Student Assessment Services | dese Massachusetts Department of Elementary and Secondary Education | Curriculum & Instruction

Science and Technology/Engineering (STE)

Instructional Guidelines
High School Biology

Purpose: The intention of this document is to help provide additional guidance around the instruction and content of the High School Biology standards. This guidance is aligned with the assessment expectations of the Biology MCAS test based on the 2016 Massachusetts Science and Technology/Engineering Curriculum Framework. The information provided in this document is **not an exhaustive list** of what will be assessed on the MCAS Biology test. This document may be updated as necessary. Contact STEM@mass.gov with questions about this document.

Science and Engineering Practices (SEPs): The SEPs are the skills students should be practicing in the classroom daily to explain phenomena. Reference the practice matrix in the 2016 Massachusetts STE Curriculum Framework to learn how the SEPs progress from pre-K to grade 12. Multiple practices may be assessed on MCAS with the DCI of a particular standard, even if that practice is not listed in the standard. The MCAS bundles the SEPs into three practice categories, which are listed in the table below.

Science and Engineering Practices Assessed on MCAS

MCAS Practice Category	Science and Engineering Practices
A. Investigations and Questioning	Asking Questions and Defining Problems Planning and Carrying Out Investigations
B. Mathematics and Data	Analyzing and Interpreting Data Using Mathematics and Computational Thinking
C. Evidence, Reasoning, and Modeling	Developing and Using Models Constructing Explanations and Designing Solutions Engaging in Argument from Evidence Obtaining, Evaluating, and Communicating Information

Disciplinary Core Ideas (DCIs) Learning Progressions: See the standards navigator, strand maps, or (DCI) progression matrix for additional information on the conceptual relationship between content in the standards within and across grades. These tools allow for targeted pre-assessment, contextualization, and/or identification of boundaries for any standard that is being taught. This can be an efficient way to visualize how elementary and middle school standards lead to high school standards.

Science and Technology/Engineering (STE)

LS1. From Molecules to Organisms: Structures and Processes
HS-LS1-1. Construct a model of transcription and translation to explain the roles of DNA and RNA that code for proteins that regulate and carry out essential functions of life. *Clarification Statements: Proteins that regulate and carry out essential functions of life include enzymes (which speed up chemical reactions), structural proteins (which provide structure and enable movement), and hormones and receptors (which send and receive signals). The model should show the double-stranded structure of DNA, including genes as part of DNA's transcribed strand, with complementary bases on the non-transcribed strand. State Assessment Boundaries: Specific names of proteins or specific steps of transcription and translation are not expected in state assessment. Cell structures included in transcription and translation will be limited to nucleus, nuclear membrane, and ribosomes for state assessment.* **HS-LS1-4. Construct an explanation using evidence for why the cell cycle is necessary for the growth, maintenance, and repair of multicellular organisms. Model the major events of the cell cycle, including (a) cell growth and DNA replication, (b) separation of chromosomes (mitosis), and (c) separation of cell contents.** *State Assessment Boundary: Specific gene control mechanisms or specific details of each event (e.g., phases of mitosis) are not expected in state assessment.*

Additional Guidelines

Students should be able to:

- Create, analyze, and complete models and descriptions of the cell cycle, including interphase and cell division. Models of interphase may include DNA replication and cell growth. Cell division should include mitosis and cytokinesis.
- Analyze, modify, and complete models of mitosis.
- Construct an explanation of the importance of the end products of mitosis, DNA replication, transcription, and translation.
- Create, analyze, and complete models and descriptions of protein synthesis (transcription and translation) to show how an amino acid chain (a polypeptide) is formed.
- Determine the complementary base pairs in a replicated section of DNA given the original DNA strand.
- Calculate the percentage of a nucleotide base when given the percentage of another nucleotide base by recognizing that the amount of adenine (A) is equal to that of thymine (T) and the amount of guanine is equal to that of cytosine (C) in a DNA molecule (Chargaff's rule).[1]
- Explain how regions of DNA called genes determine the structure of proteins, which carry out the essential functions of life through systems of specialized cells (tissues).
- Communicate that all cells in an organism have the same genetic content, but tissues are made up of cells expressing specific genes (such as muscle tissue and skin tissue).
- Communicate and evaluate information on the basic functions and importance of the following types of proteins: enzymes, hormones, receptors, and structural proteins (in tissues such as, muscle, skin, nails, feathers, etc.).
- Note: The processes of DNA replication and protein synthesis are also included under LS3. Heredity (HS-LS3-2).

