

- Other traits like hair color, skin color, and height can be affected by the environment.
- Most traits are influenced by both genetic and environmental factors.
- Some disorders such as certain types of cancer or even psychiatric disorders are traits that are both genetic and environmental because there is evidence that they run in families and because there is evidence that supports their modification by changing the environment.
- There are other factors that influence sex determination in animals, for example, temperature with reptiles.

Discontinuous traits and Continuous traits may be explored in context of the inheritance of traits

- Discontinuous traits are controlled by variation in one gene.
- A continuous trait is determined by multiple genes (polygenic), such as height or hair color.

Assessment Guidelines:
Students should engage in multiple science and engineering practices when interacting with the content outlined in this performance indicator. For further information please see SEP Support Guide at:
https://ed.sc.gov/scdoe/assets/File/instruction/standards/Science/Support%20Documents/Complete_2014SEPsGuide_SupportDoc2_0.pdf

Learning Connections	**Previous Learning Connections (6-8):** **7.L.4A.3** Develop and use models (Punnett squares) to describe and predict patterns of the inheritance of single genetic traits from parent to offspring (including dominant and recessive traits, incomplete dominance, and codominance). **7.L.4A.4** Use mathematical and computational thinking to predict the probability of phenotypes and genotypes based on patterns of inheritance.

Heredity: Inheritance and Variation of Traits

Standard H.B.4. The student will demonstrate an understanding of the specific mechanisms by which characteristics or traits are transferred from one generation to the next via genes.	
H.B.4C. Conceptual Understanding: Sex cells are formed by a process of cell division in which the number of chromosomes per cell is halved after replication. With the exception of sex chromosomes, for each chromosome in the body cells of a multicellular organism, there is a second similar, but not identical, chromosome. Although these pairs of similar chromosomes can carry the same genes, they may have slightly different alleles. During meiosis the pairs of similar chromosomes may cross and trade pieces. One chromosome from each pair is randomly passed on to form sex cells resulting in a multitude of possible genetic combinations. The cell produced during fertilization has one set of chromosomes from each parent.	
Performance Indicator	**H.B.4C.3** Construct explanations for how meiosis followed by fertilization ensures genetic variation among offspring within the same family and genetic diversity within populations of sexually reproducing organisms.
Science and Engineering Practice	**H.B.1A.6** Construct explanations of phenomena using (1) primary or secondary scientific evidence and models, (2) conclusions from scientific investigations, (3) predictions based on observations and measurements, or (4) data communicated in graphs, tables, or diagrams.
Crosscutting Concepts	The following Crosscutting Concepts may be applied to the content of the indicator. For more information see page 6. Cause and Effect Scale, Proportion, and Quantity Systems and System Models Structure and Function

Essential Learning Experiences:
It is essential for students to construct explanations for how meiosis, followed by fertilization, increases genetic variation among offspring and within a population.

Populations of sexually reproducing species generally have much greater genetic diversity than do populations of asexually reproducing species.
Sexual reproduction requires the fusion of gametes (fertilization) and uses the process of meiosis to create haploid gametes. Offspring produced by sexual reproduction are different from the parents because new gene combinations result from fertilization followed by the process of meiosis (See H.B.4C.1).

NOTE TO TEACHER: Indicators H.B.4C.1, C.2 & C.3 may be utilized as a collective to address the larger concept.

Extended Learning Experiences:
Students could construct explanations regarding how asexual reproduction results in genetically diverse populations.

- Asexual reproduction does not involve the union of gametes (fertilization) and, therefore, only one parent produces offspring that are genetically identical to the parent.
    - Asexual reproduction is accomplished by cell division: binary fission in prokaryotes and mitosis in eukaryotes.
    - Examples of asexual reproduction are budding, fragmentation, and vegetative propagation.
    - Genetic variability can occur only through mutations in the DNA passed from parent to offspring.
- The asexual reproduction rate is much higher than sexual reproduction, so mutation, though rare, can produce genetic diversity in an asexually reproducing population.

Assessment Guidelines:
Students should engage in multiple science and engineering practices when interacting with the content outlined in this performance indicator. For further information please see SEP Support Guide at:
https://ed.sc.gov/scdoe/assets/File/instruction/standards/Science/Support%20Documents/Complete_2014SEPsGuide_SupportDoc2_0.pdf

Learning Connections	**Previous Learning Connections (6-8):** **7.L.4A.3** Develop and use models (Punnett squares) to describe and predict patterns of the inheritance of single genetic traits from parent to offspring (including dominant and recessive traits, incomplete dominance, and codominance). **7.L.4A.4** Use mathematical and computational thinking to predict the probability of phenotypes and genotypes based on patterns of inheritance.

Heredity: Inheritance and Variation of Traits

Standard H.B.4. The student will demonstrate an understanding of the specific mechanisms by which characteristics or traits are transferred from one generation to the next via genes.	
H.B.4D. Conceptual Understanding: Imperfect transmission of genetic information may have positive, negative, or no consequences to the organism. DNA replication is tightly regulated and remarkably accurate, but errors do occur and result in mutations which (rarely) are a source of genetic variation.	
Performance Indicator	**H.B.4D.1** Develop and use models to explain how mutations in DNA that occur during replication (1) can affect the proteins that are produced or the traits that result and (2) may or may not be inherited.
Science and Engineering Practice	**H.B.1A.2** Develop, use, and refine models to (1) understand or represent phenomena, processes, and relationships, (2) test devices or solutions, or (3) communicate ideas to others.
Crosscutting Concepts	The following Crosscutting Concepts may be applied to the content of the indicator. For more information see page 6. Cause and Effect Scale, Proportion, and Quantity Systems and System Models Structure and Function

Essential Learning Experiences:
It is essential for students to develop and use models to explain how mutations in DNA affect the proteins that are produced and to communicate how a mutation may or may not have an affect on an organism.

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 processes of mitosis or 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 can be passed to all subsequent daughter cells of the mutant cell, which may have negative, positive or no consequences for the cell, organism, or 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 offspring 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 nucleotide base pair in the gene that codes for one of the proteins of hemoglobin.
        - Other examples of genetic disorders caused by gene mutations are Tay-Sachs disease, Huntington's disease, Cystic fibrosis, Hemophilia A or albinism.

    - If the mutation affects a group of genes or an entire chromosome, it is known as a chromosomal mutation.
        - Malfunction during meiosis can result in a gamete with an abnormal number of chromosomes.
        - Examples of abnormalities in humans due to an abnormal number of sex chromosomes are Klinefelter's syndrome (male; XXY genotype) and Turner's syndrome (female; missing or structurally altered X).
        - An example of an abnormality in humans due to an abnormal number of autosomal chromosomes (refer to H.B.4A.1)is Down's 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 will eventually increase in frequency in a population.

- Gene mutations that occur during replication may or may not affect the production or function of the protein for which the gene codes.
    - A point mutation is the substitution, addition, or removal of a single nucleotide.
    - In a substitution mutation, one nucleotide replaces another.
        - The new codon may or may not signal the insertion of the wrong amino acid.
        - Sometimes the insertion of the wrong amino acid does not affect protein function because the change does not significantly alter the protein's structure (shape).
    - The deletion or addition or a nucleotide causes all subsequent codons to be misread (frameshift mutation) so are likely to have a disastrous effect on the protein's function.

