North Carolina K-12 Science Support Documents

Biology: 2023 Support Document

Purpose:
The 2023 North Carolina K-12 Science Standards were officially approved by the State Board of Education on July 6, 2023. The Standard Course of Study is designed to help students continually grow their science knowledge and abilities. The standards are intended to foster conceptual understanding, develop scientifically literate students, and provide opportunities to build knowledge and practices within each grade band or course.

The K-12 Science Support Documents serve as resources for teachers, administrators, science specialists, instructional coaches, parents, and other stakeholders in understanding the standards and planning instruction. They do not serve as curricula nor as a means to limit instruction in the classroom, but rather are intended to serve as a guide for discerning and describing features of students and their work necessary to meet grade level proficiency.

Science Teaching and Learning:
A coherent and consistent approach throughout grades K-12 is key to realizing the vision for science education embodied in *A Framework for K-12 Science Education*. Students should actively engage in science and engineering practices and apply crosscutting concepts in every grade level to deepen their understanding of each field's disciplinary core ideas.

Science Safety:
It is the responsibility of teachers and school administrators to use appropriate legal standards and best professional practices under duty of care to make the science laboratory safe. Follow the Public School Unit's guidelines regarding safety in the classroom. For more information, review the National Science Teaching Association's position statement on safety and school science instruction.

Thank You:
We wish to express sincere appreciation for the many hours dedicated to this process by nonformal science educators, representatives of higher education, business and industry representatives, community members, parents, and especially the K-12 science educators.

Resources:
The resources used to inform the development of the K-12 Science Support Documents include:

- Benchmarks for Science Literacy
- Earth Science Literacy Principles
- National Assessment of Educational Progress (NAEP) Science Assessment Framework (2019 & 2028)
- National Research Council: A K-12 Framework for Science Education:Practices, Crosscutting Concepts, and Core Ideas
- National Science Teaching Association: Three-Dimensional Progression Matrix on Science and Engineering Practices
- Ocean Literacy Principles
- STEM Teaching Tool #41: Prompts for Integrating Crosscutting Concepts into Assessment and Instruction
- Trends in International Mathematics and Science Study (TIMSS) 2023 Assessment Framework

This template illustrates the organization of the K-12 Science Support Documents and provides detailed explanations regarding the standards to inform curriculum development and support both instruction and classroom assessment.

Strand

Organizes the standards into broader contexts within a K-12 vertical progression. The standards are organized within 11 strands which articulate vertical alignment. As students progress from one grade to the next, the depth of knowledge and level of sophistication increases.

Standards Organization
The 2023 Science Standards are grouped in three domains: Physical Science, Life Science, and Earth & Space Science. The standards are organized in K-12 strands which increase in sophistication through the grade bands. The eleven strands include:

- Matter and Its Interactions
- Motion and Stability: Forces and Interactions
- Energy
- Waves and Their Applications in Technologies for Information Transfer
- From Molecules to Organisms: Structures and Functions
- Ecosystems: Interactions, Energy, and Dynamics
- Heredity: Inheritance and Variation
- Biological Evolution: Unity and Diversity
- Earth's Place in the Universe

- Earth's Systems
- Earth and Human Activity

K-12 Vertical Alignment
Progression of the K-12 Science Standards for each strand

Standards and Objectives: The North Carolina Standard Course of Study sets expectations for student learning in K-12 Science. Standards and objectives communicate what students should know and be able to do to master the content.

Standard - Broader content that frames the objectives
Objectives - Objectives are specific content that support the standard. Each standard contains two or more objectives. Each objective contains a Science and Engineering Practice (SEP), a Revised Bloom's Taxonomy (RBT) verb, and a Disciplinary Core Idea (content).

Standard - Broader content that frames the objectives

Objective - Objectives are specific content that support the standard. Each standard contains two or more objectives. The objectives in 2023 Science Standards represent what students at the "standard" level should know, understand, and be able to do. For high school honors level course implementation, refer to the Honors Level Course Development and Evaluation Tool.

Clarification Statement(s): Some objectives are followed by statements which supply additional information or clarification.

Boundary Statement(s): The purpose of this section is to provide limits on classroom assessment.

Dimension 1: Science and Engineering Practice (SEP)

[Science and Engineering Practice included in Objective]
Practices refer to the things that scientists and engineers do and how they actively engage in their work. This section provides further clarification for what students should be doing to engage in this practice. There are various ways that each practice can be used, as articulated in *A Framework for K-12 Science Education* (NRC, 2012) and the *NSTA's SEP Matrix*.

The Framework identifies a small number of disciplinary core ideas that all students should learn with increasing depth and sophistication, from Kindergarten through grade twelve. Key to the vision expressed in the Framework is for students to learn these disciplinary core ideas in the context of science and engineering practices. The importance of combining science and engineering practices and disciplinary

core ideas is stated in the Framework as follows: Standards and performance expectations that are aligned to the framework must take into account that students cannot fully understand scientific and engineering ideas without engaging in the practices of inquiry and the discourses by which such ideas are developed and refined. At the same time, they cannot learn or show competence in practices except in the context of specific content (NRC Framework, 2012, p. 218).
The eight practices of science and engineering that the Framework identifies as essential for all students to learn and describes in detail are listed below:
1. Asking questions (for science) and defining problems (for engineering)
2. Developing and using models
3. Planning and carrying out investigations
4. Analyzing and interpreting data
5. Using mathematics and computational thinking
6. Constructing explanations (for science) and designing solutions (for engineering)
7. Engaging in argument from evidence
8. Obtaining, evaluating, and communicating information

Dimension 2: Crosscutting Concepts (CCC)

Crosscutting concepts are conceptual tools used along with the SEP and DCI to help students explain and predict science phenomena. They support students in making connections between disciplines and provide a context for sense-making. Teachers should encourage students to frame their thinking around the terminology of the CCC through questions and classroom discussions.

The most relevant Crosscutting Concepts may vary in light of the specific learning objectives and how the teacher structures the topic. Teachers should choose the one(s) that best support(s) their instructional goals and help(s) students make connections across different aspects of the content.

Suggested Crosscutting Concept(s): [Crosscutting Concept Name(s)]

A Framework for K-12 Science Education identifies seven crosscutting concepts that bridge disciplinary boundaries and unite core ideas. Their purpose is to help students deepen their understanding of the disciplinary core ideas and develop a coherent and scientifically based view of the world (p. 83).

The seven crosscutting concepts of the Framework are:

1. **Patterns -** Observed patterns of forms and events guide organization and classification, and they prompt questions about relationships and the factors that influence them.
2. **Cause and effect: Mechanism and explanation -** 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.
3. **Scale, proportion, and quantity -** 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.
4. **Systems and system models -** 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.
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 way in which an object or living thing is shaped and its substructure determine many of its properties and functions.
7. **Stability and change -** 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.

Dimension 3: Disciplinary Core Ideas (DCI)

[DCI Code]: [DCI Name]
The purpose of this section is to articulate the conceptual ideas students should know and be able to use **within specific grade bands** to support the explanation of science phenomena. Although these core ideas primarily are found in *A Framework for K-12 Science Education*, information may be included from other sources such as the Benchmarks for Science Literacy, Ocean Literacy Principles, Earth Science Literacy Principles, NAEP 2028 Framework, and TIMSS 2023 Framework. *This section is not intended to be a checklist of content for students to memorize.*

What does it look like to demonstrate proficiency?
This section provides statements of what students should know and be able to do to demonstrate proficiency of a standard. These statements can be used to plan learning goals, tasks, and assessments during the instructional sequence, and should address how the dimensions of *The Framework* interact. *These proficiency statements are not intended to be used as curriculum or to dictate instruction.*

Academic Language: The tools in this section help teachers encourage classroom discussion and facilitate science discourse.

[*Question/Sentence Stems that utilize academic language]:)

Effective science instruction requires discipline-specific communication skills. This means that effective science learning occurs when students are expected to speak, listen, read, and write in ways that are appropriate to science.
*Resource: *STEM Teaching Tool #41: Prompts for Integrating Crosscutting Concepts Into Assessment and Instruction*

[Words to support student discourse]:
This section is not intended to be an exhaustive vocabulary list of terms students need to know; rather it is a list of words meant to support classroom discussion. Teaching words or concepts in isolation or prior to experiences that give context (frontloading) does not allow students the opportunities for sense-making that lead to a greater depth of conceptual understanding.

How do I send Feedback? We intend the explanations and examples in this document to be helpful and specific. That said, we believe that as this document is used, teachers and educators will find ways in which it can be improved and made ever more useful.

Please use this Google form to send us feedback. Thank You!

BIOLOGY

K-12 Vertical Alignment

Formative Assessment Examples

Strands:
From Molecules to Organisms **(Standards 1-3)**
Ecosystems - Interactions, Energy, and Dynamics **(Standards 4-5)**
Heredity - Inheritance and Variation of Traits **(Standards 6-8)**
Biological Evolution - Unity and Diversity **(Standards 9-10)**

Reference Table- Amino Acid Sequence Chart

From Molecules to Organisms

Standard and Objectives:

LS.Bio.1 Analyze how the relationship between structure and function supports life processes within organisms.

- LS.Bio.1.1 Construct an explanation to illustrate relationships between structure and function of major macromolecules essential for life.
- LS.Bio.1.2 Carry out investigations to illustrate how enzymes act as catalysts for biochemical reactions and how environmental factors affect enzyme activity.
- LS.Bio.1.3 Use models to explain how the structure of organelles determines its function and supports overall cell processes.
- LS.Bio.1.4 Construct an explanation to compare prokaryotic and eukaryotic cells in terms of structures and degree of complexity.
- LS.Bio.1.5 Construct an explanation to summarize how DNA and RNA direct the synthesis of proteins.

LS.Bio.2 Analyze the growth and development processes of organisms.

- LS.Bio.2.1 Use models to illustrate how cellular division results in the reproduction, growth, and repair of organisms.

LS.Bio.2.2 Construct an explanation to illustrate that proteins regulate gene expression resulting in cellular differentiation, specialized cells with specific functions, and uncontrolled cell growth.

LS.Bio.3 Analyze the relationship between biochemical processes and energy use.

LS.Bio.3.1 Carry out investigations to explain how homeostasis is maintained through feedback mechanisms.
LS.Bio.3.2 Use models to illustrate how photosynthesis transforms light energy into chemical energy.
LS.Bio.3.3 Use models to illustrate how cellular respiration [aerobic and anaerobic] transforms chemical energy into ATP.

LS.Bio.1 Analyze how the relationship between structure and function supports life processes within organisms.

LS.Bio.1.1 Construct an explanation to illustrate relationships between structure and function of major macromolecules essential for life.

Clarification Statement:

- Emphasis should be on understanding the role of each macromolecule and how each supports life and life functions.
  - Students are expected to know the functions of the major macromolecules (carbohydrates, lipids, proteins, and nucleic acids).

Boundary Statement:

- Students are expected to know the elemental composition of each macromolecule.
  - Students are *not* expected to know elemental ratios, atomic bonding pattern, or the molecular bonding pattern.
  - Students are *not* expected to know the specific molecular structure of macromolecules.
- Students are expected to know that nutrients (carbon, nitrogen, phosphorus) are obtained from foods we eat and are part of larger nutrient cycles.
  - Students are *not* expected to know the steps of nutrient cycles.

Dimension 1: Science and Engineering Practice (SEP): *Construct an Explanation*
NAEP (2028 Framework)

- S12.18: Construct or revise an explanation that uses a chain of cause and effect or evidence-based associations between factors to account for the qualitative or quantitative relationships between variables in a phenomenon.

NSTA Progression

- Construct and revise an explanation based on valid and reliable evidence obtained from a variety of sources (including students' own investigations, models, theories, simulations, peer review) and the assumption that theories and laws that

describe the natural world operate today as they did in the past and will continue to do so in the future.
- Apply scientific reasoning, theory, and/or models to link evidence to the claims to assess the extent to which the reasoning and data support the explanation or conclusion.

Dimension 2: Crosscutting Concepts (CCC):
Crosscutting concepts are conceptual tools used along with the SEP and DCI to help students explain and predict phenomena. They support students in making connections between disciplines and provide a context for sense-making. Teachers should encourage students to frame their thinking around the terminology of the CCC through questions* and classroom discussions. The most relevant Crosscutting Concepts may vary in light of the specific learning objectives and how the topic is structured. Choose the one(s) that best support(s) the instructional goals and help(s) students make connections across different aspects of the content.
Suggested Crosscutting Concept: (A Framework for K-12 Science Education)
- **Structure and Function**

**STEM Teaching Tool #41: Prompts for Integrating Crosscutting Concepts Into Assessment and Instruction*

Dimensions 3: Disciplinary Core Ideas (DCI):
A Framework for K-12 Science Education
- LS1.A: Systems of specialized cells within organisms help them perform the essential functions of life, which involve chemical reactions that take place between different types of molecules, such as water, proteins, carbohydrates, lipids, and nucleic acids.

Benchmarks for Science Literacy
- 5C/H8: A living cell is composed of a small number of chemical elements mainly carbon, hydrogen, nitrogen, oxygen, phosphorus, and sulfur. Carbon, because of its small size and four available bonding electrons, can join to other carbon atoms in chains and rings to form large and complex molecules.

NAEP (2028 Framework)
- L12.1: Systems of specialized cells within organisms help them perform the essential functions of life, which involve chemical reactions that take place between different types of molecules.

What does it look like to demonstrate proficiency?

***Revised Bloom's Taxonomy*:** **Illustrate-** Finding a specific example or illustration of a concept or principle

Construct Explanation
Students construct an explanation that includes:

- a description of the structure and function relationship for each macromolecule - carbohydrates, lipids, proteins, and nucleic acids.
- a description of how macromolecules support the survival of all living things.

Evidence
Students identify and describe* the evidence to construct the explanation, including:

- The major functions of each macromolecule:
  - Carbohydrate: provide quick energy in organisms and can be used in the formation of cell walls
  - Lipid: store energy, provide insulation and protection
  - Proteins: build cellular (microtubules, enzymes) and organism (hair, nail, collagen) structures; send chemical signals/messages
  - Nucleic acids: store and transmit genetic information (DNA, RNA)
- The 4 essential elements that make up all organisms - Carbon (C), Hydrogen (H), Oxygen (O), Nitrogen (N).
- The elemental composition (not ratio) of each macromolecule:
  - Carbohydrate: C, H, O
  - Lipid: C, H, O
  - Protein: C, H, O, N
  - Nucleic Acid: C, H, O, N, Phosphorus
- The monomer to the polymer for each macromolecule ***(in name only, not model or structure)***
  - Carbohydrate: Monosaccharide (monomer), Polysaccharide (polymer)
  - Lipid: Fatty Acids + Glycerol (monomer)
  - Protein: Amino Acid (monomer), Polypeptide (polymer)
  - Nucleic Acid: Nucleotide (monomer) = Phosphate + Sugar + Nitrogenous Base
    - Deoxyribonucleic Acid (DNA) is a double helix composed of: Phosphate + Deoxyribose + (Adenine, Thymine, Guanine or Cytosine)
    - Ribonucleic Acid (RNA) is a single strand composed of: Phosphate + Ribose + (Adenine, Uracil, Guanine or Cytosine)

Reasoning
Students use reasoning to connect evidence and construct an explanation about structure and function of macromolecules. Students describe* the following chain of reasoning in their explanation:

- Essential elements (carbon, oxygen, hydrogen, nitrogen, phosphorus) exist within, and cycle between, living organisms as biomolecules.
- Monomers are subunits of larger molecules called *polymers*. Polymers can be used to build larger structures necessary for survival. For example:

- Plants use glucose to form starches, which are used to build cellulose for cell walls.
- Phospholipids (which are built from lipids) have hydrophobic properties, which allow for the formation of a cellular membrane/phospholipid bilayer in all cells.
- Proteins are built from amino acid chains, which then fold into a 3-D shape that correlates to a specific function.

- If the structure of a macromolecule is changed, the function may be altered (e.g., changes in protein shape).

**Note: When "describe" is referenced, any of the following descriptions could be used: written, oral, pictorial, and kinesthetic.*

Suggestion: The connection between nutrient cycles (carbon, nitrogen, phosphorus) and biological processes (generation of macromolecules) should be highlighted throughout the course.

Academic Language
Questions/Sentence Stems that utilize academic language:

- What structures are present in _____? What function does each structure have in _____(scenario)?
- The relationship between the structure and the function?
- Why does the shape of _____ matter for its function? What other properties of the structure might allow it to have certain behaviors?
- The individual structures of _____ function to _____. The structures together allow the system to _____.

Words to support student discourse: monomer, polymer, carbohydrate, monosaccharide, polysaccharide, protein, amino acid, polypeptide, lipid, nucleic acid, metabolism, acid, base, pH, homeostasis, elements (C,H,O,N,P), catalyst, glucose, cellulose, phospholipid, RNA, DNA

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LS.Bio.1.2 Carry out investigations to illustrate how enzymes act as catalysts for biochemical reactions and how environmental factors affect enzyme activity.

Clarification Statement:

- Emphasis should be on observing, carrying out, and referencing investigations that model how enzymes speed up biochemical reactions under optimum and varying environmental conditions (e.g., temperature, pH).
- Students are expected to use experimental data to draw conclusions about cause-and-effect relationships between enzyme activity and changing environmental conditions.