[1] Guidance added August 2023

Science and Technology/Engineering (STE)

LS1. From Molecules to Organisms: Structures and Processes
HS-LS1-2. Develop and use a model to illustrate the key functions of animal body systems, including (a) food digestion, nutrient uptake, and transport through the body; (b) exchange of oxygen and carbon dioxide; (c) removal of wastes; and (d) regulation of body processes. *Clarification Statement: Emphasis is on the primary function of the following body systems (and structures): digestive (mouth, stomach, small intestine [villi], large intestine, pancreas), respiratory (lungs [alveoli], diaphragm), circulatory (heart, veins, arteries, capillaries), excretory (kidneys, liver, skin), and nervous (neurons, brain, spinal cord). State Assessment Boundary: Chemical reactions in cells, details of particular structures (such as the structure of the neuron), or the identification of specific proteins in cells are not expected in state assessment.* **HS-LS1-3. Provide evidence that homeostasis maintains internal body conditions through both body-wide feedback mechanisms and small-scale cellular processes.** *Clarification Statements: Feedback mechanisms include the promotion of a stimulus through positive feedback (e.g., injured tissues releasing chemicals in blood that activate platelets to facilitate blood clotting), and the inhibition of stimulus through negative feedback (e.g., insulin reducing high blood glucose to normal levels). Cellular processes include (a) passive transport and active transport of materials across the cell membrane to maintain specific concentrations of water and other nutrients in the cell and (b) the role of lysosomes in recycling wastes, macromolecules, and cell parts into monomers. State Assessment Boundary: Interactions at the molecular level (for example, how insulin is produced) are not expected in state assessment.*

Additional Guidelines

Students should be able to:

- Explain how different body systems work together to maintain life functions including how red blood cells carry oxygen to body cells, and how villi transfer nutrients to the blood for body cells.
- Interpret and complete a model using motor and sensory neurons to show the path of a nerve impulse.
- Complete or revise a model of a body system. In addition to the list in the standard, students should be familiar with the role of the esophagus in the digestive system.[2]
- Analyze, explain, and complete a model showing how negative and positive feedback loops help to maintain homeostasis within an organism, including when the feedback loop is not functioning properly.
- Use and analyze data (such as salt or water concentrations in models) to describe the functions of diffusion, osmosis, and active transport in maintaining a stable cell environment, including the movement of water, nutrients, oxygen, and waste (e.g., carbon dioxide) across the cell membrane.
- Analyze data and models to describe how concentration gradients determine the net movement of substances in passive transport and how ATP is used in active transport to move substances against their concentration gradient.
- Communicate information about how hormones travel through the bloodstream to bind with receptors on target cells to regulate body processes.
- Construct an explanation for how proteins contribute to small-scale cellular processes (e.g., how protein channels in cellular transport and transport proteins in the bloodstream contribute to maintaining homeostasis).

[2] Guidance revised August 2023

Science and Technology/Engineering (STE)

LS1. From Molecules to Organisms: Structures and Processes

HS-LS1-5. Use a model to illustrate how photosynthesis uses light energy to transform water and carbon dioxide into oxygen and chemical energy stored in the bonds of sugars and other carbohydrates. *Clarification Statements: Emphasis is on illustrating inputs and outputs of matter and the transfer and transformation of energy in photosynthesis by plants and other photosynthesizing organisms. Examples of models could include diagrams, chemical equations, and conceptual models. State Assessment Boundary: Specific biochemical steps of light reactions or the Calvin Cycle, or chemical structures of molecules are not expected in state assessment.*

HS-LS1-6. Construct an explanation based on evidence that organic molecules are primarily composed of six elements, where carbon, hydrogen, and oxygen atoms may combine with nitrogen, sulfur, and phosphorus to form monomers that can further combine to form large carbon-based macromolecules. *Clarification Statements: Monomers include amino acids, monosaccharides, nucleotides, and fatty acids. Organic macromolecules include proteins, carbohydrates (polysaccharides), nucleic acids, and lipids. State Assessment Boundary: Details of specific chemical reactions or identification of specific macromolecule structures are not expected in state assessment.*