Extended Learning Experiences:
Students may analyze and interpret data to explain:
- the exact characteristics of the nondisjunction mutation abnormalities listed above, and
- the mechanism through which somatic mutations can cause various cancers.

Assessment Guidelines:
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Learning Connections	**Previous Learning Connections (6-8):** **7.L.4A.5** Construct scientific arguments using evidence to support claims for how changes in genes (mutations) may have beneficial, harmful, or neutral effects on organisms.

Evolution

Standard H.B.5 The student will demonstrate an understanding of biological evolution and the diversity of life.	
H.B.5. Conceptual Understanding: H.B.5 is derived from 2005 B-5 which had no conceptual understanding.	
Performance Indicator	**H.B.5.1:** Summarize the process of natural selection.
Science and Engineering Practice	**H.B.1A.6:** Construct explanations of phenomena using (1) primary or secondary scientific evidence and models, (2) conclusions from scientific investigations, (3) predictions based on observations and measurements, or (4) data communicated in graphs, tables, or diagrams.
Crosscutting Concepts	The following Crosscutting Concepts may be applied to the content of the indicator. For more information see page 6. Patterns Cause and Effect

Essential Learning Experiences:
It is essential for students to construct explanations of the process and theory of natural selection.

Biological evolution is a scientific framework that analyzes how heritable traits change in frequency within a population over time. These traits include physical characteristics (morphology), molecular sequences (genetic and proteomic), and behavioral traits to describe changes that have transformed life on Earth from the earliest beginnings to the diversity of organisms in the world today. Biological evolution is a unifying theme of biology and may occur on a small time and spatial scale affecting the gene pool of a single population (microevolution) or when those small changes accumulate over vast lengths of time producing noticeable changes in species (macroevolution).

One mechanism that produces biological evolution is natural selection. Other mechanisms include nonrandom mating, genetic drift, mutation and gene flow (see H.B.5.4). Natural selection results in changes in frequency in the inherited traits of a population over time and occurs when different traits of the individual members of a population result in those organisms dealing either more or less effectively with the current environment than the other members of the population. In comparison, artificial selection is when humans select which traits are preferred and intentionally breed organisms for a particular set of characteristics (e.g. how modern dog breeds such as the Great Dane or the Chihuahua were developed from their wolf ancestors). In the case of natural selection, if the environment remains stable for multiple generations, a population's fitness (the ability of organisms to survive and reproduce) will increase over time as those advantageous traits become more and more common and honed. If the environment changes however, then different traits are likely to be advantageous. There are four prerequisites that must be in place in order for natural selection to occur:

1. Overproduction of Offspring
   - Most species produce more offspring than the environment can support, so some individuals will not be able to reach their full potential for reproduction.
   - The ability of a population to produce many offspring raises the chance that some will survive but also increases the competition for resources.
2. Variation
   - Fundamental to the process of natural selection is genetic variation upon which selective forces can act in order for evolution to occur.
   - Within every population, there are inherited traits that show variability among individuals.
   - This variation is seen in the different phenotypes (body structures and characteristics) of the individuals within a 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 determined by the organism's genotype and by 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.
3. 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.
     - Individuals with inherited traits that are beneficial in that environment become more common.
     - As each generation progresses, those organisms that carry genes that hinder their ability to meet day to day needs become less and less common 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.
4. 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 and therefore, 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.

Extended Learning Experiences:
Students may obtain, communicate, and evaluate

- The history of the significant scientific contributions to the study of natural selection and also compare different types of natural selection (directional, stabilizing, disruptive, and sexual).

Assessment Guidelines:
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https://ed.sc.gov/scdoe/assets/File/instruction/standards/Science/Support%20Documents/Complete_2014SEPsGuide_SupportDoc2_0.pdf

Learning Connections	**Previous Learning Connections (6-8):** **7.L.4A.1** Obtain and communicate information about the relationship between genes and chromosomes to construct explanations of their relationship to inherited characteristics.

Evolution

Standard H.B.5. The student will demonstrate an understanding of biological evolution and the diversity of life.	
H.B.5 Conceptual Understanding: is derived from 2005 B-5 which had no conceptual understanding.	
Performance Indicator	**H.B.5.2:** Explain how genetic processes result in the continuity of life-forms over time.
Science and Engineering Practice	**H.B.1A.8:** Obtain and evaluate scientific information to (1) answer questions, (2) explain or describe phenomena, (3) develop models, (4) evaluate hypotheses, explanations, claims, or designs or (5) identify and/or fill gaps in knowledge. Communicate using the conventions and expectations of scientific writing or oral presentations by (1) evaluating grade-appropriate primary or secondary scientific literature, or (2) reporting the results of student experimental investigations.
Crosscutting Concepts	The following Crosscutting Concepts may be applied to the content of the indicator. For more information see page 6. Stability and Change

Essential Learning Experiences:
It is essential for students to explain how sexual and asexual reproduction and the synthesis of nucleic acids and proteins result in the continuity of life-forms over time.

The continuity of lifeforms 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. The continuity of life forms over time is due to the genetic processes
that all organisms share.

- All living things that have ever existed on Earth, share at least two structures:
  (1) Nucleic acids (RNA or DNA) that carry the genetic code for the synthesis of the organism's proteins
  (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. In general, the same sequences of nucleotides code for the same specific amino acids.

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

Sexual Reproduction

In sexual reproduction, two parents contribute genetic information to produce unique offspring. Sexual reproduction uses the processes of meiosis (to create gametes) and fertilization to produce offspring that have new combinations of alleles that are different from those of the parents.

- Sexual reproduction is an important source of genetic variation among individuals within a population.
- The inheritance of allele combinations that result in traits that improve an individual's chance of survival or reproduction ensures the continuity of that life form over time.

Asexual Reproduction

Asexual reproduction generates offspring that are genetically identical to a single parent.

- Examples of asexual reproduction are budding, fragmentation, and vegetative propagation.
- The asexual reproduction rate is much higher than sexual reproduction and produces many individual 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 become extinct.

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.

Extended Learning Experiences:

- Students may develop and use models to illustrate examples of sexual and asexual life cycles.

Assessment Guidelines:

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https://ed.sc.gov/scdoe/assets/File/instruction/standards/Science/Support%20Documents/Complete_2014SEPsGuide_SupportDoc2_0.pdf

Learning Connections	**Previous Learning Connections (6-8):** **6.L.4A.1** Obtain and communicate information to support claims that living organisms (1) obtain and use resources for energy, (2) respond to stimuli, (3) reproduce, and (4) grow and develop. **7.L.3A.1** Obtain and communicate information to support claims that (1) organisms are made of one or more cells, (2) cells are the basic unit of structure and function of organisms, and (3) cells come only from existing cells.

Evolution

Standard H.B.5. The student will demonstrate an understanding of biological evolution and the diversity of life.	
H.B.5 Conceptual Understanding: is derived from 2005 B-5 which had no conceptual understanding.	
Performance Indicator	**H.B.5.3:** Explain how diversity within a species increases the chances of survival.
Science and Engineering Practice	**H.B.1A.8:** Obtain and evaluate scientific information to (1) answer questions, (2) explain or describe phenomena, (3) develop models, (4) evaluate hypotheses, explanations, claims, or designs or (5) identify and/or fill gaps in knowledge. Communicate using the conventions and expectations of scientific writing or oral presentations by (1) evaluating grade-appropriate primary or secondary scientific literature, or (2) reporting the results of student experimental investigations.
Crosscutting Concepts	The following Crosscutting Concepts may be applied to the content of the indicator. For more information see page 6. Scale, Proportion, and Quantity Stability and Change

Essential Learning Experiences:
It is essential for students to explain how variation within populations increases the chances of survival.