Boundary Statement:

- Students are *not* expected to know the following concepts: coenzyme, inhibitors, competitive enzymes, dehydration synthesis, hydrolysis, and condensation reaction.
- Students are *not* expected to know specific enzyme or substrate names, but they may be introduced to many examples in instruction.

Dimension 1: Science and Engineering Practice (SEP): Plan and Carry Out Investigations
NAEP (2028 Framework)

- S12.5: Plan an investigation that will produce data to serve as the basis for evidence as part of building and revising models, supporting explanations for phenomena, or testing solutions to problems. Consider possible confounding variables or effects and evaluate the investigation's design to ensure appropriate variables are controlled.
- S12.8: Predict the outcome of an investigation or test of a design plan and support that prediction with an argument including evidence from models, evidence from prior experiments, and/or the application of science knowledge to support the prediction.

NSTA Progression

- Plan and conduct an investigation individually and collaboratively to produce data to serve as the basis for evidence, and in the design: decide on types, how much, and accuracy of data needed to produce reliable measurements and consider limitations on the precision of the data (e.g., number of trials, cost, risk, time), and refine the design accordingly. Plan and conduct an investigation or test a design solution in a safe and ethical manner including considerations of environmental, social, and personal impacts.
- Select appropriate tools to collect, record, analyze, and evaluate data.
- Make directional hypotheses that specify what happens to a dependent variable when an independent variable is manipulated.
- Manipulate variables and collect data about a complex model of a proposed process or system to identify failure points or improve performance relative to criteria for success or other variables.

Dimension 2: Crosscutting Concepts (CCC):
Crosscutting concepts are conceptual tools used along with the SEP and DCI to help students explain and predict phenomena. They support students in making connections between disciplines and provide a context for sense-making. Teachers should encourage students to frame their thinking around the terminology of the CCC through questions* and classroom discussions. The most relevant Crosscutting Concepts may vary in light of the specific learning objectives and how the topic is structured. Choose the one(s) that best support(s) the instructional goals and help(s) students make connections across different aspects of the content.
Suggested Crosscutting Concept: (A Framework for K-12 Science Education)

- **Cause and Effect**

*[STEM Teaching Tool #41: Prompts for Integrating Crosscutting Concepts Into Assessment and Instruction]

Dimension 3: Disciplinary Core Ideas (DCI):
A Framework for Science Education
- LS1.A: Specialized structures within cells are also responsible for specific cellular functions. These essential functions of a cell involve chemical reactions between many types of molecules, including water, proteins, carbohydrates, lipids, and nucleic acids.

Benchmarks for Science Literacy
- 5C/H9**(SFAA): Some protein molecules assist in replicating genetic information, repairing cell structures, helping other molecules get in or out of the cell, and generally catalyzing and regulating molecular interactions.

NAEP (2028 Framework)
- L12.1: Systems of specialized cells within organisms help them perform the essential functions of life, which involve chemical reactions that take place between different types of molecules.

What does it look like to demonstrate proficiency?

***Revised Bloom's Taxonomy*:** **Illustrate-** Finding a specific example or illustration of a concept or principle

Carrying out the investigation
In the investigation, students describe:
- How to conduct the investigation safely, ethically, and with consideration of environmental impact.
- What data is needed, how much is enough, and how accurate and precise it needs to be to help make the best conclusions.
- Appropriate tools to collect, record, analyze, and evaluate data for investigation.

Collecting the data
Students collect and record data about:
- Enzymes acting as catalysts for specific reactions with specific substrates (e.g., lactase only catalyzes the breakdown of lactose) including:
  - Enzymes speed up the chemical reaction by lowering the activation energy.
  - Enzymes are reusable.
- Enzyme function changes with varying environmental factors (like pH and temperature); data can be used to demonstrate how an enzyme may be denatured with extreme temperature and pH changes.
  - Enzymes have a 3D shape that is specific to their substrate, similar to a lock and key. If that 3D shape gets changed due to environmental conditions changing, the enzyme can no longer function.
- Optimum environmental conditions (pH and/or temperature) for a specific enzyme to function in order to catalyze a

biochemical reaction
    - This may include constructing and analyzing graphs of enzyme function/activity.

Drawing conclusions
Students summarize findings to include:
- Enzymes are proteins that speed up chemical reactions (catalysts) by lowering the activation energy.
- Enzymes are reusable and specific.
- Enzymes are affected by such factors as pH and temperature.
- Enzymes are necessary for all biochemical reactions.
- Enzyme function can be altered when the enzyme structure/shape is compromised.

Refining the design
Students evaluate their assessment including:
- Assessment of the accuracy and precision of the data, as well as limitations (e.g., cost, risk, time) of the investigation, and make suggestions and refinement
- Assessment of the ability of the data to provide the evidence required

If necessary, students refine the investigational plan to
- Produce more generalizable data about factors that affect enzyme structure or function.

Academic Language
Questions/Sentence Stems that utilize academic language:
- What caused the patterns you observed?
- Follow up question: How do you know that _____ caused _____?
- Does the fact that that the data showed that _____ always happened [after/whenever]
- _____ occurred mean that _____ causes _____? Why or why not?
- Follow up question: How can you test whether _____ caused _____ to happen?
- What do you predict would happen if [extrapolate to a new, related situation]?
- What would you predict in [present new situation involving same mechanism] would happen?
- How is the situation similar to or different from [the presented scenario]?
- How do _____ and _____ affect _____?
- How do _____ and _____ affect each other over time?
- What evidence presented in the scenario supports the claim that _____ causes _____?
- Is the evidence presented sufficient to conclude that _____ caused _____? If not, what additional evidence is needed?

Words to support student discourse: enzyme, protein, catalyst, activation energy, reactants, products, denature, temperature, pH, buffer, substrate, active site, enzyme-substrate complex, specificity (substrate to enzyme), homeostasis, structure, function

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LS.Bio.1.3 Use models to explain how the structure of organelles determines its function and supports overall cell processes.

Clarification Statement:

- Emphasis should be on how each organelle or cellular structure supports operations within and among cells.
  - Organelles and cell structures include: nucleus, plasma membrane, cell wall, mitochondria, vacuoles, chloroplasts, ribosomes, smooth and rough endoplasmic reticulum, lysosomes, Golgi apparatus, cytoplasm, flagella, and cilia.
  - Function examples: Folded inner membrane in mitochondria increases surface area for energy production during aerobic cellular respiration; this energy supports daily cell operation.

Boundary Statement:

- Students are *not* expected to identify the following cell structures: microtubules, filaments, nucleolus, cristae or matrix (in the mitochondria), stroma or granum (in chloroplasts), or centrioles.
- Students are *not* expected to know the origin of mitochondria or chloroplasts through the Endosymbiotic Theory.

Dimension 1: Science and Engineering Practice (SEP): *Develop and Use Models*
NAEP (2028 Framework)

- S12.16: Develop, use, and/or revise a model that includes mathematical relationships (including both visible and invisible quantities) to describe, explain, and/or predict phenomena or to test a proposed design solution.

NSTA Progression

- Develop a complex model that allows for manipulation and testing of a proposed process or system.
- Develop, revise, and/or use a model based on evidence to illustrate and/or predict the relationships between systems or between components of a system.

Dimension 2: Crosscutting Concepts (CCC):
Crosscutting concepts are conceptual tools used along with the SEP and DCI to help students explain and predict phenomena. They support students in making connections between disciplines and provide a context for sense-making. Teachers should encourage students to frame their thinking around the terminology of the CCC through questions* and classroom discussions. The most relevant Crosscutting Concepts may vary in light of the specific learning objectives and how the topic is structured. Choose

the one(s) that best support(s) the instructional goals and help(s) students make connections across different aspects of the content.

Suggested Crosscutting Concept: (A Framework for K-12 Science Education)

- **Structure and Function**

*STEM Teaching Tool #41: Prompts for Integrating Crosscutting Concepts Into Assessment and Instruction

Dimension 3: Disciplinary Core Ideas (DCI):

A Framework for K-12 Science Education

- LS1.A: Organisms and their parts are made of cells, which are the structural units of life and which themselves have molecular substructures that support their functioning. Specialized structures within cells are also responsible for specific cellular functions. These essential functions of a cell involve chemical reactions between many types of molecules, including water, proteins, carbohydrates, lipids, and nucleic acids. Within cells, special structures are responsible for particular functions, and the cell membrane forms the boundary that controls what enters and leaves the cell.

Benchmarks for Science Literacy

- 5C/H1a: Every cell is covered by a membrane that controls what can enter and leave the cell.
- 5C/H2a: Within the cells are specialized parts for the transport of materials, energy capture and release, protein building, waste disposal, passing information, and even movement.

NAEP (2028 Framework)

- L12.2: Multicellular organisms have a hierarchical organization, in which its systems support functions necessary for the organism's survival and reproduction. Each system is made up of numerous parts and is itself a component of the next level.

What does it look like to demonstrate proficiency?

Revised Bloom's Taxonomy: **Explain**- Constructing a cause-and-effect model of a system

Components of the model

From the given model, students identify and describe* the components of the model in order to:

- Distinguish between plant and animal cell diagrams based on organelles present
    - Students may use light microscopes or digital microscope simulations in order to attain models of cells and cell structures.
    - Students may use representations from light and electron microscopes for comparison of cell structures.
- Explain how the structure of the organelle determines its function. (e.g., folded inner membrane in mitochondria increases surface area for energy production during aerobic cellular respiration).

- Explain the implications of specific organelles not functioning properly in cells.

Relationships
Students identify the following relationship between components of the given model:

- Summarize how organelles interact to carry out functions such as energy production and use, transport of molecules, disposal of waste, and synthesis of new molecules (e.g., DNA codes for proteins which are assembled by the ribosomes and used as enzymes for energy production at the mitochondria).
- Structures within and/or shapes of specialized cells are related to specific cellular functions (or the shape of nerve cells and muscle cells).

Connections
Students use the given model to illustrate/explain:

- The proportion and quantity of organelles within a specific type of cell compared to a different cell type can lead to specializations or differences in cell functionality (e.g., high amount of mitochondria could mean a muscle cell; large amounts of golgi bodies could mean an endocrine cell based on functionality of the cell type).
- Cause and effect relationships between quantity of organelles to cell function (e.g., more mitochondria in muscle and nerve cells than in skin cells, presence of chloroplasts in leaf cells, more ribosomes in pancreatic cells)

**Note: When "describe" is referenced, any of the following descriptions could be used: written, oral, pictorial, and kinesthetic.*

Academic Language
Questions/Sentence Stems that utilize academic language:

- The _____ structures help _____ to function because _____.
- I/we think that the _____ structures in the system (choose the system) function _____.
- The _____ structures are present in _____ and are related to the function _____.

Words to support student discourse: cell, prokaryote, eukaryote, nucleus, organelle, plasma membrane, cell wall, chloroplast, cilia, cytoplasm, cytoskeleton, endoplasmic reticulum (smooth/rough), vesicles, flagella, Golgi apparatus, lysosome, mitochondria, ribosome, vacuole, chlorophyll, microscope, homeostasis, phospholipid, selective permeability, transport proteins, structure, function

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LS.Bio.1.4 Construct an explanation to compare prokaryotic and eukaryotic cells in terms of structures and degree of complexity.

Clarification Statement:

- Emphasis should be on exploring structures (genetic materials, plasma membrane, internal and external structures) in order to determine that there is a difference in complexity between prokaryotic and eukaryotic cells.

Boundary Statement:

- Students are *not* expected to know the following terms or concepts: pili, gram positive or negative, and capsule.

Dimension 1: Science and Engineering Practice (SEP): Construct an Explanation
NAEP (2028 Framework)

- S12.18: Construct or revise an explanation that uses a chain of cause and effect or evidence-based associations between factors to account for the qualitative or quantitative relationships between variables in a phenomenon.

NSTA Progression

- Construct and revise an explanation based on valid and reliable evidence obtained from a variety of sources (including students' own investigations, models, theories, simulations, peer review) and the assumption that theories and laws that describe the natural world operate today as they did in the past and will continue to do so in the future.
- Apply scientific ideas, principles, and/or evidence to provide an explanation of phenomena and solve design problems, taking into account possible unanticipated effects.

Dimension 2: Crosscutting Concepts (CCC):
Crosscutting concepts are conceptual tools used along with the SEP and DCI to help students explain and predict phenomena. They support students in making connections between disciplines and provide a context for sense-making. Teachers should encourage students to frame their thinking around the terminology of the CCC through questions* and classroom discussions. The most relevant Crosscutting Concepts may vary in light of the specific learning objectives and how the topic is structured. Choose the one(s) that best support(s) the instructional goals and help(s) students make connections across different aspects of the content.
Suggested Crosscutting Concept: (A Framework for K-12 Science Education)

- **Structure and Function**

**STEM Teaching Tool #41: Prompts for Integrating Crosscutting Concepts Into Assessment and Instruction*

Dimension 3: Disciplinary Core Ideas (DCI):
A Framework for Science Education

- LS1.A: A central feature of life is that organisms grow, reproduce, and die. Organisms range in composition from a single cell (unicellular microorganisms) to multicellular organisms, in which different groups of large numbers of cells work together to form systems of tissues and organs (i.e., circulatory, respiratory, nervous, musculoskeletal), that are specialized

for particular functions.

Benchmarks for Science Literacy

- 5C/H1b: In all but quite primitive cells, a complex network of proteins provides organization and shape and, for animal cells, movement.

What does it look like to demonstrate proficiency?

Revised Bloom's Taxonomy: **Compare**- Finding similarities and differences between two or more objects, events, ideas, problems, or situations

Constructing Explanations

Students construct an explanation that includes:

- Prokaryotic cells are less complex than eukaryotic cells; eukaryotic cells contain complex cell structures and organelles.
- While all living things are made up of cells, there exists both unicellular and multicellular organisms. Different types of cells can exist within one multicellular organism.

Evidence

Students identify and describe* the evidence to construct the explanation, including:

- Eukaryotes contain the presence of membrane bound organelles – mitochondria, nucleus, vacuole, and chloroplasts are not present in prokaryotes.
- Ribosomes are found in both prokaryotes and eukaryotes.
- DNA and RNA are present in both, but are not enclosed by a membrane in prokaryotes.
- Chromosome structure is different- eukaryotes have chromosomes and prokaryotes have a single circular strand of DNA.
- Contrasts in size – prokaryotic cells are smaller than eukaryotic cells.
- All cells are small and are unable to be seen with the unaided eye and require engineered magnification devices to be seen.

Reasoning

Students use reasoning to connect evidence and construct an explanation about complexity of cell types. Students describe* the following chain of reasoning in their explanation:

- Prokaryotic cells are smaller, do not contain membrane-bound organelles, and genetic material is in the the form of a single circular strand of DNA.
- Eukaryotic cells are larger, contain membrane-bound organelles, and genetic material is in the form of a chromosome.
- After investigation into similarities and differences of genetic material, cell structures, and cell size, we can determine that all eukaryotic cells are more complex than prokaryotic cells.

- All cells that do not contain membrane-bound organelles and are considerably small in size should be classified a prokaryotic cell.

**Note: When "describe" is referenced, any of the following descriptions could be used: written, oral, pictorial, and kinesthetic.*

Academic Language
Question/Sentence Stems that utilize academic language:

- The _____ structures help _____ to function because _____.
- I/We think that the organism is _____ (prokaryotic/eukaryotic) because _____.
- The _____ (structures) are present in _____ and are related to the _____ (function).
- How does the structure of a prokaryotic cell compare to the structure of a eukaryotic cell?

Words to support student discourse: prokaryotic, eukaryotic, animal, fungi, protist, membrane-bound organelles, chromosome (linear),membrane, cell size, complexity

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LS.Bio.1.5 Construct an explanation to summarize how DNA and RNA direct the synthesis of proteins.

Clarification Statement:

- DNA has a double-helix structure, with weak hydrogen bonds holding nucleotides together.
  - Replication of DNA occurs prior to mitosis (LS.Bio.2.1) or meiosis (LS.Bio.6.2).
- The sequence of nucleotides in DNA codes for RNA, which determines the amino acid sequence of proteins (transcription and translation).
  - Transcription produces messenger RNA (complementary single-stranded copy of a gene).
  - Ribosomes translate messenger RNA into proteins.
- DNA codes for the structure of proteins, which regulate and carry out the essential functions of life and result in specific traits.

Boundary Statement:

- Students are expected to interpret an amino acid sequence chart.
- Students are *not* expected to identify specific cell or tissue types, whole body systems, specific protein structures and functions, or the biochemistry of protein synthesis (e.g., do not need to know the role of RNA polymerase, the process of initiation, promotion, elongation, or termination in protein synthesis).

Dimension 1: Science and Engineering Practice (SEP): *Construct an Explanation*
NAEP (2028 Framework)

- S12.18: Construct or revise an explanation that uses a chain of cause and effect or evidence-based associations between factors to account for the qualitative or quantitative relationships between variables in a phenomenon.

NSTA Progression

- Construct and revise an explanation based on valid and reliable evidence obtained from a variety of sources (including students' own investigations, models, theories, simulations, peer review) and the assumption that theories and laws that describe the natural world operate today as they did in the past and will continue to do so in the future.
- Apply scientific ideas, principles, and/or evidence to provide an explanation of phenomena and solve design problems, taking into account possible unanticipated effects.