HS-LS1-7. Use a model to illustrate that aerobic cellular respiration is a chemical process whereby the bonds of food molecules and oxygen molecules are broken and new bonds form, resulting in new compounds and a net transfer of energy. *Clarification Statements: Emphasis is on the conceptual understanding of the inputs and outputs of the process of aerobic cellular respiration. Examples of models could include diagrams, chemical equations, and conceptual models. The model should include the role of ATP for energy transfer in this process. Food molecules include sugars (carbohydrates), fats (lipids), and proteins. State Assessment Boundary: Identification of the steps or specific processes involved in cellular respiration is not expected in state assessment.*

Additional Guidelines

Students should be able to:

- Analyze and classify monomer and macromolecule structures and determine, from information given, the basic organic elements that make up a structure.
- Analyze a building block of a macromolecule to identify the class of macromolecule.
- Communicate information about the functions of carbohydrates, lipids, proteins, and nucleic acids. Examples of functions include:
    - carbohydrates: monosaccharides, such as glucose, provides nutrients to cells; polysaccharides, such as cellulose, provide structural support for plants
    - lipids: wax repels water; fats store energy and can serve as insulation; hormones help to regulate biological processes, such as growth; phospholipids make up cell membranes
    - proteins: enzymes act as catalysts; structural proteins provide support; hormones regulate biological process, such as blood sugar levels; antibodies provide immune protection; storage proteins provide amino acid nutrients; transport proteins move molecules, such as oxygen through the bloodstream
    - nucleic acids: DNA is the genetic material inherited by offspring that stores information for protein production; RNA controls protein synthesis
- Develop, analyze, and modify models of photosynthesis and cellular respiration, including the basic word and symbol equations for each process. In the models, show how these processes are interrelated. Models may include the locations of the processes within an organism or its cells (such as leaves, chloroplasts, chlorophyll, and mitochondria).
- Use models to show that products produced by photosynthesis are used to produce usable energy (ATP) and to build starches and cellulose for a plant.

Science and Technology/Engineering (STE)

- Explain how the ATP produced by cellular respiration is used to meet the cell's energy needs (for example, cell movement, growth, and repair, including copying DNA, making proteins and other macromolecules, cell division, active transport, & chemical reactions).

LS2. Ecosystems: Interactions, Energy, and Dynamics
HS-LS2-1. Analyze data sets to support explanations that biotic and abiotic factors affect ecosystem carrying capacity. *Clarification Statements: Examples of biotic factors could include relationships among individuals (e.g., feeding relationships, symbioses, competition) and disease. Examples of abiotic factors could include climate and weather conditions, natural disasters, and availability of resources. Example data sets can be derived from simulations or historical data.* **HS-LS2-2. Use mathematical representations to support explanations that biotic and abiotic factors affect biodiversity, including genetic diversity within a population and species diversity within an ecosystem.** *Clarification Statements: Examples of biotic factors could include relationships among individuals (feeding relationships, symbiosis, competition) and disease. Examples of abiotic factors could include climate and weather conditions, natural disasters, and availability of resources. Examples of mathematical representations include finding the average, determining trends, and using graphical comparisons of multiple sets of data.* **HS-LS2-6. Analyze data to show ecosystems tend to maintain relatively consistent numbers and types of organisms even when small changes in conditions occur but that extreme fluctuations in conditions may result in a new ecosystem. Construct an argument supported by evidence that ecosystems with greater biodiversity tend to have greater resistance to change and resilience.** *Clarification Statement: Examples of changes in ecosystem conditions could include modest biological or physical changes, such as moderate hunting or a seasonal flood; and extreme changes, such as volcanic eruption, fires, the decline or loss of a keystone species, climate changes, ocean acidification, or sea level rise.* **HS-LS2-7. Analyze direct and indirect effects of human activities on biodiversity and ecosystem health, specifically habitat fragmentation, introduction of non-native or invasive species, overharvesting, pollution, and climate change. Evaluate and refine a solution for reducing the impacts of human activities on biodiversity and ecosystem health.** *Clarification Statement: Examples of solutions can include captive breeding programs, habitat restoration, pollution mitigation, energy conservation, and ecotourism.*