A species is a population or group of populations whose members have the potential to interbreed and produce fertile offspring in nature.

- Because of interbreeding among individuals, species share a common gene pool (all genes, including all the different alleles, possessed by 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, variability of phenotypic traits leads to diversity among individuals of the species. The greater the diversity within a population or species, the greater the chances are for that population or species to survive 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.
- 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.

Extended Learning Experiences:

- Students may also obtain, communicate, and evaluate information regarding speciation and reproductive isolation.

Assessment Guidelines:
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https://ed.sc.gov/scdoe/assets/File/instruction/standards/Science/Support%20Documents/Complete_2014SEPsGuide_SupportDoc2_0.pdf

Learning Connections	**Previous Learning Connections (6-8):** **7.L.4A.1** Obtain and communicate information about the relationship between genes and chromosomes to construct explanations of their relationship to inherited characteristics.

Evolution

Standard H.B.5: The student will demonstrate an understanding of biological evolution and the diversity of life.	
H.B.5 Conceptual Understanding: is derived from 2005 B-5 which had no conceptual understanding.	
Performance Indicator	**H.B.5.4:** Explain how genetic variability and environmental factors lead to biological evolution.
Science and Engineering Practice	**H.B.1A.8:** Obtain and evaluate scientific information to (1) answer questions, (2) explain or describe phenomena, (3) develop models, (4) evaluate hypotheses, explanations, claims, or designs or (5) identify and/or fill gaps in knowledge. Communicate using the conventions and expectations of scientific writing or oral presentations by (1) evaluating grade-appropriate primary or secondary scientific literature, or (2) reporting the results of student experimental investigations.
Crosscutting Concepts	The following Crosscutting Concepts may be applied to the content of the indicator. For more information see page 6. Cause and Effect Stability and Change

Essential Learning Experiences:
It is essential for students to explain or describe factors that influence genetic variability within a population and to obtain and evaluate scientific information on environmental factors that lead to biological evolution.

Genetic variation is random and ensures that each new generation results in individuals with unique genotypes and phenotypes. This genetic variability is a prerequisite 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.
- Mutations increase the frequencies and types of allele changes within the population.

- Natural selection allows for the most favorable phenotypes to survive and thus be passed onto future generations.

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 by biological evolution from a preexisting species.

- New species may 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 fertile offspring. At this point the two groups are by definition different species.

Some observed patterns of macroevolution are:

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.

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 suddenly (such as a massive volcanic eruption, or a meteor hitting the earth causing climatic changes). It is often impossible for a species to adapt to rapid and extreme environmental changes.

Extended Learning Experiences:
Students may also

- use mathematical and computational thinking to calculate allele frequencies for a particular sample of a population using the precepts of Hardy-Weinberg equilibrium and explore the concept of convergent evolution.

Assessment Guidelines:
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Learning Connections	**Previous Learning Connections (6-8):** **8.E.6A.1** Develop and use models to organize Earth's history (including era, period, and epoch) according to the geologic time scale using evidence from rock layers. **8.E.6A.2** Analyze and interpret data from index fossil records and the ordering of rock layers to infer the relative age of rocks and fossils. **8.E.6A.3** Construct explanations from evidence for how catastrophic events (including volcanic activities, earthquakes, climatic changes, and the impact of an asteroid/comet) may have affected the conditions on Earth and the diversity of its life forms. **8.E.6A.4** Construct and analyze scientific arguments to support claims that different types of fossils provide evidence of (1) the diversity of life that has been present on Earth, (2) relationships between past and existing life forms, and (3) environmental changes that have occurred during Earth's history. **8.E.6A.5** Construct explanations for why most individual organisms, as well as some entire taxonomic groups of organisms, that lived in the past were never fossilized. **8.E.6B.1** Construct explanations for how biological adaptations and genetic variations of traits in a population enhance the probability of survival in a particular environment. **8.E.6B.2** Obtain and communicate information to support claims that natural and human-made factors can contribute to the extinction of species.

Evolution

Standard H.B.5: The student will demonstrate an understanding of biological evolution and the diversity of life.	
H.B.5 Conceptual Understanding: is derived from 2005 B-5 which had no conceptual understanding.	
Performance Indicator	**H.B.5.5:** Exemplify scientific evidence in the fields of anatomy, embryology, biochemistry, and paleontology that underlies the theory of biological evolution.
Science and Engineering Practice	**H.B.1A.6:** Construct explanations of phenomena using (1) primary or secondary scientific evidence and models, (2) conclusions from scientific investigations, (3) predictions based on observations and measurements, or (4) data communicated in graphs, tables, or diagrams.
Crosscutting Concepts	The following Crosscutting Concepts may be applied to the content of the indicator. For more information see page 6. Patterns Stability and Change

Essential Learning Experiences:
It is essential for students to exemplify scientific evidence from different fields of science that contributed to the theory of evolution.

Scientific studies in the fields of anatomy, embryology, biochemistry, and paleontology have all 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 consider homologous structures as evidence of an evolutionary relationship between two groups of organisms (for example two species or two families).
    - Organisms that have diverged from a common ancestor often have homologous structures (similar characteristics resulting from common ancestry). The greater the numbers of shared homologous 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 for which the structure has remained functional.

- The study of the anatomy also reveals that species living in different locations under similar ecological conditions may evolve similar structures and behaviors. Such structures, called analogous structures, are not evidence of evolution because they do not result from shared ancestry.

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 evidence of life forms and environments along a timeline and supports evolutionary relationships by showing the similarities between current species and ancient species.
- 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.
- In general, the older the fossils, the less resemblance there is to modern species.

Extended Learning Experiences:

Students may also

- construct explanations of the process of relative, absolute, or radiometric dating or explanations of how fossils are formed..

Assessment Guidelines:
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Learning Connections	**Previous Learning Connections (6-8):** **8.E.6A.1** Develop and use models to organize Earth's history (including era, period, and epoch) according to the geologic time scale using evidence from rock layers. **8.E.6A.2** Analyze and interpret data from index fossil records and the ordering of rock layers to infer the relative age of rocks and fossils. **8.E.6A.3** Construct explanations from evidence for how catastrophic events (including volcanic activities, earthquakes, climatic changes, and the impact of an asteroid/comet) may have affected the conditions on Earth and the diversity of its life forms. **8.E.6A.4** Construct and analyze scientific arguments to support claims that different types of fossils provide evidence of (1) the diversity of life that has been present on Earth, (2) relationships between past and existing life forms, and (3) environmental changes that have occurred during Earth's history. **8.E.6A.5** Construct explanations for why most individual organisms, as well as some entire taxonomic groups of organisms, that lived in the past were never fossilized. **8.E.6B.1** Construct explanations for how biological adaptations and genetic variations of traits in a population enhance the probability of survival in a particular environment. **8.E.6B.2** Obtain and communicate information to support claims that natural and human-made factors can contribute to the extinction of species.