Dimension 2: Crosscutting Concepts (CCC):
Crosscutting concepts are conceptual tools used along with the SEP and DCI to help students explain and predict phenomena. They support students in making connections between disciplines and provide a context for sense-making. Teachers should encourage students to frame their thinking around the terminology of the CCC through questions* and classroom discussions. The most relevant Crosscutting Concepts may vary in light of the specific learning objectives and how you structure the topic. Choose the one(s) that best support(s) your instructional goals and help(s) students make connections across different aspects of the content.
Suggested Crosscutting Concept: (A Framework for K-12 Science Education)

- **Structure and Function**

**STEM Teaching Tool #41: Prompts for Integrating Crosscutting Concepts Into Assessment and Instruction*

Dimensions 3: Disciplinary Core Ideas (DCI):
A Framework for K-12 Science Education

- LS1.A: All cells contain genetic information in the form of DNA molecules. Genes are regions in the DNA that contain the instructions that code for the formation of proteins, which carry out most of the work of cells**.**
- LS3.A: In all organisms the genetic instructions for forming species' characteristics are carried in the chromosomes. Each chromosome consists of a single very long DNA molecule, and each gene on the chromosome is a particular segment of that DNA. The instructions for forming species' characteristics are carried in DNA. All cells in an organism have the same genetic content, but the genes used (expressed) by the cell may be regulated in different ways. Not all DNA codes for a protein; some segments of DNA are involved in regulatory or structural functions, and some have no as-yet known function.

Benchmarks for Science Education

- 5C/H4a: The genetic information encoded in DNA molecules provides instructions for assembling protein molecules.
- 5C/H4b: The genetic information encoded in DNA molecules is virtually the same for all life forms.

- 5B/H3*: The information passed from parents to offspring is coded in DNA molecules, long chains linking just four kinds of smaller molecules, whose precise sequence encodes genetic information.
- 5C/H3: The work of the cell is carried out by the many different types of molecules it assembles, mostly proteins. Protein molecules are long, usually folded chains made from 20 different kinds of amino acids molecules. The function of each protein molecule depends on this specific sequence of amino acids and its shape. The shape of the chain is a consequence of attractions between its parts.
- 5A/H4**(SFAA): Most complex molecules of living organisms are built up from smaller molecules. The various kinds of small molecules are much the same in all life forms, but the specific sequences of components that make up the very complex molecules are characteristic of a given species.

NAEP (2028 Framework)

- L12.14: Each chromosome consists of a single very long DNA molecule, and each gene on the chromosome is a particular region of that DNA. Genes contain the instructions to code for the formation of proteins that determine traits. Not all DNA codes for a protein; some segments of DNA are involved in regulatory or structural functions, and some have no currently known function.

What does it look like to demonstrate proficiency?

Revised Bloom's Taxonomy: **Summarize-** Condensing larger information into a general theme or major point(s)

Constructing Explanations

Students construct an explanation that includes:

- Segments of DNA (called *genes*) code for specific traits within an organism.
- DNA controls the expression of traits by being transcribed into mRNA, which is translated by ribosomes into a protein.
- In DNA:
    - Each chromosome consists of a single very long DNA molecule, and each gene on the chromosome is a particular segment of that DNA.
    - The structure of DNA is a double helix formed from 2 complementary strands of nucleotides held together by weak hydrogen bonds.
    - DNA molecules contain four different kinds of building blocks, called *nucleotides* (composed of a phosphate, a deoxyribose sugar, and a nitrogenous base) linked together in a sequential chain (LS.Bio.1.1).
        - Adenine (A) pairs with Thymine (T).
        - Guanine (G) pairs with Cytosine (C).
    - Regions of DNA called *genes* determine the structure of proteins, which carry out the essential functions of life through systems of specialized cells.
    - DNA serves as a template for messenger RNA (mRNA) and amino acid sequence.

- In RNA:
  - Guanine (G) pairs with Cytosine (C).
  - Adenine (A) pairs with Uracil (U).
    - During transcription, Uracil (U) substitutes for Thymine (T).
  - RNA is single-stranded.
- On ribosomes:
  - Groups of three mRNA nucleotides (called *codons*) are paired with complementary transfer RNA (tRNA) which carries a unique amino acid.
  - Students use a codon chart to determine the amino acid sequence produced by a particular sequence of bases.
  - Amino acids are linked by peptide bonds to form polypeptides.

Evidence
Students identify and describe* the evidence to construct the explanation, including:
- All cells contain DNA.
- DNA contains regions that are called *genes*.
- The sequence of genes contains instructions that code for proteins.
- Transcription of the DNA template to mRNA occurs in the nucleus.
- Translation of mRNA to protein occurs when tRNA delivers amino acids to ribosomes in the cytoplasm.
- Proteins are necessary to carry out functions that are essential to the cell and/or organism.

Reasoning
- Because all cells contain DNA, all cells contain genes that can code for the formation of proteins.
- Body tissues are systems of specialized cells with similar structures and functions, each of whose functions are mainly carried out by the proteins they produce.
- Mistakes in any process can result in changes to amino acid sequence and protein function.
- Proper function of many proteins is necessary for the proper functioning of the cells.
- Gene sequence affects protein function, which in turn affects the function of body tissues.

**Note: When "describe" is referenced, any of the following descriptions could be used: written, oral, pictorial, and kinesthetic.*

Academic Language
Question/Sentence Stems that utilize academic language:
- What structures are present in _____? What function does each structure have in _____[scenario or process]?
- The relationship between the structure and its function is _____?
- What do the individual structures do? How do the structures work together to allow the system to function?
- For the model, describe the behaviors by which the structures accomplish their functions.

Words to support student discourse: DNA, RNA, protein, amino acid, double helix, nitrogenous base, Adenine, Guanine, Cytosine, Thymine, Uracil, deoxyribose, ribose, phosphate, hydrogen bond, template, transcription, translation, mRNA, tRNA, cell, nucleus, ribosome, nucleotide, base pair, peptide/polypeptide, codon, sequence, expression, chromosome, gene

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LS.Bio.2 Analyze the growth and development processes of organisms.

LS.Bio.2.1 Use models to illustrate how cellular division results in the reproduction, growth, and repair of organisms.

Clarification Statement:

- Emphasis is on the conceptual understanding the role mitosis plays in the production, growth, repair, and maintenance of systems within complex organisms.
- Genetically identical cells are the product of mitosis.
- Students are expected to describe major events in the cell cycle including cell growth, DNA replication, separation of chromosomes, and remaining cellular components.

Note: The role of meiosis in producing gametes for sexual reproduction is addressed in LS.Bio.6.1.

Boundary Statement:

- Students are responsible for knowing the overall purpose, process, and products of mitosis.
- Students are *not* responsible for knowing order of mitotic stages.
- Students are expected to determine or compare haploid and diploid numbers of chromosomes in different cell types.
    - Students are expected to describe/identify ploidy using given information:
        - Haploid = n = sex/reproductive cells/gametes
        - Diploid = 2n = body/somatic cells
    - Students are expected to calculate n, when given 2n and calculate 2n, when given n.
- Students are *not* responsible for knowing specific cell cycle control proteins.

Dimension 1: Science and Engineering Practice (SEP): *Develop and Use Models*
NAEP (2028 Framework)

- S12.16: Develop, use, and/or revise a model that includes mathematical relationships (including both visible and invisible quantities) to describe, explain, and/or predict phenomena or to test a proposed design solution.

NSTA Progression

- Develop a complex model that allows for manipulation and testing of a proposed process or system.
- Develop, revise, and/or use a model based on evidence to illustrate and/or predict the relationships between systems or between components of a system.

Dimension 2: Crosscutting Concepts (CCC):
Crosscutting concepts are conceptual tools used along with the SEP and DCI to help students explain and predict phenomena. They support students in making connections between disciplines and provide a context for sense-making. Teachers should encourage students to frame their thinking around the terminology of the CCC through questions* and classroom discussions. The most relevant Crosscutting Concepts may vary in light of the specific learning objectives and how you structure the topic. Choose the one(s) that best support(s) your instructional goals and help(s) students make connections across different aspects of the content.
Suggested Crosscutting Concept: (A Framework for K-12 Science Education)

- **Systems and System Models**

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Dimension 3: Disciplinary Core Ideas (DCI):
A Framework for K-12 Science Education

- LS1.B: In multicellular organisms individual cells grow and then divide via a process called *mitosis*, thereby allowing the organism to grow. The organism begins as a single cell (fertilized egg) that divides successively to produce many cells, with each parent cell passing identical genetic material (two variants of each chromosome pair) to both daughter cells.

Benchmarks for Science Literacy

- 5C/H4c: Before a cell divides, the instructions are duplicated so that each of the two new cells gets all the necessary information for carrying on.

What does it look like to demonstrate proficiency?

***Revised Bloom's Taxonomy*:** **Illustrate-** Finding a specific example or illustration of a concept or principle

Components of the model
From the given model, students identify and describe* the components of the model in order to:

- Illustrate the role of mitotic cell division in producing and maintaining complex organisms.
    - Genetic material is organized in separate DNA strands (called *chromosomes*) with different genes on different chromosomes.
    - Inputs of mitotic cell division are called *parent cells*. Outputs are called *daughter cells*.

Relationships
Students identify and *describe the relationship between model components:

- Parent cells replicate DNA in preparation for cell division (LS. Bio 1.5).
- Genetic information moves through specific mitotic stages.
- Daughter cells receive identical genetic information from the parent cell.
- Mitotic cell division produces two genetically identical daughter cells from a parent cell (same number and type of chromosomes).
- Genetic material moves in predictable patterns to allow for the production of identical daughter cells.

Connections
Students use the model to illustrate that mitotic cell division in cells:

- Allows for the growth of organisms.
- Can replace old, dead, or damaged cells to maintain a complex organism.
- Allows for reproduction of unicellular organisms.

Students differentiate between the accuracy of the model and the process of mitosis.
Students compare the purpose, process, and products of mitosis and meiosis (LS.Bio.6.1).

**Note: When "describe" is referenced, any of the following descriptions could be used: written, oral, pictorial, and kinesthetic.*

Academic Language
Questions/Sentence Stems that utilize academic language:

- How do daughter cells relate to parent cells?
- How do the parts of the system work together to accomplish mitotic cell division?
- How does genetic information flow within the system?
- In the system, _____ and _____ are shown in the model.
- In the system, _____ and _____ work together to _____.

Words to support student discourse:
mitosis, growth, maintenance, cell cycle, cell signaling, DNA replication, chromosomes, diploid (2n), identical, multicellular, nucleus, daughter cell, parent cell, DNA, tissue, organ, asexual reproduction, somatic or body cells, interphase, Growth 1, synthesis, DNA replication, Growth 2, mitosis, prophase, metaphase, anaphase, telophase, cytokinesis, binary fission, **haploid (n)- when comparing mitosis and meiosis*

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LS.Bio.2.2 Construct an explanation to illustrate that proteins regulate gene expression resulting in cellular differentiation, specialized cells with specific functions, and uncontrolled cell growth.

Clarification Statement:

- Emphasis is on typical mitotic cell division as well as instances in which cell division is uncontrolled.
- Cell division and differentiation produce and maintain complex organisms.
- Genetically identical stem cells undergo differentiation into diverse cell types, which build systems of tissues and organs that work together to meet the needs of the whole organism.

Boundary Statement:

- Students are responsible for knowing all cells within an organism have the same DNA sequence. Gene expression determines protein production within different cells, which result in the specialization of cell types and functions.
- Students are responsible for knowing that uncontrolled cell growth can result in tumors, which can either be benign (growths) or malignant (cancer).
    - Students are responsible for understanding that cancer results from mutations, which cause accelerated cell division.
    - Students are *not* responsible for specific mechanisms of oncogenesis or stages of cancer.
- Students are *not* expected to explain the specifics of transcriptional regulation (gene control regulation) or biochemical modifications (DNA methylation or histone modifications) of DNA that regulate gene expression and result in differentiation.

Dimension 1: Science and Engineering Practice (SEP): *Construct an Explanation*
NAEP (2028 Framework)

- S12.18: Construct or revise an explanation that uses a chain of cause and effect or evidence-based associations between factors to account for the qualitative or quantitative relationships between variables in a phenomenon.

NSTA Progression

- Construct and revise an explanation based on valid and reliable evidence obtained from a variety of sources (including students' own investigations, models, theories, simulations, peer review) and the assumption that theories and laws that describe the natural world operate today as they did in the past and will continue to do so in the future.
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The most relevant Crosscutting Concepts may vary in light of the specific learning objectives and how you structure the topic. Choose the one(s) that best support(s) your instructional goals and help(s)s students make connections across different aspects of the content.

Suggested Crosscutting Concept: (A Framework for K-12 Science Education)

- **Cause and Effect**

**STEM Teaching Tool #41: Prompts for Integrating Crosscutting Concepts Into Assessment and Instruction*

Dimension 3: Disciplinary Core Ideas (DCI):

A Framework for K-12 Science Education

- LS1.B: As successive subdivisions of an embryo's cells occur, programmed genetic instructions and small differences in their immediate environments activate or inactivate different genes, which cause the cells to develop differently- a process called differentiation. Cellular division and differentiation produce and maintain a complex organism, composed of systems of tissues and organs that work together to meet the needs of the whole organism.

Benchmarks for Science Literacy

- 5C/H2b: In addition to the basic cellular functions common to all cells, most cells in multicellular organisms perform some special function that others do not.
- 5B/H6a: The many body cells in an individual can be very different from one another, even though they are all descended from a single cell and thus have essentially identical genetic instructions.
  5B/H6b: Different parts of the genetic instructions are used in different types of cells, influenced by the cell's environment and past history.
- 6B/H1: As successive generations of an embryo's cells form by division, small differences in their immediate environments cause them to develop slightly differently, by activating or inactivating different parts of the DNA information.

What does it look like to demonstrate proficiency?

Revised Bloom's Taxonomy: Illustrate- Finding a specific example or illustration of a concept or principle

Constructing Explanations

Students construct an explanation that includes:

- Genetic material encodes instructions for proteins.
- Organisms make many proteins with diverse functions.
- Different cell types contain different types of proteins.
- A multicellular organism is a collection of differentiated cells.

Evidence

Students identify and *describe the evidence to construct the explanation, including:

- Daughter cells are genetically identical to parent cells.
- Genetic material within an organism is identical across cell types.
- Multicellular organisms begin as undifferentiated stem cells.
- Variation in DNA expression and gene activity determines the differentiation of cells and ultimately their specialization.
- Differences between cell types are due to differences in gene expression.
- Different cell types have different functions in multicellular organisms (e.g., nerve cells, muscle cells, blood cells, and/or sperm cells).

Reasoning

Students use reasoning to connect the evidence and to construct the explanation that all cells come from pre-existing cells. Students describe* the following chain of reasoning in their explanation:

- All cells in an organism contain the same DNA sequence, which code for specific genes, which control protein production.
- This DNA sequence is passed to new cells through the process of mitotic cell division.
- Mitotic cell division allows for the growth and repair of organisms, by way of making new cells of the same kind.
- Genes within the cellular DNA can be expressed differently (cellular differentiation), resulting in different cell types (neurons, muscle cells, bone cells, etc).
- Different cells have different cellular structures, which may reflect specialized cellular function (e.g., elongated neurons, communication).
- Daughter cells can replace old, dead, or damaged cells to maintain a complex organism.
- Mitosis that is not controlled may result in tumors (benign or malignant).

Revising the explanation

Given new evidence or context, students revise or expand their explanation about the differentiation of cells, and justify their revision. Examples may include:

- Embryonic stem cells can differentiate into any mature cell.
- Chemical signals may be released by one cell to influence the development and activity of another cell.
- Gene expression changes as stem cells differentiate into mature cells.
- Adult stem cells (e.g., bone marrow stem cells) can differentiate into a limited number of types of cell.
- Adults cells, with the right laboratory culture conditions, can be re-programmed to a stem cell-like state.
- Overproduction, underproduction, or production of proteins at the incorrect times may result in cancer.
- Cancerous cells divide more rapidly than healthy cells.

**Note: When "describe" is referenced, any of the following descriptions could be used: written, oral, pictorial, and kinesthetic.*

Academic Language
Question/Sentence Stems that utilize academic language:

- What do you predict would happen if differentiation did not occur?
- What do you predict would happen if checkpoints did not exist in cell division?
- How does gene expression affect cellular function?
- How does DNA sequence impact cell specialization?
- How does gene expression and cellular environment affect cell specialization?

Words to support student discourse:
mitosis, stem cell, differentiation, signaling, cell cycle, DNA/gene expression, protein, DNA replication, chromosomes, checkpoints, mutation, identical, multicellular, nucleus, daughter cell, parent cell, specialized cell, cell function, tissue, organ, system, cancer, benign, malignant, metastasize, growth, tumor

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LS.Bio.3 Analyze the relationship between biochemical processes and energy use.

LS.Bio.3.1 Carry out investigations to explain how homeostasis is maintained through feedback mechanisms.

