# Biology, High School

Learning Standards for a Full First-Year Course

## I. Content Standards

**1. The Chemistry of Life**

*Central Concept:* Chemical elements form organic molecules that interact to perform the basic functions of life.

1.1 Recognize that biological organisms are composed primarily of very few elements. The six most common are C, H, N, O, P, and S.

1.2 Describe the basic molecular structures and primary functions of the four major categories of organic molecules (carbohydrates, lipids, proteins, nucleic acids).

1.3 Explain the role of enzymes as catalysts that lower the activation energy of biochemical reactions. Identify factors, such as pH and temperature, that have an effect on enzymes.

**2. Cell Biology**

*Central Concepts:* Cells have specific structures and functions that make them distinctive. Processes in a cell can be classified broadly as growth, maintenance, and reproduction.

2.1 Relate cell parts/organelles (plasma membrane, nuclear envelope, nucleus, nucleolus, cytoplasm, mitochondrion, endoplasmic reticulum, Golgi apparatus, lysosome, ribosome, vacuole, cell wall, chloroplast, cytoskeleton, centriole, cilium, flagellum, pseudopod) to their functions. Explain the role of cell membranes as a highly selective barrier (diffusion, osmosis, facilitated diffusion, active transport).

2.2 Compare and contrast, at the cellular level, the general structures and degrees of complexity of prokaryotes and eukaryotes.

2.3 Use cellular evidence (e.g., cell structure, cell number, cell reproduction) and modes of nutrition to describe the six kingdoms (Archaebacteria, Eubacteria, Protista, Fungi, Plantae, Animalia).

2.4 Identify the reactants, products, and basic purposes of photosynthesis and cellular respiration. Explain the interrelated nature of photosynthesis and cellular respiration in the cells of photosynthetic organisms.

2.5 Explain the important role that ATP serves in metabolism.

2.6 Describe the cell cycle and the process of mitosis. Explain the role of mitosis in the formation of new cells, and its importance in maintaining chromosome number during asexual reproduction.

2.7 Describe how the process of meiosis results in the formation of haploid cells. Explain the importance of this process in sexual reproduction, and how gametes form diploid zygotes in the process of fertilization.

2.8 Compare and contrast a virus and a cell in terms of genetic material and reproduction.

**3. Genetics**

*Central Concepts:* Genes allow for the storage and transmission of genetic information. They are a set of instructions encoded in the nucleotide sequence of each organism. Genes code for the specific sequences of amino acids that comprise the proteins characteristic to that organism.

3.1 Describe the basic structure (double helix, sugar/phosphate backbone, linked by complementary nucleotide pairs) of DNA, and describe its function in genetic inheritance.

**3. Genetics (cont.)**

3.2 Describe the basic process of DNA replication and how it relates to the transmission and conservation of the genetic code. Explain the basic processes of transcription and translation, and how they result in the expression of genes. Distinguish among the end products of replication, transcription, and translation.

3.3 Explain how mutations in the DNA sequence of a gene may or may not result in phenotypic change in an organism. Explain how mutations in gametes may result in phenotypic changes in offspring.

3.4 Distinguish among observed inheritance patterns caused by several types of genetic traits (dominant, recessive, codominant, sex-linked, polygenic, incomplete dominance, multiple alleles).

3.5 Describe how Mendel's laws of segregation and independent assortment can be observed through patterns of inheritance (e.g., dihybrid crosses).

3.6 Use a Punnett Square to determine the probabilities for genotype and phenotype combinations in monohybrid crosses.

**4. Anatomy and Physiology**

*Central Concepts:* There is a relationship between the organization of cells into tissues and the organization of tissues into organs. The structures and functions of organs determine their relationships within body systems of an organism. Homeostasis allows the body to perform its normal functions.

4.1 Explain generally how the digestive system (mouth, pharynx, esophagus, stomach, small and large intestines, rectum) converts macromolecules from food into smaller molecules that can be used by cells for energy and for repair and growth.

4.2 Explain how the circulatory system (heart, arteries, veins, capillaries, red blood cells) transports nutrients and oxygen to cells and removes cell wastes. Describe how the kidneys and the liver are closely associated with the circulatory system as they perform the excretory function of removing waste from the blood. Recognize that kidneys remove nitrogenous wastes, and the liver removes many toxic compounds from blood.

4.3 Explain how the respiratory system (nose, pharynx, larynx, trachea, lungs, alveoli) provides exchange of oxygen and carbon dioxide.

4.4 Explain how the nervous system (brain, spinal cord, sensory neurons, motor neurons) mediates communication among different parts of the body and mediates the body's interactions with the environment. Identify the basic unit of the nervous system, the neuron, and explain generally how it works.

4.5 Explain how the muscular/skeletal system (skeletal, smooth and cardiac muscles, bones, cartilage, ligaments, tendons) works with other systems to support the body and allow for movement. Recognize that bones produce blood cells.

4.6 Recognize that the sexual reproductive system allows organisms to produce offspring that receive half of their genetic information from their mother and half from their father, and that sexually produced offspring resemble, but are not identical to, either of their parents.