Additional Guidelines

Students should be able to:

- Construct an explanation for how different types of biotic and abiotic factors affect carrying capacity.
- Use evidence to determine how climate change may affect organisms living in an ecosystem (including increases in CO_2 levels and temperatures in the atmosphere and hydrosphere, more extreme weather events, and increased ocean acidification).
- Analyze data and models to determine environmental changes in an ecosystem and to determine the most likely impact that these changes will have on an ecosystem.
- Calculate changes in population sizes for a given situation using the population growth equation, including birth, death, immigration, and/or emigration rates.
- Analyze, evaluate, and modify models such as a food web, to determine the different ecological relationships that may exist, including predation, parasitism, competition, commensalism, and mutualism; and to determine the likely impact on populations due to changes to an ecosystem.
- Use evidence from data to analyze and construct explanations for different solutions to environmental issues, including preventative and restorative measures to reduce the impacts of human activities on an ecosystem.
- Explain the impact of invasive species on an ecosystem, including characteristics of the invasive species, such as competition with native species, lack of natural predators, harmful to native species/new

ecosystem, fast growth, quickly reaching adulthood, and rapid reproduction, and harming the native ecosystem.[3]

LS2. Ecosystems: Interactions, Energy, and Dynamics
HS-LS2-4. Use a mathematical model to describe the transfer of energy from one trophic level to another. Explain how the inefficiency of energy transfer between trophic levels affects the relative number of organisms that can be supported at each trophic level and necessitates a constant input of energy from sunlight or inorganic compounds from the environment. *Clarification Statement: The model should illustrate the "10% rule" of energy transfer and show approximate amounts of available energy at each trophic level in an ecosystem (up to five trophic levels).*

Additional Guidelines

Students should be able to:

- Communicate information about how producers, consumers (primary, secondary, and tertiary), and decomposers obtain and use nutrients from the environment, given an energy pyramid, food web, or other information.
- Create or modify energy pyramid models given data and information.
- Calculate the amount of energy available and stored at different trophic levels.
- Construct an explanation for why relatively little energy passes from one trophic level to the next due to: energy metabolism (growth and reproduction), heat energy lost to the environment, and waste (nutrients not eaten or used by a consumer).
- Complete a model to show that there is more biomass in lower trophic levels than in higher trophic levels.[4]
- Complete or revise a model to show the biomasses of different trophic levels and how the are affected with a changing environment.

[3] Guidance added August 2023

[4] Guidance added August 2023

Science and Technology/Engineering (STE)

LS2. Ecosystems: Interactions, Energy, and Dynamics

HS-LS2-5. Use a model that illustrates the roles of photosynthesis, cellular respiration, decomposition, and combustion to explain the cycling of carbon in its various forms among the biosphere, atmosphere, hydrosphere, and geosphere.
Clarification Statements: The primary forms of carbon include carbon dioxide, hydrocarbons, waste (dead organic matter), and biomass (organic materials of living organisms). Examples of models could include simulations and mathematical models. State Assessment Boundary: The specific chemical steps of respiration, decomposition, and combustion are not expected in state assessment.

Additional Guidelines

Students should be able to:

- Describe how carbon flows through an ecosystem in various forms (e.g., CO_2, living biomass, waste, hydrocarbons).
- Complete or modify a model to show the processes (photosynthesis, cellular respiration, decomposition, and combustion) that transform carbon compounds from one form to another.
- Use models, such as the basic equations of photosynthesis and cellular respiration to show how carbon atoms cycle through organisms and the environment.
- Analyze and modify models with producers, consumers, decomposers, and fossil fuels to show how carbon is cycled in different forms. Determine what will happen to the cycling of the carbon if one or more of these factors in the model are disrupted.
- Analyze and interpret data to explain that the increased combustion of fossil fuels (such as coal, oil, and natural gas) has released more CO_2 into the environment, resulting in climate change.