Clarification Statement:

- Students are expected to carry out investigations to illustrate the need for homeostasis within organisms.
- On a cellular level, emphasis should be on how cells maintain stability in changing conditions by transporting materials across the plasma membrane. Emphasis is on how large and small particles can pass through the plasma membrane to maintain homeostasis.
- On an organism level, emphasis should be on responses to changing conditions (e.g., heart rate response to exercise, stomata response to moisture and temperature, and root development in response to water levels).

Boundary Statement:

- Students are expected to understand the overall concepts of cellular transport and homeostasis.
  - Students are *not* responsible for knowing these specific terms: *hypotonic, hypertonic, isotonic, endocytosis, exocytosis, phagocytosis, pinocytosis, water potential, facilitated diffusion, specific examples of pumps (sodium-potassium pump).*
- Students are *not* expected to know the cellular and chemical processes involved in the feedback mechanism.
- Students are expected to know the role of buffers in maintaining pH; however, they are not expected to know specific buffers.

Dimension 1: Science and Engineering Practice (SEP): *Plan and Carry Out Investigations*
NAEP (2028 Framework)

- S12.5: Plan an investigation that will produce data to serve as the basis for evidence as part of building and revising models, supporting explanations for phenomena, or testing solutions to problems. Consider possible confounding variables or effects and evaluate the investigation's design to ensure appropriate variables are controlled.
- S12.8: Predict the outcome of an investigation or test of a design plan and support that prediction with an argument including evidence from models, evidence from prior experiments, and/or the application of science knowledge to support the prediction.

NSTA Progression

- Plan and conduct an investigation individually and collaboratively to produce data to serve as the basis for evidence, and in the design: decide on types, how much, and accuracy of data needed to produce reliable measurements and consider limitations on the precision of the data (e.g., number of trials, cost, risk, time), and refine the design accordingly. Plan and conduct an investigation or test a design solution in a safe and ethical manner including considerations of environmental, social, and personal impacts.
- Select appropriate tools to collect, record, analyze, and evaluate data.
- Make directional hypotheses that specify what happens to a dependent variable when an independent variable is manipulated.
- Manipulate variables and collect data about a complex model of a proposed process or system to identify failure points or improve performance relative to criteria for success or other variables.

Dimension 2: Crosscutting Concepts (CCC):
Crosscutting concepts are conceptual tools used along with the SEP and DCI to help students explain and predict phenomena. They support students in making connections between disciplines and provide a context for sense-making. Teachers should encourage students to frame their thinking around the terminology of the CCC through questions* and classroom discussions. The most relevant Crosscutting Concepts may vary in light of the specific learning objectives and how you structure the topic. Choose the one(s) that best support(s) your instructional goals and help(s) students make connections across different aspects of the content.
Suggested Crosscutting Concept: (A Framework for K-12 Science Education)

- **Stability and Change**

**STEM Teaching Tool #41: Prompts for Integrating Crosscutting Concepts Into Assessment and Instruction*

Dimension 3: Disciplinary Core Ideas (DCI):
A Framework for K-12 Science Education

- LS1.A: Feedback mechanisms maintain a living system's internal conditions within certain limits and mediate behaviors,

allowing it to remain alive and functional even as external conditions change within some range. Outside that range (e.g., at a too high or too low external temperature, with too little food or water available), the organism cannot survive. Feedback mechanisms can encourage (through positive feedback) or discourage (negative feedback) what is going on inside the living system.

Benchmarks for Science Literacy

- 5C/H1a: Every cell is covered by a membrane that controls what can enter and leave the cell.
- 5C/H9** (SFAA): Some protein molecules assist in replicating genetic information, repairing cell structures, helping other molecules get in or out of the cell, and generally catalyzing and regulating molecular interactions.

NAEP (2028 Framework)

- L12.3: Feedback mechanisms maintain a living system's internal conditions within certain limits. Feedback mechanisms discourage change by means of negative feedback or proceed with changes through a system of positive feedback.

What does it look like to demonstrate proficiency?

Revised Bloom's Taxonomy: Explain- Constructing a cause-and-effect model of a system

Carrying out the investigation

In the investigation, students describe:

- how the change in the external environment (e.g., pH, concentration, temperature, activity level) is to be measured or identified.
- how the response of the cell and/or living system will be measured or identified (e.g., pH change, increased or decreased water levels, heart rate, shivering, sweating, panting).
- the experimental procedure, the evidence derived from the data, and identification of limitations on the precision of data to include types and amounts.

Collecting the data

Students collect and record data on/about:

- Changes in the external environment and cell and/or organisms responses, including changes as a function of time (i.e., response time to a change in stimulus).

Drawing conclusions

Students summarize findings to include:

- The feedback mechanisms at the cellular level and organism level maintain homeostasis (diffusion, osmosis, active transport, passive transport).

    - Passive transport mechanisms move with the concentration gradient (from high to low concentration, until equilibrium).
    - Active transport mechanisms move against the concentration gradient (from low to high concentration).
- Within cells, special structures are responsible for particular functions, and the plasma membrane forms the boundary that controls what enters and leaves the cell (e.g., water moves with the concentration gradient causing swelling or shrinking of cells).
- Cell transport facilitates feedback mechanisms, which maintain a living system's internal conditions within certain limits and mediate behaviors, allowing it to remain alive and functional even as external conditions change within some range (e.g., contractile vacuoles in protists).
- Organisms respond to stimuli from their environment and actively maintain their internal environment through homeostasis (e.g., physiological or behavioral responses that maintain homeostasis).

Refining the design
Students evaluate their assessment including:

- Assessment of the accuracy and precision of the data, as well as limitations of the investigation (e.g., cost, risk, time), and make suggestions for refinement.
- Assessment of the ability of the data to provide the evidence required.

Academic Language
Question/Sentence Stems that utilize academic language:

- In this system, homeostasis is maintained by water moving from ___ to ___ concentration.
- In this system, homeostasis is maintained by water moving from ___ to ___.
- In this system, homeostasis is maintained _____.
- The _____(event) changed this system by _____.
- _____ was affected by the change of _____.
- The parts of the system that stay the same are _____.The parts of the system that change are _____.

Words to support student discourse: stability, homeostasis, balance, temperature, pH, plasma membrane, regulation, feedback mechanism, feedback loop, active transport, passive transport, diffusion, osmosis, concentration gradient, ATP, cell membrane, semipermeable, solute, solvent, molecules, particles, equilibrium, stimulus, response, input, output, external environment, internal environment, pump, buffer

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LS.Bio.3.2 Use models to illustrate how photosynthesis transforms light energy into chemical energy.

Clarification Statement:

- In photosynthesis, carbon dioxide and water in the presence of light energy is converted into glucose and oxygen.

$$\text{carbon dioxide + water} \xrightarrow{\text{sunlight}} \text{glucose + oxygen}$$

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

- The glucose molecules formed in photosynthesis contain carbon, hydrogen, and oxygen, which can be assembled into larger molecules (e.g., amino acids in proteins, sugars in DNA and RNA) or used for chemical energy to power life's processes.

Boundary Statement:

- Students are expected to recognize the reactants and products of photosynthesis (chemical formulas and words) and the organelle involved (chloroplasts).
- Students are *not* expected to explain the specific chemical steps of photosynthesis (i.e., light and dark reactions).
- Students are *not* expected to recall specific examples of photosynthetic organisms for assessment items.

Dimension 1: Science and Engineering Practice (SEO): *Develop and Use Models*
NAEP (2028 Framework)

- S12.16: Develop, use, and/or revise a model that includes mathematical relationships (including both visible and invisible quantities) to describe, explain, and/or predict phenomena or to test a proposed design solution.

NSTA Progression

- Develop a complex model that allows for manipulation and testing of a proposed process or system.
- Develop, revise, and/or use a model based on evidence to illustrate and/or predict the relationships between systems or between components of a system.

Dimension 2: Crosscutting Concepts (CCC):
Crosscutting concepts are conceptual tools used along with the SEP and DCI to help students explain and predict phenomena. They support students in making connections between disciplines and provide a context for sense-making. Teachers should encourage students to frame their thinking around the terminology of the CCC through questions* and classroom discussions. The most relevant Crosscutting Concepts may vary in light of the specific learning objectives and how you structure the topic. Choose the one(s) that best support(s) your instructional goals and help(s) students make connections across different aspects of the content.
Suggested Crosscutting Concept: (A Framework for K-12 Science Education)

- **Energy and Matter: Flows, Cycles, and Conservation**

*STEM Teaching Tool #41: Prompts for Integrating Crosscutting Concepts Into Assessment and Instruction

Dimension 3: Disciplinary Core Ideas (DCI):
A Framework for K-12 Science Education

- LS1.C: The process of photosynthesis converts light energy to stored chemical energy by converting carbon dioxide plus water into sugars plus released oxygen. The sugar molecules thus formed contain carbon, hydrogen, and oxygen; their hydrocarbon backbones are used to make amino acids and other carbon-based molecules that can be assembled into larger molecules (such as proteins or DNA), used for example to form cells. As matter and energy flow through different organizational levels of living systems, chemical elements are recombined in different ways to form different products. As a result of these chemical reactions, energy is transferred from one system of interacting molecules to another. Matter and energy are conserved in each change. This is true of all biological systems, from individual cells to ecosystems.

Benchmarks for Science Literacy

- 4C/H1*: Plants on land and underwater alter the earth's atmosphere by removing carbon dioxide from it, using the carbon to make sugars and releasing oxygen. This process is responsible for the oxygen content in the air.

What does it look like to demonstrate proficiency?

Revised Bloom's Taxonomy: Illustrate- Finding a specific example or illustration of a concept or principle

Components of the model
From the given model, students identify and describe* the components of the model in order to:

- Illustrate that photosynthesis transforms light energy into stored chemical energy by converting carbon dioxide and water into glucose and oxygen, including:
  - Energy in the form of light
  - Chloroplasts absorb light energy
  - Breaking of chemical bonds to absorb energy
  - Formation of chemical bonds to release energy
  - Matter in the form of carbon dioxide, water, sugar, and oxygen
  - Photosynthetic organisms may include: plants, phytoplankton, algae, and photosynthetic bacteria (students are not expected to recall specific examples of photosynthetic organisms for assessment items).

Relationships
Students use models to explain the following relationship between components of the given model:

- To occur, the process of photosynthesis requires the presence of light.
- Varying inputs (e.g., light intensity, amounts of water, carbon dioxide) affects the rate of photosynthesis.

Connections
Students will use a model of photosynthesis to explain:

- How photosynthesis results in the storage of chemical energy (in the form of glucose).

Students will use models of photosynthesis and cellular respiration (LS.Bio.3.3) to explain:

- How the chemical reaction of oxygen and glucose releases energy as the matter is rearranged, existing chemical bonds are broken, and new chemical bonds are formed; matter and energy are neither created nor destroyed.
- How matter transfers and how energy flows between organisms and their environment during photosynthesis and cellular respiration.
    - The products of photosynthesis are the reactants of aerobic cellular respiration.
    - The products of aerobic respiration are the reactants of photosynthesis.
- How glucose and oxygen transfer energy (ATP) to the cell to sustain life's processes (e.g., maintaining homeostasis).
- How stored chemical energy (glucose, starch, glycogen) can be used for cellular processes in plants and animals when sources are not readily available.
- The role of photosynthesis in the carbon cycle.

**Note: When "describe" is referenced, any of the following descriptions could be used: written, oral, pictorial, and kinesthetic.*

Academic Language
Question/Sentence Stems that utilize academic language:

- The matter in the system enters from _____.
- When the matter leaves the system, it goes _____.
- The flow of energy causes _____ to occur in the system.
- In the system, the cycling of matter _____.

Words to support student discourse: carbon dioxide, water, glucose, oxygen, matter, enzyme, carbohydrates, glycogen, starch, chemical reaction, reactant, (waste) product, molecule, bond, photosynthesis, input, output, chemical energy, light energy, chloroplast, chlorophyll, autotroph, cellular respiration

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LS.Bio.3.3 Use models to illustrate how cellular respiration [aerobic and anaerobic] transforms chemical energy into ATP.

Clarification Statement:

- Emphasis is on understanding the inputs and outputs of the processes of aerobic and anaerobic cellular respiration.
- In aerobic cellular respiration, glucose and oxygen are converted into carbon dioxide, water, and ATP.

glucose + oxygen ⟶ carbon dioxide + water + cell energy

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

- In anaerobic respiration, oxygen is not a reactant. Compared to aerobic respiration, less ATP is produced.

Boundary Statement:

- Students are expected to recognize the reactants and products of aerobic cellular respiration (chemical formulas and words) and the organelle involved (mitochondria in animals and plants).
- Students are expected to recognize that under anaerobic conditions, less ATP is produced (compared to aerobic conditions) followed by either lactic acid fermentation or alcoholic fermentation.
- Students are expected to compare the amounts of energy produced in aerobic and anaerobic cellular respiration.
- Students are *not* expected to identify the specific steps involved in cellular respiration (glycolysis, Kreb's or Citric Acid Cycle, Electron Transport Chain).

Dimension 1: Science and Engineering Practice (SEP): *Develop and Use Models*
NAEP (2028 Framework)

- S12.16: Develop, use, and/or revise a model that includes mathematical relationships (including both visible and invisible quantities) to describe, explain, and/or predict phenomena or to test a proposed design solution.

NSTA Progression

- Develop a complex model that allows for manipulation and testing of a proposed process or system.
- Develop, revise, and/or use a model based on evidence to illustrate and/or predict the relationships between systems or between components of a system.

Dimension 2: Crosscutting Concepts (CCC):
Crosscutting concepts are conceptual tools used along with the SEP and DCI to help students explain and predict phenomena. They support students in making connections between disciplines and provide a context for sense-making. Teachers should encourage students to frame their thinking around the terminology of the CCC through questions* and classroom discussions. The most relevant Crosscutting Concepts may vary in light of the specific learning objectives and how you structure the topic. Choose the one(s) that best support(s) your instructional goals and help(s) students make connections across different aspects of the content.
Suggested Crosscutting Concept: (A Framework for K-12 Science Education)

- **Energy and Matter: Flows, Cycles, and Conservation**

*STEM Teaching Tool #41: Prompts for Integrating Crosscutting Concepts Into Assessment and Instruction

Dimension 3: Disciplinary Core Ideas (DCI):
A Framework for K-12 Science Education

- LS1.C: As matter and energy flow through different organizational levels of living systems, chemical elements are recombined in different ways to form different products. As a result of these chemical reactions, energy is transferred from one system of interacting molecules to another. For example aerobic (in the presence of oxygen) cellular respiration is a chemical process in which the bonds of food molecules and oxygen molecules are broken and new compounds are formed that can transport energy to muscles. Anaerobic (without oxygen) cellular respiration follows a different and less efficient chemical pathway to provide energy in cells. Cellular respiration also releases the energy needed to maintain body temperature despite ongoing energy loss to the surrounding environment. Matter and energy are conserved in each change. This is true of all biological systems, from individual cells to ecosystems.

What does it look like to demonstrate proficiency?

***Revised Bloom's Taxonomy*: Illustrate-** Finding a specific example or illustration of a concept or principle

Components of the model
From the given model, students identify and describe* the components of the model in order to:

- Illustrate how aerobic respiration breaks down stored chemical energy (glucose) in the presence of oxygen, releasing water, carbon dioxide, and generating cellular energy (ATP).
    - Matter in the form of glucose, oxygen, water, and carbon dioxide
    - Generation of energy (ATP) from chemical reactions
    - Location of aerobic respiration: mitochondria in eukaryotes (animals and plants)
    - The breaking of chemical bonds in glucose and ATP makes energy available for cell use.
- Illustrate how fermentation may follow anaerobic respiration under anaerobic conditions.
    - Animals use the process of lactic acid fermentation under anaerobic conditions.
    - Yeast and some bacteria use the process of alcoholic fermentation.

Relationships
Students will use a model to explain the relationship between components of the given models:

- The process of aerobic respiration produces more ATP than the process of anaerobic respiration.

Connections
Students will use models of cellular respiration to explain:

- How organisms convert energy under different oxygen conditions.

Students will use models of photosynthesis and cellular respiration (LS.Bio.3.2) to explain:

- How the chemical reaction of oxygen and glucose releases energy as the matter is rearranged, existing chemical bonds are broken, and new chemical bonds are formed; matter and energy are neither created nor destroyed.
    - Cellular respiration is a chemical process in which the bonds between atoms of food molecules and oxygen molecules are broken and new compounds are formed. The energy released can drive energy requiring biological processes and help maintain body temperature despite ongoing energy transfer to the surrounding environment.
- How matter transfers and how energy flows between organisms and their environment during photosynthesis and cellular respiration.
    - The products of photosynthesis are the reactants of aerobic cellular respiration.
    - The products of aerobic respiration are the reactants of photosynthesis.
- How glucose and oxygen transfer energy (ATP) to the cell to sustain life's processes (e.g., maintaining homeostasis)
- How stored chemical energy (glucose, starch, glycogen) can be used for cellular processes in plants and animals when sources are not readily available.
- The role of respiration in the carbon cycle.

Suggestion: The connection between nutrient cycles (carbon through cellular respiration and phosphorus within ATP) and biological processes should be highlighted throughout the course.