4.7 Recognize that communication among cells is required for coordination of body functions. The nerves communicate with electrochemical signals, hormones circulate through the blood, and some cells produce signals to communicate only with nearby cells.

4.8 Recognize that the body's systems interact to maintain homeostasis. Describe the basic function of a physiological feedback loop.

**5. Evolution and Biodiversity**
*Central Concepts:* Evolution is the result of genetic changes that occur in constantly changing environments. Over many generations, changes in the genetic make-up of populations may affect biodiversity through speciation and extinction.

5.1 Explain how evolution is demonstrated by evidence from the fossil record, comparative anatomy, genetics, molecular biology, and examples of natural selection.
5.2 Describe species as reproductively distinct groups of organisms. Recognize that species are further classified into a hierarchical taxonomic system (kingdom, phylum, class, order, family, genus, species) based on morphological, behavioral, and molecular similarities. Describe the role that geographic isolation can play in speciation.
5.3 Explain how evolution through natural selection can result in changes in biodiversity through the increase or decrease of genetic diversity within a population.

**6. Ecology**
*Central Concept:* Ecology is the interaction among organisms and between organisms and their environment.

6.1 Explain how birth, death, immigration, and emigration influence population size.
6.2 Analyze changes in population size and biodiversity (speciation and extinction) that result from the following: natural causes, changes in climate, human activity, and the introduction of invasive, non-native species.
6.3 Use a food web to identify and distinguish producers, consumers, and decomposers, and explain the transfer of energy through trophic levels. Describe how relationships among organisms (predation, parasitism, competition, commensalism, mutualism) add to the complexity of biological communities.
6.4 Explain how water, carbon, and nitrogen cycle between abiotic resources and organic matter in an ecosystem, and how oxygen cycles through photosynthesis and respiration.

## II. Scientific Inquiry Skills Standards

Scientific literacy can be achieved as students inquire about the biological world. The curriculum should include substantial hands-on laboratory and field experiences, as appropriate, for students to develop and use scientific skills in biology, along with the inquiry skills listed below.

**SIS1. Make observations, raise questions, and formulate hypotheses.**

- Observe the world from a scientific perspective.
- Pose questions and form hypotheses based on personal observations, scientific articles, experiments, and knowledge.
- Read, interpret, and examine the credibility and validity of scientific claims in different sources of information, such as scientific articles, advertisements, or media stories.

**SIS2. Design and conduct scientific investigations.**

- Articulate and explain the major concepts being investigated and the purpose of an investigation.
- Select required materials, equipment, and conditions for conducting an experiment.
- Identify independent and dependent variables.
- Write procedures that are clear and replicable.
- Employ appropriate methods for accurately and consistently
    - making observations
    - making and recording measurements at appropriate levels of precision
    - collecting data or evidence in an organized way
- Properly use instruments, equipment, and materials (e.g., scales, probeware, meter sticks, microscopes, computers) including set-up, calibration (if required), technique, maintenance, and storage.
- Follow safety guidelines.

**SIS3. Analyze and interpret results of scientific investigations.**

- Present relationships between and among variables in appropriate forms.
    - Represent data and relationships between and among variables in charts and graphs.
    - Use appropriate technology (e.g., graphing software) and other tools.
- Use mathematical operations to analyze and interpret data results.
- Assess the reliability of data and identify reasons for inconsistent results, such as sources of error or uncontrolled conditions.
- Use results of an experiment to develop a conclusion to an investigation that addresses the initial questions and supports or refutes the stated hypothesis.
- State questions raised by an experiment that may require further investigation.

**SIS4. Communicate and apply the results of scientific investigations.**

- Develop descriptions of and explanations for scientific concepts that were a focus of one or more investigations.
- Review information, explain statistical analysis, and summarize data collected and analyzed as the result of an investigation.
- Explain diagrams and charts that represent relationships of variables.
- Construct a reasoned argument and respond appropriately to critical comments and questions.
- Use language and vocabulary appropriately, speak clearly and logically, and use appropriate technology (e.g., presentation software) and other tools to present findings.
- Use and refine scientific models that simulate physical processes or phenomena.

## III. MATHEMATICAL SKILLS

Students are expected to know the content of the *Massachusetts Mathematics Curriculum Framework,* through grade 8. Below are some specific skills from the *Mathematics Framework* that students in this course should have the opportunity to apply:

- ✓ Construct and use tables and graphs to interpret data sets.
- ✓ Solve simple algebraic expressions.
- ✓ Perform basic statistical procedures to analyze the center and spread of data.
- ✓ Measure with accuracy and precision (e.g., length, volume, mass, temperature, time)
- ✓ Convert within a unit (e.g., centimeters to meters).
- ✓ Use common prefixes such as *milli-, centi-,* and *kilo-*.
- ✓ Use scientific notation, where appropriate.
- ✓ Use ratio and proportion to solve problems.

The following skills are not detailed in the *Mathematics Framework*, but are necessary for a solid understanding in this course:

- ✓ Determine the correct number of significant figures.
- ✓ Determine percent error from experimental and accepted values.
- ✓ Use appropriate metric/standard international (SI) units of measurement for mass (kg); length (m); and time (s).
- ✓ Use the Celsius scale.