Science and Technology/Engineering (STE)

LS3. Heredity: Inheritance and Variation of Traits
HS-LS3-1. Develop and use a model to show how DNA in the form of chromosomes is passed from parents to offspring through the processes of meiosis and fertilization in sexual reproduction. *Clarification Statement: The model should demonstrate that an individual's characteristics (phenotype) result, in part, from interactions among the various proteins expressed by one's genes (genotype). State Assessment Boundary: Identification of specific phases of meiosis or the biochemical mechanisms involved are not expected in state assessment.* **HS-LS3-2. Make and defend a claim based on evidence that genetic variations (alleles) may result from (a) new genetic combinations via the processes of crossing over and random segregation of chromosomes during meiosis, (b) mutations that occur during replication, and/or (c) mutations caused by environmental factors. Recognize that mutations that occur in gametes can be passed to offspring.** *Clarification Statement: Examples of evidence of genetic variation can include the work of McClintock in crossing over of maize chromosomes and the development of cancer due to DNA replication errors and UV ray exposure. State Assessment Boundary: Specific phases of meiosis or identification of specific types of mutations are not expected in state assessment.* **HS-LS3-3. Apply concepts of probability to represent possible genotype and phenotype combinations in offspring caused by different types of Mendelian inheritance patterns.** *Clarification Statements: Representations can include Punnett squares, diagrams, pedigree charts, and simulations. Inheritance patterns include dominant-recessive, codominance, incomplete dominance, and sex-linked.*

Additional Guidelines

Students should be able to:

- Describe how chromosomes are passed from parents to offspring through the formation of haploid gametes (sperm and egg cells) in meiosis, which are combined to form a fertilized diploid zygote in fertilization. Explain why only some traits and mutations from each parent are passed on to offspring.
- Explain the importance of genetic variation as an advantage to the species, including the processes of fertilization (random pairing of an egg cell and a sperm cell), mutations, crossing over and the segregation of chromosomes during meiosis.
- Determine the normal number of chromosomes resulting from meiosis or mitosis.
- Develop or analyze a model, such as a Punnett square, to determine the probabilities of genotypes and phenotypes in a monohybrid or dihybrid cross. Describe how a genotype determines an individual's phenotype.
- Create, analyze, and modify models to show how mutations that occur in DNA may or may not result in a difference in a protein (change in phenotype). Models may include the replication of DNA, the transcription of DNA to RNA, the translation of RNA to amino acids, and the production of amino acid chains (polypeptides). Models may show a nucleotide being removed from a DNA sequence, a nucleotide being added to a DNA sequence, or a nucleotide changing to another nucleotide.
- Use an mRNA codon table to determine and explain if a given mutation will result in a change to the to the resulting amino acid sequence/polypeptide/protein.
- Use data or other information (such as a range of phenotypes) to identify polygenic inheritance for a certain trait.
- Analyze a pedigree or a set of data to determine if an individual would carry an allele for a given trait, or to identify the inheritance pattern for a given gene, allele, or trait.

Science and Technology/Engineering (STE)

LS3. Heredity: Inheritance and Variation of Traits
HS-LS3-4(MA). Use scientific information to illustrate that many traits of individuals, and the presence of specific alleles in a population, are due to interactions of genetic factors and environmental factors. *Clarification Statements: Examples of genetic factors include the presence of multiple alleles for one gene and multiple genes influencing a trait. An example of the role of the environment in expressed traits in an individual can include the likelihood of developing inherited diseases (e.g., heart disease, cancer) in relation to exposure to environmental toxins and lifestyle; an example in populations can include the maintenance of the allele for sickle-cell anemia in high frequency in malaria-affected regions because it confers partial resistance to malaria. State Assessment Boundary: Hardy-Weinberg calculations are not expected in state assessment.*

Additional Guidelines

Students should be able to:

- Describe how genes can be expressed (activated) or not expressed with different environmental pressures, and how a trait can be advantageous in one environment and disadvantageous in another.
- Analyze and interpret data about variations within a trait (such as eye color) and determine if the trait is affected by multiple genes or alleles.
- Determine the likelihood of the genotype expressing a variation of a trait given inheritance information about that trait.
- Analyze data from charts and tables to determine the likelihood of the ability of a trait to be influenced by genetics or the environment.