**Note: When "describe" is referenced, any of the following descriptions could be used: written, oral, pictorial, and kinesthetic.*

Academic Language
Question/Sentence Stems that utilize academic language:

- _____ happens to matter as it moves within the system.
- In this system, energy is entering by _____, doing _____ in the system, and leaving the system by _____.
- The energy for _____ is from _____.
- The flow of energy causes _____ to occur in the system.
- The energy is entering the system by _____.
- In the system, the cycling of matter _____.
- The matter in the system enters from _____.
- When the matter leaves the system, it goes _____.

Words to support student discourse: matter cycling, energy flow, cellular respiration, aerobic respiration, anaerobic respiration,

fermentation, lactic acid, alcohol, mitochondria, carbohydrates, glucose, water, oxygen, carbon dioxide, ATP, reactants, products, chemical reaction, heterotroph, enzyme, bonds, molecule, input, output, photosynthesis, glycogen, starch

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Ecosystems- Interactions, Energy, and Dynamics
K-12 Vertical Alignment

Standard and Objectives:

LS.Bio.4 Analyze the relationships between matter and energy within ecosystems.

LS.Bio.4.1 Use models to illustrate how processes in organisms contribute to the flow of energy and the cycling of matter within an ecosystem.

LS.Bio.4.2 Use models to explain the relationship between the flow of energy and cycling of matter among organisms in an ecosystem.

LS.Bio.5 Understand ecosystem dynamics, functioning, and resilience.

LS.Bio.5.1 Use mathematics and computational thinking to explain how interactions between organisms (predator/prey, competition) affect carrying capacity and maintain stability in an ecosystem.

LS.Bio.5.2 Engage in argument from evidence to evaluate various solutions to reduce the impact of human activities on biodiversity and ecosystem health.

LS.Bio.4 Analyze the relationships between matter and energy within ecosystems.

LS.Bio.4.1 Use models to illustrate how processes in organisms contribute to the flow of energy and the cycling of matter within an ecosystem.

Clarification Statement:

- Emphasis should be on an individual organisms' role in the cycling of matter (carbon, nitrogen, phosphorus).
- Students should be able to identify an organism's niche from a model as a producer, consumer, decomposer, or agent of

nitrogen fixation.
- Models could include diagrams and chemical equations to illustrate inputs and outputs of matter as well as the transfer and transformation of energy in photosynthesis (connect with LS.Bio.3.2, LS.Bio.3.3).
- Students are expected to explain how nutrients from plants allow for flow of energy among organisms.
    - Students are expected to illustrate the role of
        - photosynthesis (i.e., carbon sink) in the carbon cycle.
        - cellular respiration (i.e., carbon source) in the carbon cycle.
        - bacteria (i.e., fixation and nitrification) in the nitrogen cycle.
        - plants (i.e., initial phosphorus uptake) in the phosphorus cycle.

Boundary Statement:
- Students are *not* expected to memorize steps of nutrient cycles.
- Students are *not* expected to identify specific biochemical steps (glycolysis, Kreb's Cycle, electron transport chain, light & dark reactions) of photosynthesis and cellular respiration.

Dimension 1: Science and Engineering Practice (SEP): *Develop and Use Models*
NAEP (2028 Framework)
- S12.16: Develop, use, and/or revise a model that includes mathematical relationships (including both visible and invisible quantities) to describe, explain, and/or predict phenomena or to test a proposed design solution.

NSTA Progression
- Develop a complex model that allows for manipulation and testing of a proposed process or system.
- Develop, revise, and/or use a model based on evidence to illustrate and/or predict the relationships between systems or between components of a system.

Dimension 2: Crosscutting Concepts (CCC):
Crosscutting concepts are conceptual tools used along with the SEP and DCI to help students explain and predict phenomena. They support students in making connections between disciplines and provide a context for sense-making. Teachers should encourage students to frame their thinking around the terminology of the CCC through questions* and classroom discussions. The most relevant Crosscutting Concepts may vary in light of the specific learning objectives and how you structure the topic. Choose the one(s) that best support(s) your instructional goals and help(s) students make connections across different aspects of the content.
Suggested Crosscutting Concept: (A Framework for K-12 Science Education)
- **Systems and System Models**

**STEM Teaching Tool #41: Prompts for Integrating Crosscutting Concepts Into Assessment and Instruction*

Dimension 3: Disciplinary Core Ideas (DCI):
A Framework for K-12 Science Education

- LS2.B: The carbon cycle provides an example of matter cycling and energy flow 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. Photosynthesis and cellular respiration (including anaerobic processes) provide most of the energy for life processes. Plants or algae form the lowest level of the food web. At each link upward in a food web, only a small fraction of the matter consumed at the lower level is transferred upward, to produce growth and release energy in cellular respiration at the higher level. At each link in an ecosystem, matter and energy are conserved; some matter reacts to release energy for life functions, some matter is stored in newly made structures, and much is discarded. 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.

Benchmarks for Science Literacy

- 5E/H1: At times, environmental conditions are such that land and marine organisms reproduce and grow faster than they die and decompose to simple carbon-containing molecules that are returned to the environment. Over time, layers of energy-rich organic material inside the earth have been chemically changed into great coal beds and oil pools.

NAEP (2028 Framework)

- L12.9: Photosynthesis and cellular respiration (including anaerobic processes) provide most of the energy for life processes.

What does it look like to demonstrate proficiency?

Revised Bloom's Taxonomy: **Illustrate-** Finding a specific example or illustration of a concept or principle

Components

Students develop a model to:

- Describe* the transfer of matter and the flow of energy between organisms.
- Describe* the transfer of energy and cycling of matter (as atoms and molecules) between organisms.

Relationships

Students use a model to explain relationships between components.

- Explain how photosynthesis and cellular respiration (sugar and oxygen are produced by carbon dioxide and water by the process of photosynthesis and that those outputs of photosynthesis are the inputs of cellular respiration).
- Explain how cellular respiration, glucose and oxygen react to form ATP and cellular energy**.**
- Explain how bacteria convert nitrogen into a form that plants can use (not the chemistry of fixation or nitrification).

Connections
Students use a model to explain how:

- Matter (e.g., carbon, nitrogen, phosphorus) flows between organisms and their environment.
    - Photosynthesis and cellular respiration play a part in energy flow and cycling of matter within an ecosystem.
- Light energy from the sun is transformed into stored chemical energy during photosynthesis.

**Note: The connection between nutrient cycles and biological processes should be highlighted throughout the course (intentionally connect to LS.Bio.4.2).*

**Note: When "describe" is referenced, any of the following descriptions could be used: written, oral, pictorial, and kinesthetic.*

Academic Language
Question/Sentence Stems that utilize academic language:

- What are the key parts of the system?
- What do you predict would happen if _____ decreases/increases within an ecosystem?
- How does energy flow to or from *organisms* within this system?
- How does matter cycle to or from *organisms* within this system?

Words to support student discourse: ATP, carbon dioxide, cellular respiration, glucose, matter, photosynthesis, water, oxygen, light energy, niche, autotroph, heterotroph, decomposer, nitrogen fixation, nitrogen cycle, phosphorus cycle, carbon cycle, carbon sink, carbon source

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LS.Bio.4.2 Use models to explain the relationship between the flow of energy and cycling of matter among organisms in an ecosystem.

Clarification Statement:
Emphasis is on:

- Students should describe the conservation of matter and flow of energy between organisms and the ecosystem.
- Use models to support the conservation laws of energy and matter.
- Using a model (food chains, food webs, energy pyramids) to describe the transfer of energy from one trophic level to another.
- Students should understand that matter and energy are conserved as *matter cycles* and *energy flows* through *ecosystems.*

Boundary Statement:

- Students are expected to describe the flow of energy and movement of matter through food chains and food webs.
- Students are expected to use proportional reasoning to describe the amount of available energy and matter at each trophic level.
- Students are expected to recognize trends in given data to apply the '10% rule' in flow of energy.

Dimension 1: Science and Engineering Practice (SEP): *Develop and Use Models*

NAEP (2028 Framework)

- S12.16: Develop, use, and/or revise a model that includes mathematical relationships (including both visible and invisible quantities) to describe, explain, and/or predict phenomena or to test a proposed design solution.

NSTA Progression

- Develop a complex model that allows for manipulation and testing of a proposed process or system.
- Develop, revise, and/or use a model based on evidence to illustrate and/or predict the relationships between systems or between components of a system.

Dimension 2: Crosscutting Concepts (CCC):

Crosscutting concepts are conceptual tools used along with the SEP and DCI to help students explain and predict phenomena. They support students in making connections between disciplines and provide a context for sense-making. Teachers should encourage students to frame their thinking around the terminology of the CCC through questions* and classroom discussions. The most relevant Crosscutting Concepts may vary in light of the specific learning objectives and how you structure the topic. Choose the one(s) that best support(s) your instructional goals and help(s) students make connections across different aspects of the content.

Suggested Crosscutting Concept: (A Framework for K-12 Science Education)

- **Energy and Matter: Flows, Cycles, and Conservation**

**STEM Teaching Tool #41: Prompts for Integrating Crosscutting Concepts Into Assessment and Instruction*

Dimension 3: Disciplinary Core Ideas (DCI):

A Framework for K-12 Science Education

- LS2.B: Photosynthesis and cellular respiration (including anaerobic processes) provide most of the energy for life processes. Plants or algae form the lowest level of the food web. At each link upward in a food web, only a small fraction of the matter consumed at the lower level is transferred upward, to produce growth and release energy in cellular respiration at the higher level. Given this inefficiency, there are generally fewer organisms at higher levels of a food web, and there is a limit to the number of organisms that an ecosystem can sustain. The chemical elements that make up the molecules of organisms pass through food webs and into and out of the atmosphere and soil and are combined and recombined in

different ways.

Benchmarks for Science Literacy

- 5E/H3: The chemical elements that make up the molecules of living things pass through food webs and are combined and recombined in different ways. At each link in a food web, some energy is stored in newly made structures but much is dissipated into the environment. Continual input of energy from sunlight keeps the process going.

NAEP (2028 Framework)

- L12.10: Plants or algae form the lowest level of the food web. At each link upward in a food web, only a small fraction of the matter consumed at the lower level is transferred upward to produce growth and release energy in cellular respiration at the higher level.

What does it look like to demonstrate proficiency?

***Revised Bloom's Taxonomy*: Explain-** Constructing a cause-and-effect model of a system

Components

Students develop and use a model to:

- Illustrate the cycling of matter and energy flow among organisms in an ecosystem.
- Illustrate relative quantities related to organisms, matter, energy, and the food web in an ecosystem.

Relationships

Students use a model to explain relationships between components.

- Explain why each trophic level includes fewer organisms as you move up the food chain.
- Explain how available energy is used by organisms at each level causing energy loss at each trophic level.
- Demonstrate proportional reasoning with provided data by applying the '10% rule' to determine the amount of available energy at each trophic level.

Connections

Students use a model to explain connections.

- Explain how energy flows from one trophic level to another as well as through the environment.
- Explain why food chains contain a limited number of trophic levels.
- Explain why energy not transferred to higher trophic levels is instead used for growth, maintenance, or repair, and/or transferred to the environment, and the inefficiencies in transfer of matter and energy.

Academic Language

Question/Sentence Stems that utilize academic language:

- How does the flow of energy between ____ and _____ drive the cycling of matter in the system?

- What happens to matter as it moves within this system?
- What happens to energy as it flows through an ecosystem?
- Why do stable ecosystems require more _____ than _____?
- If only 10% of energy is available from one organism to another, what happens to the other 90%?

Words to support student discourse: 10% rule, biomass, energy pyramid, food chain, food web, primary consumer, producer, secondary consumer, trophic levels, food web, autotroph, heterotroph, heat (loss), light energy, photosynthesis

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LS.Bio.5 Understand ecosystem dynamics, functioning, and resilience.

LS.Bio.5.1 Use mathematics and computational thinking to explain how interactions between organisms (predator/prey, competition) affect carrying capacity and maintain stability in an ecosystem.

Clarification Statement:

- Emphasis is on analyzing factors that impact the carrying capacity of an ecosystem (e.g., abiotic factors, predator/prey, and competition relationships)
  - Examples of changes in ecosystem conditions could include modest biological or physical changes (e.g., regulated hunting or a seasonal flood); and extreme changes (e.g., unregulated hunting, volcanic eruption, or sea level rise).
  - Examples of mathematical comparisons could include graphs, charts, histograms, and population changes gathered from simulations or historical data sets.

Boundary Statement:

- Students are expected to determine carrying capacity from graphs.
- Students are *not* expected to know the types or stages of succession.
- Students are *not* expected to derive mathematical equations to make comparisons.
  - Students are expected to describe trends in graphs or tables as increase, decrease, or remain stable.
- Students are *not* expected to identify and/or analyze symbiotic interactions; symbiosis is taught in middle school.

Dimension 1: Science and Engineering Practice (SEP): *Use Mathematics and Computational Thinking*
NAEP (2028 Framework)

- S12.12: Apply mathematical techniques (such as functions, statistical reasoning, and computational algorithms) to represent and solve scientific questions and/or design problems.
- S12.14: Apply or revise algorithms when analyzing data or designing, programming, testing, and revising scientific models,

explanations, and design solutions.

NSTA Progression

- Use mathematical, computational, and/or algorithmic representations of phenomena or design solutions to describe and/or support claims and/or explanations.
- Use simple limit cases to test mathematical expressions, computer programs, algorithms, or simulations of a process or system to see if a model "makes sense" by comparing the outcomes with what is known about the real world.

Dimension 2: Crosscutting Concepts (CCC):

Crosscutting concepts are conceptual tools used along with the SEP and DCI to help students explain and predict phenomena. They support students in making connections between disciplines and provide a context for sense-making. Teachers should encourage students to frame their thinking around the terminology of the CCC through questions* and classroom discussions. The most relevant Crosscutting Concepts may vary in light of the specific learning objectives and how you structure the topic. Choose the one(s) that best support(s) your instructional goals and help(s) students make connections across different aspects of the content.

Suggested Crosscutting Concept: (A Framework for K-12 Science Education)

- **Stability and Change**

**STEM Teaching Tool #41: Prompts for Integrating Crosscutting Concepts Into Assessment and Instruction*

Dimension 3: Disciplinary Core Ideas (DCI):

A Framework for K-12 Science Education

- LS2.A: Ecosystems have carrying capacities, which are limits to the numbers of organisms and populations they can support. These limits result from such factors as the availability of living and nonliving resources and from such challenges as predation, competition, and disease. Organisms would have the capacity to produce populations of great size were it not for the fact that environments and resources are finite. This fundamental tension affects the abundance (number of individuals) of species in any given ecosystem.
- LS2.B: Competition among species is ultimately competition for the matter and energy needed for life.
- LS2.C: A complex set of interactions within an ecosystem can keep its numbers and types of organisms relatively constant over long periods of time under stable conditions. If a modest biological or physical disturbance to an ecosystem occurs, it may return to its more or less original status (i.e., the ecosystem is resilient), as opposed to becoming a very different ecosystem. Extreme fluctuations in conditions or the size of any population, however, can challenge the functioning of ecosystems in terms of resources and habitat availability.

Benchmarks for Science Literacy

- 5D/H1*: Ecosystems can be reasonably stable over hundreds or thousands of years. As any population grows, its size is limited by one or more environmental factors; availability of food, availability of nesting sites, or number of predators.

NAEP (2028 Framework)

- L12.8: Ecosystems have carrying capacities, which are limits to the numbers of organisms and populations they can support. Organisms would have the capacity to produce populations of great size were it not for the fact that environments and resources are finite. This fundamental tension affects the abundance (number of individuals) of species in any given ecosystem.
- L12.11: A complex set of interactions within an ecosystem can keep its numbers and types of organisms relatively constant over long periods of time under stable conditions. Extreme fluctuations in conditions or the size of any population, however, can challenge the functioning of ecosystems in terms of resources and habitat availability.

What does it look like to demonstrate proficiency?

***Revised Bloom's Taxonomy*: Explain-** Constructing a cause-and-effect model of a system

Using mathematics and computational thinking:

Representation

Students identify and describe* various ecological relationships and population dynamics using mathematical representations to show:

- Many organisms can be sustained in a stable ecosystem.
- A decrease in available food limits the carrying capacity of the population.
- Relationship between limiting factors and carrying capacity.
    - Limiting factors include: availability of food, water, habitat/home range, mates; competition; disease; natural disasters (floods, droughts, hurricanes, fire)
- Patterns of population growth (exponential and logistic growth).

Mathematical modeling

Students use mathematical representations to explain and predict:

- The relationship between limiting factors and carrying capacity.
- How changing factors can affect populations.
    - Number and types of species change as ecosystems mature

Analysis

Students use mathematics and computational thinking to explain that the complex interactions in ecosystems:

- Ecosystems have carrying capacities, which are limits to the numbers of organisms and populations they can support.
- In stable conditions, ecosystems maintain relatively consistent numbers and types of organisms.

- Changing conditions may result in an altered ecosystem.

Academic Language
Question/Sentence Stems that utilize academic language:
- What factors in the system change?
- What are the factors causing this system to be stable/unstable?
- What patterns do you observe in the way the system changes over time?

Words to support student discourse: carrying capacity, community, competition, interactions, limiting factors, organisms, population, predator, prey, stability, succession, symbiosis, exponential growth, logistical growth

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LS.Bio.5.2 Engage in argument from evidence to evaluate various solutions to reduce the impact of human activities on biodiversity and ecosystem health.