Evolution

Standard H.B.5: The student will demonstrate an understanding of biological evolution and the diversity of life.	
H.B.5 Conceptual Understanding: is derived from 2005 B-5 which had no conceptual understanding.	
Performance Indicator	**H.B.5.6:** Summarize ways that scientists use data from a variety of sources to investigate and critically analyze aspects of evolutionary theory.
Science and Engineering Practice	**H.B.1A.7:** Construct and analyze scientific arguments to support claims, explanations, or designs using evidence and valid reasoning from observations, data, or informational texts.
Crosscutting Concepts	The following Crosscutting Concepts may be applied to the content of the indicator. For more information see page 6. Scale, Proportion, and Quantity Stability and Change

Essential Learning Experiences:
It is essential for students to summarize ways scientists use data from different fields of science to critically analyze aspects of evolutionary theory.

Scientists study data from a variety of fields to determine the phylogeny (evolutionary history) of a species or a group of related species. The central ideas of evolution are that life has a history — has changed over time — and that different species share common ancestors.
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 2005 B-5.7)
    - Anatomical structures that share a common evolutionary history but not necessarily the same function are termed homologous. (see 2005 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.
    - 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 2005 B-5.4)

Field of Embryology:

- By comparing characteristics of embryonic development, scientists are able to compare anatomical structures to construct phylogeny.

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.
    - Different assumptions about the details of molecular evolution can yield different phylogenetic trees. (see 2005 B-5.7)
    - Natural selection can cause convergence in molecules, just as it causes convergence in anatomical structures. (see 2005 B-5.1)

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.
    - Fossils that allow scientists to fill gaps in the record are continually being discovered.

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-documented 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.

Extended Learning Experiences:
Students may also:

- use mathematical and computational thinking to calculate allele frequencies for a particular sample of a population using the precepts of Hardy-Weinberg equilibrium and explore the concept of convergent evolution.

Assessment Guidelines:
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https://ed.sc.gov/scdoe/assets/File/instruction/standards/Science/Support%20Documents/Complete_2014SEPsGuide_SupportDoc2_0.pdf

Learning Connections	**Previous Learning Connections (6-8):** **8.E.6A.1** Develop and use models to organize Earth's history (including era, period, and epoch) according to the geologic time scale using evidence from rock layers. **8.E.6A.2** Analyze and interpret data from index fossil records and the ordering of rock layers to infer the relative age of rocks and fossils. **8.E.6A.3** Construct explanations from evidence for how catastrophic events (including volcanic activities, earthquakes, climatic changes, and the impact of an asteroid/comet) may have affected the conditions on Earth and the diversity of its life forms. **8.E.6A.4** Construct and analyze scientific arguments to support claims that different types of fossils provide evidence of (1) the diversity of life that has been present on Earth, (2) relationships between past and existing life forms, and (3) environmental changes that have occurred during Earth's history. **8.E.6A.5** Construct explanations for why most individual organisms, as well as some entire taxonomic groups of organisms, that lived in the past were never fossilized. **8.E.6B.1** Construct explanations for how biological adaptations and genetic variations of traits in a population enhance the probability of survival in a particular environment. **8.E.6B.2** Obtain and communicate information to support claims that natural and human-made factors can contribute to the extinction of species.

Evolution

Standard H.B.5: The student will demonstrate an understanding of biological evolution and the diversity of life.	
H.B.5 Conceptual Understanding: is derived from 2005 B-5 which had no conceptual understanding.	
Performance Indicator	**H.B.5.7:** Use a phylogenetic tree to identify the evolutionary relationships among different groups of organisms.
Science and Engineering Practice	**H.B.1A.2:** Develop, use, and refine models to (1) understand or represent phenomena, processes, and relationships, (2) test devices or solutions, or (3) communicate ideas to others.
Crosscutting Concepts	The following Crosscutting Concepts may be applied to the content of the indicator. For more information see page 6. Cause and Effect Stability and Change

Essential Learning Experiences:
It is essential for students to develop and use phylogenetic tree to understand the evolutionary relationships among different groups of organisms.

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.

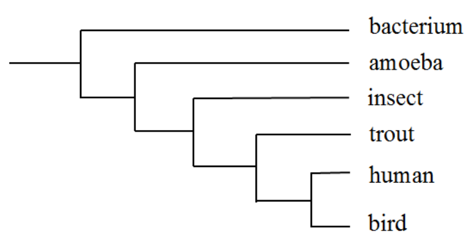

Figure 15. Phylogenic (SCDE, 2018).

- 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.

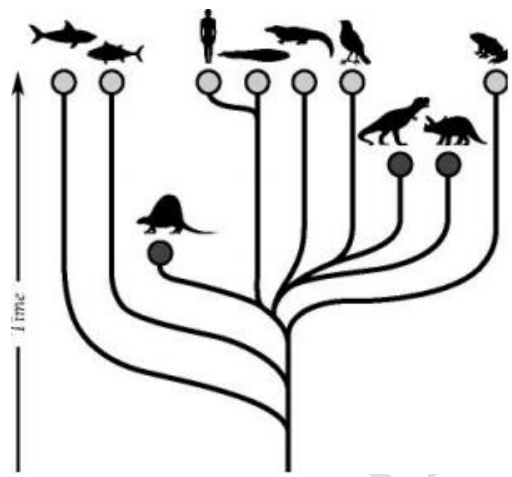

Figure 16. Phylogenic with Time (SCDE, 2005).

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?

One of the main challenges to the classification of the Earth's biodiversity is that 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. Additionally, information gained from DNA sequencing has contributed to many revisions of phylogenetic hypotheses.

The most recent classification scheme includes;
- Three domains (Bacteria, Archaea, and Eukarya)
- Six kingdoms (Eubacteria, Archaebacteria, Protista, Fungi, Plantae, and Animalia).

Extended Learning Experiences:
Students may also:
- use mathematical and computational thinking to calculate allele frequencies for a particular sample of a population using the precepts of Hardy-Weinberg equilibrium and explore the concept of convergent evolution.

Assessment Guidelines:
Students should engage in multiple science and engineering practices when interacting with the content outlined in this performance indicator. For further information please see SEP Support Guide at:
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Learning Connections	**Previous Learning Connections (6-8):** **8.E.6A.1** Develop and use models to organize Earth's history (including era, period, and epoch) according to the geologic time scale using evidence from rock layers. **8.E.6A.2** Analyze and interpret data from index fossil records and the ordering of rock layers to infer the relative age of rocks and fossils. **8.E.6A.3** Construct explanations from evidence for how catastrophic events (including volcanic activities, earthquakes, climatic changes, and the impact of an asteroid/comet) may have affected the conditions on Earth and the diversity of its life forms. **8.E.6A.4** Construct and analyze scientific arguments to support claims that different types of fossils provide evidence of (1) the diversity of life that has been present on Earth, (2) relationships between past and existing life forms, and (3) environmental changes that have occurred during Earth's history. **8.E.6A.5** Construct explanations for why most individual organisms, as well as some entire taxonomic groups of organisms, that lived in the past were never fossilized. **8.E.6B.1** Construct explanations for how biological adaptations and genetic variations of traits in a population enhance the probability of survival in a particular environment. **8.E.6B.2** Obtain and communicate information to support claims that natural and human-made factors can contribute to the extinction of species. **Earth Science Learning Connections:** **H.E.3B.4** Obtain and evaluate available data on a current controversy regarding human activities which may affect the frequency, intensity, or consequences of natural hazards. **H.E.4A.3** Construct explanations of how changes to Earth's surface are related to changes in the complexity and diversity of life using evidence from the geologic time scale. **H.E.4A.4** Obtain and evaluate evidence from rock and fossil records and ice core samples to support claims that Earth's environmental conditions have changed over time. **H.E.4A.5** Develop and use models of various dating methods (including index fossils, ordering of rock layers, and radiometric dating) to estimate geologic time.