Science and Technology/Engineering (STE)

LS4. Biological Evolution: Unity and Diversity
HS-LS4-1. Communicate scientific information that common ancestry and biological evolution are supported by multiple lines of empirical evidence, including molecular, anatomical, and developmental similarities inherited from a common ancestor (homologies), seen through fossils and laboratory and field observations. *Clarification Statement: Examples of evidence can include the work of Margulis on endosymbiosis, examination of genomes, and analyses of vestigial or skeletal structures.* **HS-LS4-2. Construct an explanation based on evidence that Darwin's theory of evolution by natural selection occurs in a population when the following conditions are met: (a) more offspring are produced than can be supported by the environment, (b) there is heritable variation among individuals, and (c) some of these variations lead to differential fitness among individuals as some individuals are better able to compete for limited resources than others.** *Clarification Statement: Emphasis is on the overall result of an increase in the proportion of those individuals with advantageous heritable traits that are better able to survive and reproduce in the environment.* **HS-LS4-5. Evaluate models that demonstrate how changes in an environment may result in the evolution of a population of a given species, the emergence of new species over generations, or the extinction of other species due to the processes of genetic drift, gene flow, mutation, and natural selection.**

Additional Guidelines

Students should be able to:

- Use evidence of changing allele frequencies in a population to support a claim that evolution is occurring.
- Construct an explanation for how each type of evidence (homologous structures, fossil structures, embryological similarities, vestigial structures, genome similarities, protein/polypeptide similarities) contributes to the theory of biological evolution and common ancestry among species. Explain that the more similar the evidence is between two species, the more likely the species are related.
- Use evidence from a model to support a claim about how animal and plant cells evolved from smaller, unicellular organisms by endosymbiosis. Evidence may include how mitochondria and chloroplasts contain their own DNA.
- Analyze cladograms to determine the relatedness among species and recognize that evolutionary evidence was used to construct the cladograms.
- Analyze models to explain how environmental selection pressures allow some species to have similar traits even though they are not closely related (convergent evolution) and some species are more closely related but have very different traits (divergent evolution).
- Use changing traits and changing allele frequencies within a population as evidence that environmental factors (such as availability of resources, presence of predators, interspecies competition, climate change, disease) act as selection pressures on a population.
- Analyze graphs and other data to describe how selection pressures can favor certain traits (adaptations). Explain how natural selection (or sexual selection) acts on a population, including how individuals with favorable traits in a population have greater survival and/or reproductive advantages than individuals without these traits.
- Explain how genetic variation is important to the survival of a species or the emergence of new species through the processes of genetic drift (geographic and reproductive isolation, bottleneck and founder effect), gene flow (migration and emigration), mutations (beneficial and harmful), and natural selection.
- Construct an explanation with evidence for how geographic or reproductive isolation can lead to a lack of gene flow between populations, and how different selection pressures in different environments can lead to speciation over time.

Science and Technology/Engineering (STE)

LS4. Biological Evolution: Unity and Diversity
HS-LS4-4. Research and communicate information about key features of viruses and bacteria to explain their ability to adapt and reproduce in a wide variety of environments. *Clarification Statement: Key features include high rate of mutations and the speed of reproduction which produces many generations with high variability in a short time, allowing for rapid adaptation. State Assessment Boundary: Specific types of viral reproduction (e.g., lytic and lysogenic) are not expected in state assessment.*

Additional Guidelines

Students should be able to:

- Analyze graphs and charts to explain that high rates of mutation and fast reproduction rates allow for the relatively fast adaptation of bacteria and viruses.
- Use evidence of the relatively simple structures of bacteria (few cell parts, no nuclei, no mitochondria, etc.) and of viruses (few structures) to make a claim that these characteristics contribute to their fast reproductive rates.
- Explain how asexual reproduction (binary fission) in bacteria and how viral particles use cell machinery for reproduction results in exponential growth of both bacteria and viruses.
- Using a model as evidence, compare the structures of viruses with the structures of bacteria and other cells (e.g., plant, animal, fungus) to draw conclusions about the relatively high rates of reproduction and mutation in viruses and bacteria.
- Use evidence, such as data sets or models, to show that natural selection occurs over many generations, so the shorter the time between generations, the faster natural selection can occur.