Clarification Statement:
- Emphasis is on determining cause-and-effect relationships for:
  - How human activities cause positive or negative changes to the environment.
  - How human activities impact the abundance and distribution of species.
    - Negative changes to the environment might include use of chemicals, pollution, overuse of resources, introduction of non-native species, urbanization, deforestation, drought, and flood.
    - Positive changes to the environment might include conservation practices (e.g., captive breeding programs, flood prevention, habitat restoration, recycling, the use of renewable energy and sustainable resources).
  - Solutions should consider benefit and risk factors (e.g., costs, safety, sustainability).

Boundary Statement:
- Students are expected to be familiar with common human activities as well as conservation practices that affect ecosystems.
- Students are expected to use provided data to determine trends and use graphical comparisons of multiple sets of data.

Dimension 1: Science and Engineering Practice (SEP): *Engage in Argument from Evidence*
NAEP (2028 Framework)
- S12.20: Evaluate and/or refine a solution for a design problem, based on scientific knowledge, evidence, prioritized criteria, and trade-off considerations.

NSTA Progression

- Construct, use, and/or present an oral and written argument or counter-arguments based on data and evidence.
- Make and defend a claim based on evidence about the natural world or the effectiveness of a design solution that reflects scientific knowledge, and student-generated evidence.

Dimension 2: Crosscutting Concepts (CCC):

Crosscutting concepts are conceptual tools used along with the SEP and DCI to help students explain and predict phenomena. They support students in making connections between disciplines and provide a context for sense-making. Teachers should encourage students to frame their thinking around the terminology of the CCC through questions* and classroom discussions. The most relevant Crosscutting Concepts may vary in light of the specific learning objectives and how you structure the topic. Choose the one(s) that best support(s) your instructional goals and help(s) students make connections across different aspects of the content.

Suggested Crosscutting Concept: (A Framework for K-12 Science Education)

- **Cause and Effect: Mechanism and Explanation**

**STEM Teaching Tool #41: Prompts for Integrating Crosscutting Concepts Into Assessment and Instruction*

Dimension 3: Disciplinary Core Ideas (DCI):

A Framework for K-12 Science Education

- LS2.C: Extreme fluctuations in conditions or the size of any population, however, can challenge the functioning of ecosystems in terms of resources and habitat availability. Moreover, anthropogenic changes (induced by human activity) in the environment- including habitat destruction, pollution, introduction of invasive species, overexploitation, and climate change- can disrupt an ecosystem and threaten the survival of some species.
- LS4.D: Humans depend on the living world. The resources and benefits provided by the living world are considered “ecosystem services”. Biodiversity results from the formation of new species (speciation) minus extinction. Biodiversity is seriously threatened by human impact in the form of habitat destruction, over-exploitation, damage by invasive species, and climate change. These have the potential to cause a major pulse of biological extinctions. Biological extinction is a critical factor in reducing biodiversity because it is irreversible. Sustaining biodiversity so productivity and ecosystem functioning remain is essential to maintaining and enhancing the quality of life of the growing human population. Thus sustaining biodiversity so that ecosystem functioning and productivity are maintained is essential to supporting and enhancing life on Earth. Sustaining biodiversity also aids humanity by preserving landscapes of recreational or inspirational value.
- EES3.C: The sustainability of human societies and the biodiversity that supports them requires responsible management of natural resources. Scientists and engineers can make major contributions- for example, by developing technologies that produce less pollution and waste and that preclude ecosystem degradation. When the source of an environmental problem is understood and international agreement can be reached, human activities can be regulated to mitigate global impacts

(e.g., acid rain and the ozone hole near Antarctica).

Benchmarks for Science Literacy

- 5D/H3: Human beings are part of the earth's ecosystems. Human activities can, deliberately or inadvertently, alter the equilibrium in ecosystems.
- 3C/H4: The human species has a major impact on other species in many ways: reducing the amount of the earth's surface available to those species, interfering with their food sources, changing the temperature and chemical composition of their habitats, introducing foreign species into their ecosystems, and altering organisms directly through selective breeding and genetic engineering. (Interdependence of Life)
- 4B/H6**: The earth's climates have changed in the past, are currently changing, and are expected to change in the future, primarily due to changes in the amount of light reaching places on the earth and the composition of the atmosphere. The burning of fossil fuels in the last century has increased the amount of greenhouse gases in the atmosphere, which has contributed to Earth's warming.

NAEP (2028 Framework)

- L12.12: Changes induced by human activity in the environment—such as habitat destruction, pollution, introduction of invasive species, overexploitation, and climate change— can disrupt an ecosystem, reduce biodiversity, and threaten the survival of some species.

What does it look like to demonstrate proficiency?

***Revised Bloom's Taxonomy*:** **Evaluate-** Make judgments based on criteria and standards

Engage in argument from evidence to:

Developing a claim

Students make a claim that includes the idea that:

- Human activity has an impact on an ecosystem.
- Solutions can prevent, mitigate, and/or limit the impact of human activity on an ecosystem.

Identifying scientific evidence

Students identify and describe* evidence that supports the claim, including:

- How human activity might affect the health of an ecosystem. (Examples could include: loss of habitat through fire, flooding, deforestation, development, pollution, overuse of natural resources, urbanization, building dams, etc.).
- Explain how human activity might affect biodiversity. (Examples could include: introduction of non-native species, overhunting, overfishing, etc.).
    - Example: Zebra mussels are an invasive species in North Carolina. When zebra mussels are transported to a new location, their population tends to grow rapidly and causes changes in population sizes of location organisms.

- Compare various solutions to reduce the effect of human activity on the health of an ecosystem.

Evaluating and critiquing evidence
Students identify the following strengths and weaknesses of the evidence used to support the claim:
- Types and numbers of sources
- Sufficiency to make and defend the claim, and to distinguish between causal and correlational relationships
- Validity and reliability of the evidence

Reasoning and synthesis
Students use reasoning to describe* links between the evidence and claim, such as:
- Explaining why human activity impacts the health of an ecosystem.
- Explaining how some solutions can prevent and/or reduce the negative impact of human activity on an ecosystem more than others.

**Note: When "describe" is referenced, any of the following descriptions could be used: written, oral, pictorial, and kinesthetic.*

Academic Language
Question/Sentence Stems that utilize academic language:
- How do patterns in the data allow you to decide whether (list human activity) caused _____?
- How do you know ___ caused ___?
- How can a small change to _____ have a big effect on _____?

Words to support student discourse: acidification, biodiversity, climate, greenhouse gases, conservation, deforestation, dynamics, ecosystem health, extinction, fossil fuels, habitat, human impact, invasive species, mitigation, overpopulation, pollution, preservation, resilience, solution, succession, restoration, overfishing, eutrophication, algal bloom

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Heredity- Inheritance and Variation of Traits
K-12 Vertical Alignment

Standard and Objectives:
LS.Bio.6 Understand genetic mechanisms for variation.

LS.Bio.6.1 Use models to explain how DNA is passed from parents to offspring through the processes of meiosis and fertilization in sexual reproduction.
LS.Bio.6.2 Construct an explanation to summarize how inheritable genetic variations may result from: new genetic combinations in meiosis, mutations during replication, or mutations caused by environmental factors.

LS.Bio.7 Understand types of inheritance and how the environment can influence traits.

LS.Bio.7.1 Use mathematics and computational thinking to predict the variation and distribution of expressed traits based on: Mendelian inheritance, codominance, incomplete dominance, multiple alleles, and sex-linked inheritance.
LS.Bio.7.2 Analyze and interpret data to explain how polygenic traits result in a wide range of phenotypes.
LS.Bio.7.3 Construct an explanation to summarize how traits result from interactions of genetic factors (multiple genes and/or alleles) and environmental factors.

LS.Bio.8 Understand applications of genetics and biotechnology.

LS.Bio.8.1 Analyze and interpret data to compare DNA samples.
LS.Bio.8.2 Obtain and communicate information that summarizes the impact of biotechnology applications on the individual, society, and the environment, including agriculture and medicine.

LS.Bio.6 Understand genetic mechanisms for variation.

LS.Bio.6.1 Use models to explain how DNA is passed from parents to offspring through the processes of meiosis and fertilization in sexual reproduction.

Clarification Statement:

- Emphasis is on how meiotic cell division supports the flow of genetic information across generations of organisms.

Boundary Statement:

- Students are expected to know the overall purpose, process, and products of meiosis.
    - Meiosis produces unique haploid gametes (sperm and egg).
    - Students are *not* expected to know the terms primary oocyte or primary spermatocyte.
- Students are expected to determine or compare haploid and diploid numbers of chromosomes in different cell types.
    - Students are expected to describe/identify ploidy using given information:
        - Haploid = n = sex/reproductive cells/gametes
        - Diploid = 2n = body/somatic cells
    - Students are expected to calculate n, when given 2n and calculate 2n, when given n.
- Students are expected to analyze karyotypes to identify biological sex or the presence of chromosomal conditions.
    - Students are *not* expected to know the names or karyotypes of specific chromosomal conditions.

        - *Note the use of the terminology "chromosomal conditions," not "chromosomal disorders" or "chromosomal abnormalities."*
- Students are *not* expected to identify or memorize meiotic phase names or sequencing of phases.

Note: The role of mitosis in producing body cells is addressed in LS.Bio.2.1.

Dimension 1: Science and Engineering Practice (SEP): *Develop and Use Models*
NAEP (2028 Framework)
- S12.16: Develop, use, and/or revise a model that includes mathematical relationships (including both visible and invisible quantities) to describe, explain, and/or predict phenomena or to test a proposed design solution.

NSTA Progression
- Develop a complex model that allows for manipulation and testing of a proposed process or system.
- Develop, revise, and/or use a model based on evidence to illustrate and/or predict the relationships between systems or between components of a system.

Dimension 2: Crosscutting Concepts (CCC):
Crosscutting concepts are conceptual tools used along with the SEP and DCI to help students explain and predict phenomena. They support students in making connections between disciplines and provide a context for sense-making. Teachers should encourage students to frame their thinking around the terminology of the CCC through questions* and classroom discussions. The most relevant Crosscutting Concepts may vary in light of the specific learning objectives and how you structure the topic. Choose the one(s) that best support(s) your instructional goals and help(s) students make connections across different aspects of the content.
Suggested Crosscutting Concept: (A Framework for K-12 Science Education)
- **Systems and System Models**

**STEM Teaching Tool #41: Prompts for Integrating Crosscutting Concepts Into Assessment and Instruction*

Dimension 3: Disciplinary Core Ideas (DCI):
A Framework for K-12 Science Education
- LS3.B: The information passed from parents to offspring is coded in the DNA molecules that form the chromosomes. In sexual reproduction, chromosomes can sometimes swap sections during the process of meiosis (cell division), thereby creating new genetic combinations and thus more genetic variation.

NAEP (2028 Framework)
- L12.15: In sexual reproduction, chromosomes can sometimes swap sections during the process of meiosis, thereby creating new genetic combinations and thus more genetic variation. Although DNA replication is tightly regulated and

remarkably accurate, errors do occur and result in mutations, which are a source of genetic variation. Environmental factors can also cause mutations in genes, and mutations can be inherited.

What does it look like to demonstrate proficiency?

***Revised Bloom's Taxonomy*: Explain-** Constructing a cause-and-effect model of a system

Components of the model
From the given model, students identify and describe* the components of the model in order to:

- Illustrate the role of meiosis in passing unique combinations of genes onto offspring during sexual reproduction.
    - Prior to meiosis, primary reproductive cells (primary oocytes and spermatocytes) have two copies of each chromosome (terminology included for clarity).
    - The DNA sequences in primary reproductive cells are the same as the DNA sequences found in other body cells throughout the organism.
        - The two copies of each chromosome may not have the same gene variants (alleles).
        - During meiosis, processes (i.e., crossing over, independent assortment) may rearrange segments of DNA.
    - Daughter cells (sperm or egg) contain one copy of each chromosome.
- Inputs of meiotic division are called *parent cells*. Outputs are called *daughter cells*.

Relationships
Students identify the following relationship between components of the given model:

- Primary reproductive cells undergo a reductive cell division, passing on only one-half of the genetic information to daughter cells (sperm or egg).
- DNA on parental chromosomes may recombine resulting in unique combinations of alleles in daughter cells (crossing over).
- Homologous chromosomes may orient on either side of the parental cell prior to division, resulting in unique combinations of chromosomes (and their alleles) in daughter cells (random or independent assortment).
- Meiotic cell division produces four genetically unique daughter cells from one parent cell.
- A haploid egg and a haploid sperm cell combine to make a diploid zygote.

Connections
Students use the given model to illustrate:

- The importance of chromosomal structure for packaging and movement of genetic information.
- Daughter cells (sperm or egg) receive unique combinations of parental chromosomes.
- Offspring from the same parents each have a unique combination of the parental genetic information.
    - Interpret karyotypes for biological sex (XX-female, XY-male) and nondisjunction.

        - Errors in the separation of chromosomes (nondisjunction) can result in chromosomal conditions (e.g., Down Syndrome, trisomy 21).
- Comparisons between meiosis and mitosis including type of reproduction (asexual or sexual), replication and separation of DNA and cellular material, changes in chromosome number, number of cell divisions, and number of cells produced in a complete cycle (LS.Bio.2.1)

**Note: When "describe" is referenced, any of the following descriptions could be used: written, oral, pictorial, and kinesthetic.*

Academic Language
Question/Sentence Stems that utilize academic language:

- How is genetic information passed between generations?
- Discuss how genetic information moves within the model.
- Use the model to predict outcomes when there is unexpected chromosomal movement.
- How does the chromosome number of a somatic cell compare to the sex cell of the same organism?
- Compare two models and discuss the causes of variation in the genetic information.

Words to support student discourse: independent assortment, crossing over, recombination, homologous, chromosome, chromatin, centromere, centriole, sister chromatids, equator (metaphase plane), spindle fibers, diploid (2n), haploid (n), Meiosis I, Meiosis II, fertilization, sexual reproduction, nondisjunction, chromosomal condition, karyotype, body cells (somatic), sex cells (gametes: sperm- male; egg- female), XX, XY, zygote

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LS.Bio.6.2 Construct an explanation to summarize how inheritable genetic variations may result from: new genetic combinations in meiosis, mutations during replication, or mutations caused by environmental factors.

Clarification Statement:

- The processes of independent assortment and crossing over result in genetically unique organisms.
    - Meiotic errors may result in chromosomal conditions.
- Mutations caused by DNA replication errors or environmental factors alter DNA sequences. These mutations may cause changes to protein function and may result in new or atypical phenotypes.

Note: The role of meiosis in producing gametes for sexual reproduction is addressed in LS.Bio.6.1.

Boundary Statement:

- Students are expected to recognize that independent assortment and crossing over during meiosis results in genetic diversity among offspring with the same parents. Sexual reproduction results in greater genetic diversity within populations than asexual reproduction.
- Students are expected to recognize that changes in nucleotide sequence (mutations) may be positive, negative, or neutral to protein function and/or the organism.
- Students are *not* expected to:
    - memorize the names of the steps or the order of the step names in meiosis.
    - identify different types of point mutations (substitution, insertion, deletion, frameshift), chromosomal mutations (inversion, deletion, duplication, translocation), or copy number mutations (gene amplification or trinucleotide repeats).
- *Note the use of the terminology "chromosomal conditions," not "chromosomal disorders" or "chromosomal abnormalities."*

Dimension 1: Science and Engineering Practice (SEP): *Construct an Explanation*
NAEP (2028 Framework)

- S12.18: Construct or revise an explanation that uses a chain of cause and effect or evidence-based associations between factors to account for the qualitative or quantitative relationships between variables in a phenomenon.

NSTA Progression

- Construct and revise an explanation based on valid and reliable evidence obtained from a variety of sources (including students' own investigations, models, theories, simulations, peer review) and the assumption that theories and laws that describe the natural world operate today as they did in the past and will continue to do so in the future.
- Apply scientific ideas, principles, and/or evidence to provide an explanation of phenomena and solve design problems, taking into account possible unanticipated effects.

Dimension 2: Crosscutting Concepts (CCC):
Crosscutting concepts are conceptual tools used along with the SEP and DCI to help students explain and predict phenomena. They support students in making connections between disciplines and provide a context for sense-making. Teachers should encourage students to frame their thinking around the terminology of the CCC through questions* and classroom discussions. The most relevant Crosscutting Concepts may vary in light of the specific learning objectives and how you structure the topic. Choose the one(s) that best support(s) your instructional goals and help(s) students make connections across different aspects of the content.
Suggested Crosscutting Concept: (A Framework for K-12 Science Education)

- **Cause and Effect: Mechanism and Explanation**

**STEM Teaching Tool #41: Prompts for Integrating Crosscutting Concepts Into Assessment and Instruction*

Dimension 3: Disciplinary Core Ideas (DCI):
A Framework for K-12 Science Education

- LS3.A:
    - Sexual reproduction provides for transmission of genetic information to offspring through egg and sperm cells. These cells, which contain only one chromosome of each parent's chromosome pair, unite to form a new individual (offspring). Thus offspring possess one instance of each parent's chromosome pair (forming a new chromosome pair). Variations of inherited traits between parent and offspring arise from genetic differences that result from the subset of chromosomes (and therefore genes) inherited or (more rarely) from mutations.
    - The information passed from parents to offspring is coded in the DNA molecules that form the chromosomes. In sexual reproduction, chromosomes can sometimes swap sections during the process of meiosis (cell division), thereby creating new genetic combinations and thus more genetic variation. Although DNA replication is tightly regulated and remarkably accurate, errors do occur and result in mutation, which are also a source of genetic variation.