Ecosystem Dynamics

Standard H.B.6: The student will demonstrate an understanding that ecosystems are complex, interactive systems that include both biological communities and physical components of the environment.	
H.B.6A Conceptual Understanding: Ecosystems have carrying capacities, which are limits to the numbers of organisms and populations they can support. Limiting factors include the availability of biotic and abiotic resources and challenges such as predation, competition, and disease.	
Performance Indicator	**H.B.6A.1:** Analyze and interpret data that depict changes in the abiotic and biotic components of an ecosystem over time or space (such as percent change, average change, correlation and proportionality) and propose hypotheses about possible relationships between the changes in the abiotic components and the biotic components of the environment.
Science and Engineering Practice	**H.B.1A.4:** Analyze and interpret data from informational texts and data collected from investigations using a range of methods (such as tabulation, graphing, or statistical analysis) to (1) reveal patterns and construct meaning, (2) support or refute hypotheses, explanations, claims, or designs, or (3) evaluate the strength of conclusions.
Crosscutting Concepts	The following Crosscutting Concepts may be applied to the content of the indicator. For more information see page 6. Scale, Proportion, and Quantity Stability and Change

Essential Learning Experiences:
It is essential for students to analyze and interpret data from texts and data collected from investigations that depict changes in the biotic (living) and abiotic (nonliving) components of an ecosystem over time.

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.

- The number of organisms in ecosystems fluctuates over time as a result of mechanisms such as migration, birth and death. These fluctuations are essential for ecosystem stability and characterize the dynamic nature of ecosystems.
- Extreme fluctuations in the size of populations offset the stability of ecosystems in terms of habitat and resource availability.
- Ecosystems can be reasonably stable over hundreds or thousands of years. If a disturbance to the biotic or abiotic components of an ecosystem occurs, the affected ecosystem may return to a system similar to the original one, or it may take a new direction and become a very different type of ecosystem.

- Ecosystems are not always stable over short periods of time. Changes in climate, migration of an invading species, and human activity can impact the stability of an ecosystem. Other changes that may impact the stability of an ecosystem include interactions among living organisms such as competition, predation, parasitism and disease (see H.B.6.A.2).
- A change in an abiotic or biotic factor may decrease the size of a population if the population 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.

A stable ecosystem is one in which:

- 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.

Extended Learning Experiences:
Students may also

- engage in scientific arguments from evidence regarding the biogeographic factors that affect the biodiversity of communities.

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https://ed.sc.gov/scdoe/assets/File/instruction/standards/Science/Support%20Documents/Complete_2014SEPsGuide_SupportDoc2_0.pdf

Learning Connections	**Previous Learning Connections (6-8):** **6. L.4B.2** Obtain and communicate information to explain how the structural adaptations and processes of animals allow for defense, movement, or resource obtainment. **6.L.4B.3** Construct explanations of how animal responses (including hibernation, migration, grouping, and courtship) to environmental stimuli allow them to survive and reproduce. **7.EC.5A.1** Develop and use models to describe the characteristics of the levels of organization within ecosystems (including species, populations, communities, ecosystems, and biomes). **7.EC.5A.2** Construct explanations of how soil quality (including composition, texture, particle size, permeability, and pH) affects the characteristics of an ecosystem using evidence from soil profiles. **7.EC.5A.3** Analyze and interpret data to predict changes in the number of organisms within a population when certain changes occur to the physical environment (such as changes due to natural hazards or limiting factors).

	Earth Science Learning Connections: **H.E.5A.8** Analyze scientific arguments regarding the nature of the relationship between human activities and climate change. **H.E.6A.4** Analyze and interpret data of a local drainage basin to predict how changes caused by human activity and other factors influence the hydrology of the basin and amount of water available for use in the ecosystem. H.E.3B.1 Obtain and communicate information to explain how the formation, availability, and use of ores and fossil fuels impact the environment. **H.E.3B.2** Construct scientific arguments to support claims that responsible management of natural resources is necessary for the sustainability of human societies and the biodiversity that supports them. **H.E.3B.3** Analyze and interpret data to explain how natural hazards and other geologic events have shaped the course of human history. **H.E.3B.4** Obtain and evaluate available data on a current controversy regarding human activities which may affect the frequency, intensity, or consequences of natural hazards. **H.E.3B.5** Define problems caused by the impacts of locally significant natural hazards and design possible devices or solutions to reduce the impacts of such natural hazards on human activities.

Ecosystem Dynamics

Standard H.B.6: The student will demonstrate an understanding that ecosystems are complex, interactive systems that include both biological communities and physical components of the environment.	
H.B.6A: Ecosystems have carrying capacities, which are limits to the numbers of organisms and populations they can support. Limiting factors include the availability of biotic and abiotic resources and challenges such as predation, competition, and disease.	
Performance Indicator	**H.B.6A.2:** Use mathematical and computational thinking to support claims that limiting factors affect the number of individuals that an ecosystem can support.
Science and Engineering Practice	**H.B.1A.5:** Use mathematical and computational thinking to (1) use and manipulate appropriate metric units, (2) express relationships between variables for models and investigations, and (3) use grade-level appropriate statistics to analyze data.
Crosscutting Concepts	The following Crosscutting Concepts may be applied to the content of the indicator. For more information see page 6. Cause and Effect

Essential Learning Experiences:
It is essential for students to use mathematical and computational thinking to identify and support claims that limiting factors affect the number of individuals that an ecosystem can support.

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 is calculated by dividing the number of individuals in a population by the unit area. The size of a population is affected by the number of births, the number of deaths, and the number of individuals that enter or leave the population.

Any factor that slows population growth is called a limiting factor. Population growth is regulated by limiting factors that can be density- dependent, density-independent, abiotic or biotic.

Density-dependent factors

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

Density-independent factors

- Limiting factors that are density-independent are those that occur regardless of how dense (crowded) the population may be. These factors 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, pollution, and natural disasters (such as fires or floods).

Carrying capacity

- Carrying capacity is the maximum number of individuals that the environment can support over a long period of time without harming the environment

Population Growth Models

The exponential growth model describes a population that grows at a constantly increasing rate. A graph of exponential growth has a characteristic J-shape. In real populations exponential growth occurs only for limited periods of time when conditions are optimal and resources are unlimited.

The logistic growth model includes the influence of limiting factors on population growth. A graph of logistic population growth has a characteristic S-shape. For example, if food or space becomes limited, a population may exhibit logistic growth following a period of exponential growth.