## Exercise Physiology

**Biology, High School**

While studying anatomy and physiology, Miss Scott helped her high school biology students understand the complex interactions between cells, organs, and organ systems through an investigation of exercise physiology. After the students learned about the general structures and functions of the respiratory, circulatory, and muscular systems, Miss Scott asked the students to brainstorm what happens to their bodies when they exercise. After the students generated a list of the body's responses, Miss Scott asked a seemingly simple question, "Which organ system is affected the most by exercise?" The students discussed their thoughts and formed three groups, with each group assigned one of the three systems.

Each group designed an experiment to measure the response to running of their group's system of interest. Students identified a measurable variable associated with their group's system: heart rate for the circulatory system; breathing rate for the respiratory system; and muscle fatigue (the number of sit-ups) for the muscular system. All the groups used *five* minutes of running on a treadmill—at a ten-minute-per-mile pace—as the standard for exercise. Before starting, Miss Scott checked each group's hypothesis, procedure, and data chart. Each group collected data from five different individuals, shown below:

**Responses to Running**

| | **Breathing Rate** (Breaths/Minute) | | | | | |
|---|---|---|---|---|---|---|
| | Student 1 | Student 2 | Student 3 | Student 4 | Student 5 | Average |
| Before Exercise | 15 | 20 | 14 | 17 | 15 | 16 |
| After Exercise | 26 | 36 | 27 | 29 | 33 | 30 |

| | **Heart Rate** (Beats/Minute) | | | | | |
|---|---|---|---|---|---|---|
| | Student 1 | Student 2 | Student 3 | Student 4 | Student 5 | Average |
| Before Exercise | 74 | 69 | 82 | 65 | 75 | 73 |
| After Exercise | 140 | 120 | 155 | 135 | 145 | 139 |

| | **Repetition Rate** (Number of Sit-ups/Minute) | | | | | |
|---|---|---|---|---|---|---|
| | Student 1 | Student 2 | Student 3 | Student 4 | Student 5 | Average |
| Before Exercise | 36 | 30 | 40 | 24 | 27 | 31 |
| After Exercise | 36 | 24 | 34 | 19 | 22 | 27 |

The students were not surprised by their findings. Exercise increased heart and breathing rates and reduced the amount of sit-ups a student could complete. But which system was affected the most? The class discussed this essential question and decided to calculate the percent change for the average response of each system. With the help of Miss Scott, the students determined that the students' average breathing rate increased 88%, heart rate increased 90%, and repetition rate decreased 13%.

Miss Scott helped the students interpret the results. The students concluded that while the heart experienced the greatest change, the whole circulatory system was not necessarily affected the most. The students realized they would need more information about how the circulatory system responded to exercise; perhaps changes in blood pressure would help them gauge how the whole system responded. The students also discussed the similarities between the changes in heart and breathing rate. Miss Scott asked the students why the breathing and heart rate changes were so similar and the repetition rate changed so little. The students described how the respiratory and circulatory system worked together to provide the muscles with oxygen to do work. Because the circulatory and respiratory system responded to the needs of the muscles, the muscles were able to keep working.

## WHAT IT LOOKS LIKE IN THE CLASSROOM

Miss Scott then asked, "Why do the muscles need so much oxygen when they are being worked?" The students explained that to move, the muscles require energy, and oxygen probably had something to do with making energy. This led to a short discussion of how cells make energy, including students' reference to prior learning about the role of mitochondria. The students had difficulty with the details, however, so Miss Scott provided them with a short reading passage on cellular respiration. She asked the students to think about how the circulatory and respiratory systems were involved in cellular respiration as they read the passage. After reading the passage, the students individually created a diagram of cellular respiration that detailed the relationships among the circulatory and respiratory systems and the cell. One student asked Miss Scott where the amino acids, glucose, fatty acids, and glycerol came from for cellular respiration. She wrote the student's question on the board and told the class that the question would be the focus of their next investigation.

**Assessment Strategies**

- Students should be provided early in the lesson with a rubric that clearly outlines the expectations for the laboratory investigation. Students can use this rubric to self-evaluate their work.
- Students can develop a labeled diagram detailing the path of oxygen into the body to the cells of a muscle, and the path of carbon dioxide from a cell out of the body.
- Students can independently create a plan for a bicyclist to maximize her or his performance during a two-day 100-mile race.

**Biology Learning Standards**

**High School**

2.5 Explain the important role that ATP serves in metabolism.

4.2 Explain how the circulatory system (heart, arteries, veins, capillaries, red blood cells) transports nutrients and oxygen to cells and removes cell wastes. …(see page 55 for entire standard)

4.3 Explain how the respiratory system (nose, pharynx, larynx, trachea, lungs, alveoli) provides exchange of oxygen and carbon dioxide.

4.5 Explain how the muscular/skeletal system (skeletal, smooth and cardiac muscles, bones, cartilage, ligaments, tendons) works with other systems to support the body and allow for movement. Recognize that bones produce blood cells.

4.8 Recognize that the body's systems interact to maintain homeostasis. Describe the basic function of a physiological feedback loop.

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