Benchmarks for Science Literacy

- 5B/H2: The sorting and recombination of genes in sexual reproduction results in a great variety of possible gene combinations in the offspring of any two parents.
- 5C/H6: Gene mutation in a cell can result in uncontrolled division called cancer. Exposure of cells to certain chemicals and radiation increases mutations and thus the chance of cancer.

NAEP (2028 Framework)

- L12.15: In sexual reproduction, chromosomes can sometimes swap sections during the process of meiosis, thereby creating new genetic combinations and thus more genetic variation. Although DNA replication is tightly regulated and remarkably accurate, errors do occur and result in mutations, which are a source of genetic variation. Environmental factors can also cause mutations in genes, and mutations can be inherited.

What does it look like to demonstrate proficiency?

Revised Bloom's Taxonomy: **Summarize-** Condensing larger information into a general theme or major point(s)

Constructing Explanations
Students construct an explanation that identifies the cause-and-effect relationships:

- Genetic variation can result from new chromosomal combinations during meiotic cell division, mutations during the replication process, and/or mutations caused by environmental factors.
- New alleles may be formed from crossing over or mutations within gametes.
    - Altered DNA sequences may lead to altered protein function, resulting in varied phenotypes.

Evidence
Students identify and describe* the evidence to construct the explanation, including:

- Meiosis includes processes which generate new combinations of alleles (crossing over) and chromosomes (independent assortment).
- The sequence of DNA contains instructions that code for proteins.
- Spontaneous mutations (deletions, additions, or substitutions) may occur during DNA replication.
- Environmental factors (e.g., chemicals, radiation) may cause mutations in DNA.

Reasoning
Students use reasoning to connect evidence and construct an explanation about heritable genetic changes. Students describe* the following chain of reasoning in their explanation:

- Genetic variation in populations supports resilience.
- Changes to the DNA of gametes (sperm or egg) may be passed to offspring.
- Changes in DNA sequences can result in changes in amino acid sequence.
- Changes in amino acid sequence may alter protein function and phenotype.
- Changes in amino acid sequence may result in genetic disorders.
- Changes in chromosome structure can result in chromosomal conditions.

**Note: When "describe" is referenced, any of the following descriptions could be used: written, oral, pictorial, and kinesthetic.*

Academic Language
Question/Sentence Stems that utilize academic language:

- What caused the patterns you observed?
  - Follow-up question: How do you know that was the cause?
- What do you predict would happen if [extrapolate to a new, related situation]?
- How can a small change to _____ have a big effect on _____?
- Is the evidence presented sufficient to conclude that _____ caused _____? If not, what additional evidence is needed?

Words to support student discourse: mutation, error, DNA replication, radiation exposure, chemical exposure, meiosis, gene, amino acid, transcription, translation, gamete, sperm, egg, body cell, variation, allele, chromosomal condition

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LS.Bio.7 Understand types of inheritance and how the environment can influence traits.

LS.Bio.7.1 Use mathematics and computational thinking to predict the variation and distribution of expressed traits based on: Mendelian inheritance, codominance, incomplete dominance, multiple alleles, and sex-linked inheritance.

Clarification Statement:

- Emphasis is on the use of mathematics to describe the probability of traits as it relates to genetic and environmental factors in the expression of traits.
- Punnett squares and pedigrees can be used to illustrate probability.

Boundary Statement:

- Students are expected to complete and interpret monohybrid Punnett squares for genotypic and phenotypic ratios.
- Students are *not* expected to:
    - complete/analyze dihybrid crosses.
    - understand the Rhesus factor of blood types.
    - demonstrate knowledge of the Hardy-Weinberg principle.
    - describe or perform test crosses.
    - identify types of inheritance using Punnett squares or pedigrees.

Dimension 1: Science and Engineering Practice (SEP): *Use Mathematics and Computational Thinking*
NAEP (2028 Framework)

- S12.12: Apply mathematical techniques (such as functions, statistical reasoning, and computational algorithms) to represent and solve scientific questions and/or design problems.

NSTA Progression

- Use mathematical, computational, and/or algorithmic representations of phenomena or design solutions to describe and/or support claims and/or explanations.
- Apply techniques of algebra and functions to represent and solve scientific and engineering problems.
- Use simple limit cases to test mathematical expressions, computer programs, algorithms, or simulations of a process or system to see if a model “makes sense” by comparing the outcomes with what is known about the real world.

Dimension 2: Crosscutting Concepts (CCC):
Crosscutting concepts are conceptual tools used along with the SEP and DCI to help students explain and predict phenomena. They support students in making connections between disciplines and provide a context for sense-making. Teachers should encourage students to frame their thinking around the terminology of the CCC through questions* and classroom discussions. The most relevant Crosscutting Concepts may vary in light of the specific learning objectives and how you structure the topic. Choose the one(s) that best support(s) your instructional goals and help(s) students make connections across different aspects of the content.

Suggested Crosscutting Concept: (A Framework for K-12 Science Education)

- **Patterns**

**STEM Teaching Tool #41: Prompts for Integrating Crosscutting Concepts Into Assessment and Instruction*

Dimension 3: Disciplinary Core Ideas (DCI):

A Framework for K-12 Science Education

- LS3.A: When organisms reproduce, genetic information is transferred to their offspring, with half coming from each parent in sexual reproduction. Inheritance is the key factor causing the similarity among individuals in a species population.
  - Heredity refers to specific mechanisms by which characteristics or traits are passed from one generation to the next via genes.
  - Each gene can have several variants, called *alleles*, which code for different variants of the trait in question. Genes reside in a cell's chromosomes, each of which contains many genes.
- LS3.B: Variation among individuals of the same species can be explained by both genetic and environmental factors. Individuals within a species have similar but not identical genes. In sexual reproduction, variations in traits between parent and offspring arise from the particular set of chromosomes (and their respective multiple genes) inherited, with each parent contributing half of each chromosome pair.
  - In species that reproduce sexually, each cell contains two variants of each chromosome, one inherited from each parent.
  - Genetic variation and the relative dominance of each of the genes in a pair play an important role in how traits develop within an individual.

Benchmarks for Science Literacy

- 5B/H2: The sorting and recombination of genes in sexual reproduction results in a great variety of possible gene combinations in the offspring of any two parents.

What does it look like to demonstrate proficiency?

***Revised Bloom's Taxonomy*:** **Predict-** Drawing a logical conclusion from presented information

Using Computational Thinking

Representation

Students identify and describe* various inheritance patterns (Mendelian inheritance, codominance, incomplete dominance, multiple alleles, and sex-linked inheritance) using mathematical representations to show:

- The cause-and-effect relationships between alleles found on chromosomes and the resulting traits observed in an organism.

- Different inheritance patterns show characteristic genotypic and phenotypic ratios.
    - Mendelian inheritance: dominant alleles mask recessive alleles.
    - Codominance: heterozygotes express both alleles.
    - Incomplete dominance: heterozygotes have an intermediate phenotype.
    - Sex-linked: males are more likely to express a sex-linked trait.

Mathematical modeling
Students use mathematical representations to explain and predict:

- Inheritance patterns based on gene expression as described in texts or depicted in pedigrees.
- The likelihood (percentage or ratio) of a single trait being passed from parent to offspring based on data in a Punnett square or pedigree.
- Examples may include:
    - autosomal inheritance of sickle cell anemia (recessive) and its relationship to malaria.
    - recessive inheritance of cystic fibrosis.
    - dominant inheritance of Huntington's disease.
    - multiple alleles and codominant inheritance of blood type (Blood Types: A, B, AB and O and Alleles: I^A, I^B, and i).
    - sex-linked inheritance of color-blindness and hemophilia.

Analysis
Students use mathematical ratios from genetic crosses of potential parental traits to identify patterns of inheritance in offspring.

- Determine probability of having offspring with a given phenotype.
- Determine if parentage is possible based on blood type.

**Note: When "describe" is referenced, any of the following descriptions could be used: written, oral, pictorial, and kinesthetic.*

Academic Language
Questions/Sentence Stems that utilize academic language:

- I/We observe the pattern of _____ in the data.
- The following predictions can be made about _____ based on the pattern found in the data.
- The pattern in the data allows me/us to conclude (know) that _____.
- The pattern in the data supports the conclusion that _____ is caused by _____ because _____.

Words to support student discourse: parent, offspring, pattern, phenotype, genotype, homozygous, heterozygous, dominant, recessive, monohybrid cross, Punnett square, pedigree, inheritance, codominance, incomplete dominance, alleles, sex-linked inheritance, trait, probability, blood type, ratio, percentage

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LS.Bio.7.2 Analyze and interpret data to explain how polygenic traits result in a wide range of phenotypes.

Clarification Statement:

- Biological traits with a wide range of phenotypes (e.g., in humans- height, facial shape, color of eyes, hair, or skin; in plants- peanut length, grain length, and flower size) are the result of the expression of multiple genes (polygenic traits).

Boundary Statement:

- Students are expected to interpret data associated with polygenic traits, using a bell-shaped distribution (bell curve) graph or a table:
  - Identify phenotypes that occur less often (lower frequency) than intermediate phenotypes that occur more often (greater frequency).
  - Students are *not* expected to use the terminology “normal distribution.”
  - Students are *not* expected to calculate standard distributions or generate bell-shaped distribution (bell curve) graphs.
- Students are *not* expected to determine genotypes for polygenic traits.
- Students are *not* expected to interpret a Punnett square of polygenic traits.

Dimension 1: Science and Engineering Practice (SEP): *Analyze and Interpret Data*
NAEP (2028 Framework)

- S12.9: Construct, analyze and/or interpret representations of small and large data sets from an investigation using tools, technologies, and/or models (e.g., computational, mathematical), including statistical analysis (descriptive statistics) and probability.
- S12.10: Analyze data to provide evidence to support or reject a model or explanation or to use to optimize a design solution relative to criteria for success.

NSTA Progression

- Analyze data using tools, technologies, and/or models (e.g., computational, mathematical) in order to make valid and reliable scientific claims or determine an optimal design solution.

Dimension 2: Crosscutting Concepts (CCC):
Crosscutting concepts are conceptual tools used along with the SEP and DCI to help students explain and predict phenomena. They support students in making connections between disciplines and provide a context for sense-making. Teachers should encourage students to frame their thinking around the terminology of the CCC through questions* and classroom discussions. The most relevant Crosscutting Concepts may vary in light of the specific learning objectives and how you structure the topic.

Choose the one(s) that best support(s) your instructional goals and help(s) students make connections across different aspects of the content.

Suggested Crosscutting Concept: (A Framework for K-12 Science Education)

- **Patterns**

**STEM Teaching Tool #41: Prompts for Integrating Crosscutting Concepts Into Assessment and Instruction*

Dimension 3: Disciplinary Core Ideas (DCI):

A Framework for K-12 Science Education

- LS3.A: When organisms reproduce, genetic information is transferred to their offspring, with half coming from each parent in sexual reproduction. Inheritance is the key factor causing the similarity among individuals in a species population.
    - Heredity refers to specific mechanisms by which characteristics or traits are passed from one generation to the next via genes.
    - Each gene can have several variants, called alleles, which code for different variants of the trait in question. Genes reside in a cell's chromosomes, each of which contains many genes.

What does it look like to demonstrate proficiency?

***Revised Bloom's Taxonomy*:** **Explain-** Constructing a cause-and-effect model of a system

Organizing Data

- Students organize data (e.g., using tables, graphs and charts) by the frequency of a phenotype for a trait (e.g., height).
- Students describe* what each data set represents.

Identifying Relationships

Students perform and use appropriate statistical analyses of data, including:

- Quantifying specific phenotypes (e.g., height in 5 cm increments) within a sample (e.g., class population) to determine distribution of phenotypes.

Interpreting Data

Students use the data analyses as evidence to support explanations about the following:

- Multiple genes may control a single trait (polygenic traits).
- Polygenic traits have a large number of possible phenotypes.
- The frequency of different phenotypes for polygenic traits produces a bell-shaped distribution (bell curve).

**Note: When "describe" is referenced, any of the following descriptions could be used: written, oral, pictorial, and kinesthetic.*

Academic Language
Question/Sentence stems that utilize academic language:

- What patterns do you observe in the data presented above in the [table, chart, graph, model output]?
- What can you conclude from the pattern of data?
- Does the pattern in the data support the conclusion that _____ is related to _____? Why or why not?

Words to support student discourse: parent, offspring, pattern, phenotype, genotype, inheritance, multiple genes, polygenic, independent assortment, gene expression, trait, probability, bell-shaped distribution, bell curve, frequency, spectrum (variety)

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LS.Bio.7.3 Construct an explanation to summarize how traits result from interactions of genetic factors (multiple genes and/or alleles) and environmental factors.

Clarification Statement:

- Many biological traits depend both on genetic and environmental factors.
- Heredity and environment interact to produce phenotypes.

Boundary Statement:

- Students are expected to summarize that environmental factors can affect traits.
- Students are *not* expected to explain the biochemical modifications (methylation or histone modifications) to DNA that regulate gene expression.

Dimension 1: Science and Engineering Practice (SEP): *Construct an Explanation*
NAEP (2028 Framework)

- S12.18: Construct or revise an explanation that uses a chain of cause and effect or evidence-based associations between factors to account for the qualitative or quantitative relationships between variables in a phenomenon.

NSTA Progression

- Construct and revise an explanation based on valid and reliable evidence obtained from a variety of sources (including students' own investigations, models, theories, simulations, peer review) and the assumption that theories and laws that describe the natural world operate today as they did in the past and will continue to do so in the future.
- Apply scientific ideas, principles, and/or evidence to provide an explanation of phenomena and solve design problems, taking into account possible unanticipated effects.

Dimension 2: Crosscutting Concepts (CCC):
Crosscutting concepts are conceptual tools used along with the SEP and DCI to help students explain and predict phenomena. They support students in making connections between disciplines and provide a context for sense-making. Teachers should encourage students to frame their thinking around the terminology of the CCC through questions* and classroom discussions. The most relevant Crosscutting Concepts may vary in light of the specific learning objectives and how you structure the topic. Choose the one(s) that best support(s) your instructional goals and help(s) students make connections across different aspects of the content.

Suggested Crosscutting Concept: (A Framework for K-12 Science Education)

- **Cause and Effect**

**STEM Teaching Tool #41: Prompts for Integrating Crosscutting Concepts Into Assessment and Instruction*

Dimension 3: Disciplinary Core Ideas (DCI):

A Framework for K-12 Science Education

- LS3.B: Environmental factors also affect expression of traits, and hence affect the probability of occurrences of traits in a population. Thus the variation and distribution of traits observed depend on both genetic and environmental factors.

Benchmarks for Science Literacy

- 5F/H6c: When an environment, including other organisms that inhabit it changes, the survival value of inherited characteristics may change.
- 6F/H1: As successive generations of an embryo's cells form by division, small differences in their immediate environments cause them to develop slightly differently, by activating or inactivating different parts of the DNA information.

NAEP (2028 Framework)

- L12.16: Environmental factors affect expression of heritable traits and hence affect the probability of occurrences of traits in a population.

What does it look like to demonstrate proficiency?

Revised Bloom's Taxonomy: **Summarize-** Condensing larger information into a general theme or major point(s)

Constructing Explanations:
Students construct an explanation that includes the idea that the expression of genes (protein production) is not the same in all cells. Gene expression can change due to genetics or environmental factors.

Evidence
Students identify and describe* the evidence to construct an explanation, including:

- Multiple genes may influence a trait (e.g., height, risk of a disease).
- Living organisms are surrounded by an array of environmental factors (e.g., nutrition, pollution, stress, chemicals or toxins, temperature, microbes).
- Exposure to environmental factors may lead to different traits. Examples of variation and patterns in distribution of traits could include:
    - Environment can change the appearance or health of identical twins over time.
    - High elevation can increase hemoglobin levels in humans.
    - Diet and lack of exercise can result in health conditions (e.g., heart disease, diabetes).
    - Exposure to toxins can result in health conditions (e.g., asthma, cancer).
    - Seasons can determine expression of coat color (e.g., dichromatic coat color of hares or arctic foxes)
    - Diet during development can determine the queen bee for a hive.
    - Temperature can determine the biological sex of reptiles.
    - Seasons can determine color expression in leaves of deciduous plants.
    - Environmental factors influence tropisms of plants (e.g., plants bend toward light).
    - pH can determine flower color in Hydrangeas.

Reasoning
Students use reasoning to connect the evidence and construct the explanation that the environment and genes both can affect traits.

- Diet, toxins, and environment provide signals (i.e., hormones) to cells that can change gene expression (protein production).
- DNA responds to cellular signals through gene expression.
- Gene expression (protein production) in cells can be regulated for cellular differentiation.
- Changes in protein production can affect traits.