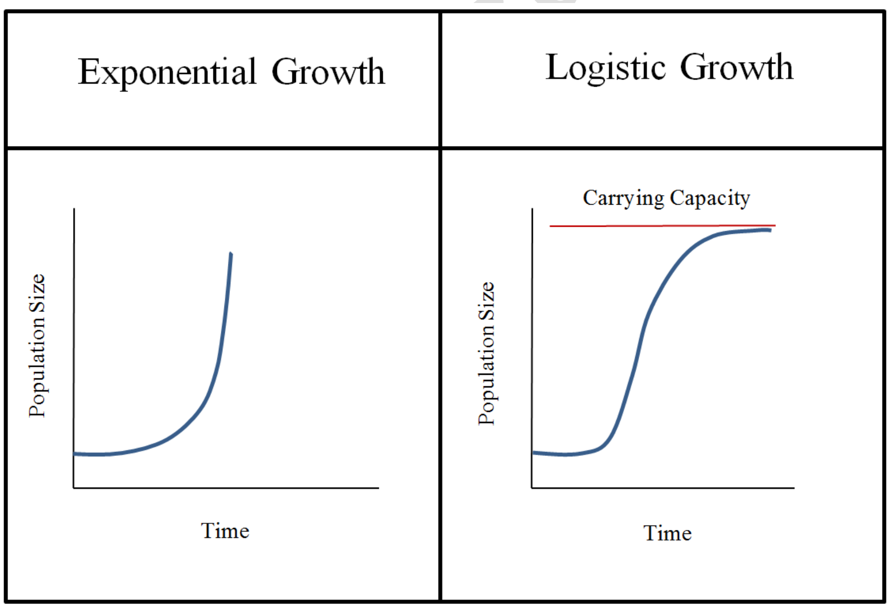

Figure 17. Growth (SCDE 2018).

Extended Learning Experiences:

Students may also

- use mathematical and computational thinking to interpret human population growth and age structure diagrams.

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https://ed.sc.gov/scdoe/assets/File/instruction/standards/Science/Support%20Documents/Complete_2014SEPsGuide_SupportDoc2_0.pdf

Learning Connections	**Previous Learning Connections (6-8):** **6.L.4B.3** Construct explanations of how animal responses (including hibernation, migration, grouping, and courtship) to environmental stimuli allow them to survive and reproduce. **6.L.4B.4** Obtain and communicate information to compare and classify innate and learned behaviors in animals. **6.L.5A.1** Analyze and interpret data from observations to compare how the structures of protists (including euglena, paramecium, and amoeba) and fungi allow them to obtain energy and explore their environment. **7.EC.5A.1** Develop and use models to describe the characteristics of the levels of organization within ecosystems (including species, populations, communities, ecosystems, and biomes). **7.EC.5A.3** Analyze and interpret data to predict changes in the number of organisms within a population when certain changes occur to the physical environment (such as changes due to natural hazards or limiting factors). **7.EC.5B.1** Develop and use models to explain how organisms interact in a competitive or mutually beneficial relationship for food, shelter, or space (including competition, mutualism, commensalism, parasitism, and predator-prey relationships). **7.EC.5B.2** Develop and use models (food webs and energy pyramids) to exemplify how the transfer of energy in an ecosystem supports the concept that energy is conserved. **7.EC.5B.3** Analyze and interpret data to predict how changes in the number of organisms of one species affects the balance of an ecosystem. **7.EC.5B.4** Define problems caused by the introduction of a new species in an environment and design devices or solutions to minimize the impact(s) to the balance of an ecosystem. **Earth Science Learning Connections** **H.E.3B.3** Analyze and interpret data to explain how natural hazards and other geologic events have shaped the course of human history. **H.E.3B.4** Obtain and evaluate available data on a current controversy regarding human activities which may affect the frequency, intensity, or consequences of natural hazards. **H.E.3B.5** Define problems caused by the impacts of locally significant natural hazards and design possible devices or solutions to reduce the impacts of such natural hazards on human activities.

Ecosystem Dynamics

<table>
<tr><td colspan="2">Standard H.B.6: The student will demonstrate an understanding that ecosystems are complex, interactive systems that include both biological communities and physical components of the environment.</td></tr>
<tr><td colspan="2">H.B.6B Conceptual Understanding: Photosynthesis and cellular respiration are important components of the carbon cycle, in which carbon is exchanged between the biosphere, atmosphere, oceans, and geosphere through chemical, physical, geological, and biological processes.</td></tr>
<tr><td>Performance Indicator</td><td>H.B.6B.1: <u>Develop and use models </u>of the carbon cycle, which include the interactions between photosynthesis, cellular respiration and other processes that release carbon dioxide, to evaluate the effects of increasing atmospheric carbon dioxide on natural and agricultural ecosystems.</td></tr>
<tr><td>Science and Engineering Practice</td><td>H.B.1A.2: <u>Develop, use, and refine models</u> to (1) understand or represent phenomena, processes, and relationships, (2) test devices or solutions, or (3) communicate ideas to others.</td></tr>
<tr><td>Crosscutting Concepts</td><td>The following Crosscutting Concepts may be applied to the content of the indicator. For more information see page 6.

Energy and Matter
Stability and Change</td></tr>
</table>

Essential Learning Experiences:
It is essential for students to develop and use models of the carbon cycle to evaluate the effects of increasing atmospheric carbon dioxide on natural and agricultural ecosystems.

All living systems need matter and energy. As energy and matter flow through an ecosystem, matter must be recycled and reused. The cycling of matter and the flow of energy within ecosystems occur through interactions among different organisms and between organisms and the physical environment. Matter fuels the energy releasing chemical reactions that provide energy for life functions and provides the material for growth and repair of tissue.

The carbon cycle provides an example of the cycling of matter and the flow of energy in ecosystems. Photosynthesis, digestion of plant matter, respiration, and decomposition are important components of the carbon cycle, in which carbon is exchanged between the biosphere, atmosphere, oceans, and geosphere through chemical, physical, geological, and biological processes.

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, 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.
  - Respiration: organisms break down glucose and carbon is released into the atmosphere as carbon dioxide.
  - Decomposition: when organisms die, decomposers break down carbon compounds that both enrich the soil or aquatic sediments; these compounds are eventually released into the atmosphere as carbon dioxide.
  - Conversion of biochemical compounds: organisms store carbon in organic molecules such as carbohydrates, proteins, lipids, and nucleic acids. For example, when consumers eat plants and/or animals, some of the compounds are used for energy; others are converted to compounds that are incorporated into the consumer's body. Still 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.

Effects of increasing atmospheric carbon dioxide on natural and agricultural ecosystems

- The warming effects of increasing CO2 and other greenhouse gases impact a variety of environmental variables in both natural and agricultural systems.
- Higher temperatures and shifting climate patterns may change the areas where crops grow best and affect the makeup of natural plant communities.
- One of the most consistent effects of elevated atmospheric CO2 on plants is an increase in the rate of photosynthetic carbon fixation by leaves. Some crops and other plants may grow more vigorously and use water more efficiently in response to increased atmospheric CO2.

NOTE TO TEACHER: See H.B.3A.2 (Photosynthesis)

Extended Learning Experiences:
Students may also

- analyze and interpret data from diagrams of the biogeochemical cycle and the nitrogen cycle, and
- write equations using chemical formulae to represent chemical reactions that characterize the cycles for other nutrients present in living organisms.

Assessment Guidelines:
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Learning Connections	**Previous Learning Connections (6-8):** **6.L.4A.1** Obtain and communicate information to support claims that living organisms (1) obtain and use resources for energy, (2) respond to stimuli, (3) reproduce, and (4) grow and develop. **6.L.4A.2** Develop and use models to classify organisms based on the current hierarchical taxonomic structure (including the kingdoms of protists, plants, fungi, and animals). **6.L.4B.1** Analyze and interpret data related to the diversity of animals to support claims that all animals (vertebrates and invertebrates) share common characteristics. **6.L.4B.2** Obtain and communicate information to explain how the structural adaptations and processes of animals allow for defense, movement, or resource obtainment. **6.L.4B.3** Construct explanations of how animal responses (including hibernation, migration, grouping, and courtship) to environmental stimuli allow them to survive and reproduce. **6.L.5B.1** Construct explanations of how the internal structures of vascular and nonvascular plants transport food and water. **6.L.5B.2** Analyze and interpret data to explain how the processes of photosynthesis, respiration, and transpiration work together to meet the needs of plants. **6.L.5B.4** Plan and conduct controlled scientific investigations to determine how changes in environmental factors (such as air, water, light, minerals, or space) affect the growth and development of a flowering plant. **H.B.3A.1** Develop and use models to explain how chemical reactions among ATP, ADP, and inorganic phosphate act to transfer chemical energy within cells. **H.B.3A.2** Develop and revise models to describe how photosynthesis transforms light energy into stored chemical energy. **H.B.3A.3** Construct scientific arguments to support claims that chemical elements in the sugar molecules produced by photosynthesis may interact with other elements to form amino acids, lipids, nucleic acids or other large organic molecules. **H.B.3A.4** Develop models of the major inputs and outputs of cellular respiration (aerobic and anaerobic) to exemplify the chemical process in which the bonds of molecules are broken, the bonds of new compounds are formed

	and a net transfer of energy results. **H.B.3A.5** Plan and conduct scientific investigations or computer simulations to determine the relationship between variables that affect the processes of fermentation and/or cellular respiration in living organisms and interpret the data in terms of real-world phenomena. **Earth Science Learning Connections** **H.E.4A.7** Develop and use models to predict the effects of an environmental change (such as the changing life forms, tectonic change, or human activity) on global carbon cycling.

Ecosystem Dynamics

Standard H.B.6: The student will demonstrate an understanding that ecosystems are complex, interactive systems that include both biological communities and physical components of the environment.	
H.B.6B Conceptual Understanding: Photosynthesis and cellular respiration are important components of the carbon cycle, in which carbon is exchanged between the biosphere, atmosphere, oceans, and geosphere through chemical, physical, geological, and biological processes.	
Performance Indicator	**H.B.6B.2:** Analyze and interpret quantitative data to construct an explanation for the effects of greenhouse gases (such as carbon dioxide and methane) on the carbon cycle and global climate.
Science and Engineering Practice	**H.B.1A.4:** Analyze and interpret data from informational texts and data collected from investigations using a range of methods (such as tabulation, graphing, or statistical analysis) to (1) reveal patterns and construct meaning, (2) support or refute hypotheses, explanations, claims, or designs, or (3) evaluate the strength of conclusions.
Crosscutting Concepts	The following Crosscutting Concepts may be applied to the content of the indicator. For more information see page 6. Cause and Effect Systems and System Models

Essential Learning Experiences:
It is essential for students to analyze and interpret quantitative data to construct an explanation for the effects of greenhouse gases on the cycling of carbon in the atmosphere and the global climate.

The greenhouse effect is the normal warming effect when gases trap heat in the atmosphere. Greenhouse gases do not allow heat to pass through very well. Therefore, the heat that Earth releases stays trapped under the atmosphere.

- Solar energy penetrates the Earth's atmosphere and warms its surface.
- Some of this energy is radiated as heat away from the Earth. Some heat escapes into space.
- Some heat is absorbed by greenhouse gases (such as carbon dioxide, oxygen, methane, and water vapor) and returned to Earth.
- The greenhouse effect is a natural and important process that keeps the Earth's surface warm enough to support life.
- The amount of carbon dioxide in the atmosphere also cycles in relation to the volume of ocean covering Earth. The salt water of oceans absorbs carbon dioxide and converts it to various salts such as calcium carbonate.

- The amount of carbon dioxide in the atmosphere cycles partly 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

NOTE TO TEACHER: See H.B.6B.1 for additional information.

Extended Learning Experiences:
Students may also

- engage in scientific arguments from evidence regarding the biogeographic factors that affect the biodiversity of communities.

Assessment Guidelines:
Students should engage in multiple science and engineering practices when interacting with the content outlined in this performance indicator. For further information please see SEP Support Guide at:
https://ed.sc.gov/scdoe/assets/File/instruction/standards/Science/Support%20Documents/Complete_2014SEPsGuide_SupportDoc2_0.pdf

Learning Connections	**Previous Learning Connections (6-8):** **6.L.4A.1** Obtain and communicate information to support claims that living organisms (1) obtain and use resources for energy, (2) respond to stimuli, (3) reproduce, and (4) grow and develop. **6.L.5B.2** Analyze and interpret data to explain how the processes of photosynthesis, respiration, and transpiration work together to meet the needs of plants. **Earth Science Learning Connections:** **H.E.4A.7** Develop and use models to predict the effects of an environmental

	change (such as the changing life forms, tectonic change, or human activity) on global carbon cycling.

Ecosystem Dynamics

Standard H.B.6: The student will demonstrate an understanding that ecosystems are complex, interactive systems that include both biological communities and physical components of the environment.	
H.B.6C Conceptual Understanding: A complex set of interactions within an ecosystem can keep its numbers and types of organisms relatively stable over long periods of time. Fluctuations in conditions can challenge the functioning of ecosystems in terms of resource and habitat availability.	
Performance Indicator	**H.B.6C.1:** Construct scientific arguments to support claims that the changes in the biotic and abiotic components of various ecosystems over time affect the ability of an ecosystem to maintain homeostasis.
Science and Engineering Practice	**H.B.1A.7:** Construct and analyze scientific arguments to support claims, explanations, or designs using evidence and valid reasoning from observations, data, or informational texts.
Crosscutting Concepts	The following Crosscutting Concepts may be applied to the content of the indicator. For more information see page 6. Systems and System Models

Essential Learning Experiences:
It is essential for students to construct scientific arguments to support claims that the fluctuations in biotic and abiotic components of an ecosystem affect homeostasis in that ecosystem.

Homeostasis in an ecosystem is a steady state or dynamic equilibrium, in which conditions are held more or less constant despite changes in biotic or abiotic environmental factors. Ecosystems are dynamic in nature; their characteristics fluctuate over time, depending on changes in the environment and in the populations of various species. Complex interactions within an ecosystem can keep its numbers and types of organisms relatively constant over long periods of time under stable conditions.

An ecosystem rich in biodiversity will likely be more stable than one in which biodiversity is low. Changing environmental conditions can cause the decline of local biodiversity. If this happens, an ecosystem's resistance and/or resilience may decline. The end result is the loss of stability in the ecosystem.

- Ecosystems that are less stable may not be able to respond to a normal environmental disturbance, which may damage ecosystem structure, ecosystem function, or both.
- An ecosystem displays resistance if it keeps its structure and continues normal functions even when environmental conditions change.

- An ecosystem displays resilience if, following a disturbance, it eventually regains its normal structure and function.
- Examples of changes in ecosystem conditions could include small biological or physical changes, such as the fall of a forest canopy tree or a seasonal flood.
- Extreme changes include volcanic eruption, fires, climate changes, ocean acidification, or sea level rise.
- Changes caused by humans--including habitat destruction, pollution, introduction of invasive species, overexploitation, and burning of fossil fuels, can disrupt an ecosystem and threaten the survival of some species.

Ecological succession is the sequence of changes in an ecosystem that regenerate a damaged community or create a community in a previously uninhabited area. There are two types of succession, primary and secondary.

- Primary succession is the development of a community in an area that was previously uninhabited: for example, bare rock surfaces after a recent volcanic eruption, rock faces that have been scraped clean of soil 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.

- Secondary succession is the reestablishment of damaged ecosystem in an area where the soil was left intact. Plants and other organisms that remain start the process of regrowth. It is similar to primary succession in the later stages, after soil has already formed.
- Succession is a continual process in all ecosystems (i.e., forest succession, pond succession, coral reef or marine succession and desert succession).
    - 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.

Extended Learning Experiences:

Students may obtain, communicate and evaluate information regarding

- the process of soil formation by pioneer species,
- the measures of biodiversity, and
- how estimates of loss of biodiversity are determined.

Assessment Guidelines:
Students should engage in multiple science and engineering practices when interacting with the content outlined in this performance indicator. For further information please see SEP Support Guide at:
https://ed.sc.gov/scdoe/assets/File/instruction/standards/Science/Support%20Documents/Complete_2014SEPsGuide_SupportDoc2_0.pdf

Learning Connections	**Previous Connections (6-8):** **7.EC.5A.3** Analyze and interpret data to predict changes in the number of organisms within a population when certain changes occur to the physical environment (such as changes due to natural hazards or limiting factors). **Earth Science Connections:** **H.E.3B.3** Analyze and interpret data to explain how natural hazards and other geologic events have shaped the course of human history. **H.E.3B.4** Obtain and evaluate available data on a current controversy regarding human activities which may affect the frequency, intensity, or consequences of natural hazards. **H.E.3B.5** Define problems caused by the impacts of locally significant natural hazards and design possible devices or solutions to reduce the impacts of such natural hazards on human activities.

Ecosystem Dynamics

Standard H.B.6: The student will demonstrate an understanding that ecosystems are complex, interactive systems that include both biological communities and physical components of the environment.	
H.B.6A Conceptual Understanding: Ecosystems have carrying capacities, which are limits to the numbers of organisms and populations they can support. Limiting factors include the availability of biotic and abiotic resources and challenges such as predation, competition, and disease.	
Performance Indicator	**H.B.6D.1:** Design solutions to reduce the impact of human activity on the biodiversity of an ecosystem.
Science and Engineering Practice	**H.B.1B.1:** Construct devices or design solutions using scientific knowledge to solve specific problems or needs: (1) ask questions to identify problems or needs, (2) ask questions about the criteria and constraints of the device or solutions, (3) generate and communicate ideas for possible devices or solutions, (4) build and test devices or solutions, (5) determine if the devices or solutions solved the problem and refine the design if needed, and (6) communicate the results.
Crosscutting Concepts	The following Crosscutting Concepts may be applied to the content of the indicator. For more information see page 6. Cause and Effect Systems and Systems Models Stability and Change

Essential Learning Experiences:
It is essential for students to design solutions to reduce the impact of human activity on the biodiversity of an ecosystem.

Humans depend on the Earth's biodiversity for food, building materials, fuel, medicines and other useful chemicals. Humans also depend on ecosystem resources to provide clean water, breathable air, and soil that can support crops. Properly functioning ecosystems recycle human wastes, including CO_2. A loss of biodiversity has long-term effects and can reduce an ecosystem's stability.

Biodiversity or Biological diversity means the variety of organisms at all levels in an ecosystem; it describes both species richness (the total number of different species) and the relative abundance of each species.

- Genetic diversity is the combination of different genes found within a population of a single species, and the pattern of variation found within different populations of the same species.
- Species diversity is the variety and abundance of different types of organisms that inhabit an area.
- Ecosystem diversity encompasses the variety of habitats that occur within a region. On land, biodiversity tends to be highest near the equator, due to warm temperatures and high primary productivity. In the oceans, biodiversity is very high along coasts in the Western Pacific, where sea surface temperature is highest.

Threats to Biodiversity

- Habitat destruction: occurs when humans convert complex natural ecosystems into simplified systems that do not support as many species, such as farmland or urban areas.
    - Tropical rainforests, in particular are threatened by habitat destruction. Currently about 1% of the rain forest biome is lost each year to logging or to clearing for agricultural use.
    - Since the 18th century much wetland habitat in the United States has been destroyed because these areas were previously viewed as waste areas that were not useful to humans.
    - Habitat fragmentation occurs when a barrier forms that prevents an organism from accessing its entire home range. Causes of habitat fragmentation include the building of roadways, the harvesting of forests, and urban development. Corridors or land bridges are one solution that can help to maintain continuous tracts of habitat.
- Invasive species
- Pollution: carbon dioxide and other greenhouse gases, human wastes and industrial and agricultural chemicals.
- Human population growth:
    - Population world-wide has grown exponentially. Based on current trends, scientists predict that the Earth's 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:
        - water shortages
        - waste removal and pollution of the environment
        - food resources and land usage
        - imbalance of biogeochemical cycles
    - As human population increases, loss of habitat and habitat fragmentation reduces biodiversity in areas into which the human population expands.

- Over-harvesting occurs when a resource is consumed at an unsustainable rate. This occurs on land in the form of overhunting, excessive logging which results in deforestation, poor soil conservation in agriculture and the illegal wildlife trade. About 25% of world's fish are now overfished to the point where they cannot be harvested sustainably.

Ecological restoration is the process of assisting the recovery of an ecosystem that has been degraded, damaged or destroyed.

NOTE TO TEACHER: See 7.EC.5B.4 regarding three ways humans can respond to invasive species - physical, chemical and biological.

Extended Learning Experiences:
Students may also

- develop and use models to predict the impact of governmental ecological restoration projects

Assessment Guidelines:
Students should engage in multiple science and engineering practices when interacting with the content outlined in this performance indicator. For further information please see SEP Support Guide at:
https://ed.sc.gov/scdoe/assets/File/instruction/standards/Science/Support%20Documents/Complete_2014SEPsGuide_SupportDoc2_0.pdf

Learning Connections	**Previous Learning Connections (6-8):** **7.EC.5B.3** Analyze and interpret data to predict how changes in the number of organisms of one species affects the balance of an ecosystem. **7.EC.5B.4** Define problems caused by the introduction of a new species in an environment and design devices or solutions to minimize the impact(s) to the balance of an ecosystem. **Earth Science Learning Connections:** **H.E.3B.3** Analyze and interpret data to explain how natural hazards and other geologic events have shaped the course of human history **H.E.3B.4** Obtain and evaluate available data on a current controversy regarding human activities which may affect the frequency, intensity, or consequences of natural hazards. **H.E.3B.5** Define problems caused by the impacts of locally significant natural hazards and design possible devices or solutions to reduce the impacts of such natural hazards on human activities

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