**Note: When "describe" is referenced, any of the following descriptions could be used: written, oral, pictorial, and kinesthetic.*

Academic Language
Question/Sentence Stems that utilize academic language:

- How do genetics and the environment collectively affect _____?
- How do _____ and _____ affect _____?
- How do _____ and _____ affect each other over time?
- How can a small change to _____ have a big effect on _____?

Words to support student discourse: genes, environment, twins, disease, diet, nutrition, stress, height, gene expression, exercise, protein production, cellular differentiation, hormones, tropism

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LS.Bio.8 Understand applications of genetics and biotechnology.

LS.Bio.8.1 Analyze and interpret data to compare DNA samples.

Clarification Statement:

- Organisms within the same species have very similar DNA sequences.
- Small differences in DNA can be used to compare groups of organisms or to identify individual organisms.
    - DNA fingerprinting is a technique where DNA is isolated and restriction enzymes are used to cut DNA.
        - DNA bands are separated using gel electrophoresis.
        - Banding patterns are compared in order to identify individuals.
    - DNA sequencing examines the order of nucleotides to compare DNA or identify individuals.
        - DNA sequencing is more sensitive at detecting differences than DNA fingerprinting.

Boundary Statement:

- Students are expected to explain how DNA sequences may be used to identify species or groups of individuals sharing a trait.
    - Students are *not* expected to describe the use of SNPs (small nucleotide polymorphisms) in identifying individuals or species.
- Students are expected to analyze DNA fingerprints to identify individuals or infer relationships.
    - Students are *not* expected to conduct gel electrophoresis experiments.
    - Students are *not* expected to know the steps of gel electrophoresis.
    - Students are *not* expected to know how fragment size affects band position in a gel.
- Students are expected to examine tables comparing DNA sequences to identify organisms.

Dimension 1: Science and Engineering Practice (SEP): *Analyze and Interpret Data*
NAEP (2028 Framework)

- S12.9: Construct, analyze and/or interpret representations of small and large data sets from an investigation using tools, technologies, and/or models (e.g., computational, mathematical), including statistical analysis (descriptive statistics) and probability.
- S12.10: Analyze data to provide evidence to support or reject a model or explanation or to use to optimize a design solution relative to criteria for success.

NSTA Progression

- Analyze data using tools, technologies, and/or models (e.g., computational, mathematical) in order to make valid and

reliable scientific claims or determine an optimal design solution.

Dimension 2: Crosscutting Concepts (CCC):
Crosscutting concepts are conceptual tools used along with the SEP and DCI to help students explain and predict phenomena. They support students in making connections between disciplines and provide a context for sense-making. Teachers should encourage students to frame their thinking around the terminology of the CCC through questions* and classroom discussions. The most relevant Crosscutting Concepts may vary in light of the specific learning objectives and how you structure the topic. Choose the one(s) that best support(s) your instructional goals and help(s) students make connections across different aspects of the content.
Suggested Crosscutting Concept: (A Framework for K-12 Science Education)

- **Patterns**

**STEM Teaching Tool #41: Prompts for Integrating Crosscutting Concepts Into Assessment and Instruction*

Dimension 3: Disciplinary Core Ideas (DCI):
Benchmarks for Science Literacy
5C/H4b: The genetic information encoded in DNA molecules is virtually the same for all life forms.

What does it look like to demonstrate proficiency?

***Revised Bloom's Taxonomy*:** **Compare-** Finding similarities and differences between two or more objects, events, ideas, problems, or situations

Analyzing Data

- Students analyze data (e.g., using tables, graphs, charts, images) by the sequence of nucleotides or electrophoresis bands (DNA fingerprinting).
- Students describe* what each data set represents.

Interpreting Data
Students use the data analyses as evidence to support explanations about the following:

- Banding patterns (DNA electrophoresis) are a result of DNA sequences.
- Overall DNA sequence similarity indicates relationships (parent-child) or can identify individuals.

Organizing Data

- Students organize data (e.g., using tables, graphs and charts) by recording frequency or location of a nucleotide pattern (i.e., DNA fingerprinting bands).
- Students describe* what each data set represents.

Identifying Relationships
Students perform and use appropriate statistical analyses of data, including:
- Comparison of samples to controls or known individuals to determine identity (e.g., forensics) or similarity (e.g., probable parentage).

Interpreting Data
Students use the data analyses as evidence to support explanations about the following:
- DNA differences result in different banding patterns.
- The degree of DNA similarity indicates the degree of relatedness.
- Banding patterns may be used to identify an individual (e.g., forensics) or similarity (e.g, probable parentage).

**Note: When "describe" is referenced, any of the following descriptions could be used: written, oral, pictorial, and kinesthetic.*

Academic Language
Question/Sentence Stems that utilize academic language:
- What patterns do you observe in the data presented above in the [table, chart, graph, model output]?
- What does the pattern of data you see allow you to conclude about _____?
- Does the pattern in the data support the conclusion that _____ is related to _____? Why or why not?

Words to support student discourse: DNA, nucleotide sequence, banding pattern, relatedness, identity, electrophoresis, restriction enzyme, similarity, DNA fingerprint, DNA sequencing, forensics, parentage, probable

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LS.Bio.8.2 Obtain and communicate information that summarizes the impact of biotechnology applications on the individual, society, and the environment, including agriculture and medicine.

Clarification Statement:
- Biotechnology has applications in medicine, agriculture, and environmental science.
  - Biotechnology applications in medicine create access to diagnoses and treatments that can increase the quantity and quality of life (e.g., genetic risk for breast cancer, bacterial transformation to produce insulin, gene therapy to

treat cystic fibrosis).
    - Biotechnology applications in agriculture can increase the availability and quality of agricultural products (e.g., drought- and disease-resistance and nutrient enrichment in food production, increased production of renewable energy sources).
    - Biotechnology applications help mitigate the impact of humans on the environment (e.g., pollution reduction, restoration of species, renewable energy sources)./

Boundary Statement:

- Students are expected to conduct literature research and summarize their findings.
    - Students are responsible for summarizing the challenge addressed by biotechnology.
    - Students are responsible for identifying benefits (pros) and drawbacks (cons).
- Students are *not* responsible for an in-depth understanding of specific techniques (e.g., bacterial transformation, CRISPR).
    - Students are *not* required to know the steps for bacterial transformation or any other biotechnique. The focus should be on the value and impact of the biotechnology processes and their products.

Dimension 1: Science and Engineering Practice (SEP): *Obtain, Evaluate and Communicate Information*

NAEP (2028 Framework)

- S12.25: Evaluate scientific and/or technical information from multiple sources, assessing the evidence used by and the information on qualifications and expertise of each source.

NSTA Progression

- Critically read scientific literature adapted for classroom use to determine the central ideas or conclusions and/or to obtain scientific and/or technical information to summarize complex evidence, concepts, processes, or information presented in a text by paraphrasing them in simpler but still accurate terms.
- Communicate scientific and/or technical information or ideas (e.g. about phenomena and/or the process of development and the design and performance of a proposed process or system) in multiple formats (including orally, graphically, textually, and mathematically).

Dimension 2: Crosscutting Concepts (CCC):

Crosscutting concepts are conceptual tools used along with the SEP and DCI to help students explain and predict phenomena. They support students in making connections between disciplines and provide a context for sense-making. Teachers should encourage students to frame their thinking around the terminology of the CCC through questions* and classroom discussions. The most relevant Crosscutting Concepts may vary in light of the specific learning objectives and how you structure the topic. Choose the one(s) that best support(s) your instructional goals and help(s) students make connections across different aspects of the content.

Suggested Crosscutting Concept: (A Framework for K-12 Science Education)

- **Cause and Effect: Mechanism and Explanation**

*STEM Teaching Tool #41: Prompts for Integrating Crosscutting Concepts Into Assessment and Instruction

Dimension 3: Disciplinary Core Ideas (DCI):

A Framework for K-12 Science Education

- ETS2.B: Modern civilization depends on major technological systems, including those related to agriculture, health, water, energy, transportation, manufacturing, construction, and communications. Engineers continuously modify these technological systems by applying scientific knowledge and engineering design practices to increase benefits while decreasing costs and risks. Widespread adoption of technological innovations often depends on market forces or other societal demands, but it may also be subject to evaluation by scientists and engineers and to eventual government regulation. New technologies can have deep impacts on society and the environment, including some that were not anticipated or that may build up over time to a level that requires attention or mitigation. Analysis of costs, environmental impacts, and risks, as well as of expected benefits, is a critical aspect of decisions about technology use.

Benchmarks for Science Literacy

- 1C/H5a*: Current ethics in science hold that research involving human subjects may be conducted only with the informed consent of the subjects, even if this constraint limits some kinds of potentially important research or influences the results.
- 8F/H7: Biotechnology has contributed to health improvement in many ways, but its cost and application have led to a variety of controversial social and ethical issues.

What does it look like to demonstrate proficiency?

***Revised Bloom's Taxonomy*: Summarize-** Condensing larger information into a general theme or major point(s)

Obtaining Information

Students gather information from credible sources (e.g., literature, media, visual displays, data) about how biotechnology impacts medicine, agriculture, or the environment.

Evaluating Information

Students determine the credibility, accuracy, usefulness, and possible bias of each source of information, including:

- main ideas
- methodology
- findings and/or conclusions
- comparison among sources

Communication Style and Format

Students use various formats (e.g., oral, graphical, textual, mathematical) to communicate scientific information, including:

- an overview of the technique
- the challenge(s) it attempts to address
- effectiveness of addressing the challenge or condition
- ethical considerations
- advantages and disadvantages associated with the technique
- appropriate citations

Connections

- Students identify the impact of the technique on a condition or challenge, such as:
    - Increased production or quality of food (transgenic or genetically modified organisms - GMOs)
        - Pesticide or herbicide resistance in corn, cotton, or potatoes
        - Disease resistance in papaya or squash
        - Increased shelf life in tomatoes or apples
        - Increase nutritional value (e.g., vitamin A in bananas)
    - Illness, disease, or genetic conditions
        - Animal use in research (e.g., mouse strains that model disease states)
        - Vaccines
        - Stem cell therapies
        - Personalized medicine
        - Gene therapy
        - CRISPR
        - Biological pharmaceuticals produced by transgenic or genetically modified bacteria:
            - insulin
            - botulinum neurotoxin (botox)
            - human growth factors
    - Cloning plants, pets, livestock, or extinct organisms
    - Removal of pollution (bioremediation) and renewable energy production (biofuels or biomass)

**Note: When "describe" is referenced, any of the following descriptions could be used: written, oral, pictorial, and kinesthetic.*

Academic Language:
Question/Sentence Stems that utilize academic language:

- What caused the patterns you observed?
- How can a small change to _____ have a big effect on _____?
- What do you predict would happen if [extrapolate to a new, related situation]? How is the situation similar to or different from [the presented scenario]?

Words to support student discourse: biotechnology, bioethics, credible, GMOs, clone, CRISPR, vaccine, stem cells, transgenic

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Biological Evolution- Unity and Diversity
K-12 Vertical Alignment

Standard and Objectives:

LS.Bio.9 Understand natural selection as a mechanism for biological evolution.

LS.Bio.9.1 Analyze and interpret data to summarize how various factors such as geographic isolation, pesticide resistance, antibiotic resistance can influence natural selection.

LS.Bio.9.2 Construct an explanation to illustrate how common ancestry and biological evolution are supported by multiple lines of empirical evidence.

LS.Bio.9.3 Use models to illustrate the conditions required for natural selection, including the overproduction of offspring, inherited variation, and the struggle to survive.

LS.Bio.9.4 Construct an explanation to explain how natural selection leads to adaptations within populations.

LS.Bio.10 Analyze evolutionary relationships among organisms.

LS.Bio.10.1 Construct an explanation to illustrate how varying environmental conditions may result in: changes in the number of individuals of a species; the emergence of new species over time, or the extinction of other species.

LS.Bio.10.2 Use models (including dichotomous keys, scientific nomenclature, cladograms, phylogenetic trees) to identify organisms and exemplify relationships.

LS.Bio.9 Understand natural selection as a mechanism for biological evolution.

LS.Bio.9.1 Analyze and interpret data to summarize how various factors such as geographic isolation, pesticide resistance, antibiotic resistance can influence natural selection.

Clarification Statement:

- Emphasis is on considering how multiple factors can alter the outcomes of natural selection.
    - Geographic isolation is a mechanism that results in new species forming due to limited opportunities to reproduce (e.g., populations on islands, populations on different sides of large rivers or canyons).
    - Pesticide resistance occurs when a pesticide kills some individuals in a population (e.g., herbicide fails to kill all of the weeds along a fence). Surviving individuals have favorable conditions for reproduction, resulting in more pesticide-resistant individuals and reduced effectiveness of the pesticide.
    - Antibiotic resistance occurs when bacteria become less susceptible to the antibiotics that are designed to kill them. The result is the reproduction of antibiotic-resistant bacteria.
    - Antifungal resistance occurs when fungi become less susceptible to medications that are designed to treat fungal infections. The result is reproduction of antifungal-resistance fungi.

Boundary Statement:

- Students are *not* expected to know mechanisms of evolution other than natural selection (e.g., genetic drift, gene flow through migration, coevolution, non-random mating).

Dimension 1: Science and Engineering Practice (SEP): *Analyze and Interpret Data*
NAEP (2028 Framework)

- S12.9: Construct, analyze and/or interpret representations of small and large data sets from an investigation using tools, technologies, and/or models (e.g., computational, mathematical), including statistical analysis (descriptive statistics) and probability.
- S12.10: Analyze data to provide evidence to support or reject a model or explanation or to optimize a design solution relative to criteria for success.

NSTA Progression

- Analyze data using tools, technologies, and/or models (e.g., computational, mathematical) in order to make valid and reliable scientific claims or determine an optimal design solution.

Dimension 2: Crosscutting Concepts (CCC):
Crosscutting concepts are conceptual tools used along with the SEP and DCI to help students explain and predict phenomena. They support students in making connections between disciplines and provide a context for sense-making. Teachers should encourage students to frame their thinking around the terminology of the CCC through questions* and classroom discussions. The most relevant Crosscutting Concepts may vary in light of the specific learning objectives and how you structure the topic.

Choose the one(s) that best support(s) your instructional goals and help(s) students make connections across different aspects of the content.

Suggested Crosscutting Concept: (A Framework for K-12 Science Education)

- **Cause and Effect: Mechanism and Explanation**

**STEM Teaching Tool #41: Prompts for Integrating Crosscutting Concepts Into Assessment and Instruction*

Dimension 3: Disciplinary Core Ideas (DCI):

A Framework for K-12 Science Education

- LS4.B: Genetic variation in a species results in individuals with a range of traits. In any particular environment individuals with particular traits may be more likely than others to survive and produce offspring. This process is called *natural selection* and may lead to the predominance of certain inherited traits in a population and the suppression of others. Natural selection occurs only if there is variation in the genetic information within a population that is expressed in traits that lead to differences in survival and reproductive ability among individuals under specific environmental conditions. If the trait differences do not affect reproductive success, then natural selection will not factor one trait over others.
- LS4.C: Changes in the physical environment, whether naturally occurring or human induced, have thus contributed to the expansion of some species, the emergence of new distinct species as populations diverge under different conditions, and the decline– and sometimes the extinction– of some species. Species become extinct because they can no longer survive and reproduce in their altered environment. If members cannot adjust to change that is too fast or too drastic, the opportunity for the species' evolution is lost.

What does it look like to demonstrate proficiency?

Revised Bloom's Taxonomy: Summarize- Condensing larger information into a general theme or major point(s)

Organizing Data

- Students organize data (e.g., using tables, graphs and charts) by the traits of organisms over time when a new factor (e.g., antibiotic resistance, geographic isolation, pesticide resistance) is introduced to a population.
- Students describe* what each data set represents.

Identifying Relationships

Students perform and use appropriate statistical analyses of data, including:

- quantifying organisms with various traits (e.g., antibiotic resistance) after a new factor (e.g., a new antibiotic) is introduced
- determining the distribution of traits over time

Interpreting Data
Students use the data analyses as evidence to support explanations about the following:

- Natural selection is a mechanism that causes populations to adapt and evolve through differential reproductive success.
- Organisms best suited to an environment are more likely to survive, reproduce, and pass favorable traits to offspring.
    - Reproduction rates may be affected by expression of a new trait (e.g., antibiotic resistance, pesticide resistance, traits observed after geographic isolation event).
- Favorable traits will increase in frequency over time.

Academic Language
Question/Sentence Stems that utilize academic language:

- What caused the patterns you observed?
- How do you know that _____ caused _____?
- If the data shows _____ (e.g., frequency of a trait), will it always show _____ (e.g., the same frequency)? Why or why not?
- What do you predict would happen to frequency if a trait is no longer favorable?
- Which trait do you predict will (increase/decrease) in frequency in _____ conditions?
- How does _____ condition (e.g., decreased rainfall) affect _____ (e.g., reproduction rates of a given plant) over time?

Words to support student discourse: geographic isolation, antibiotic resistance, pesticide resistance, natural selection, evolve (evolution), species, trait, beneficial, survive, reproduction rate, frequency, distribution, mutation

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LS.Bio.9.2 Construct an explanation to illustrate how common ancestry and biological evolution are supported by multiple lines of empirical evidence.

Clarification Statement:

- Lines of empirical evidence could include:
    - molecular biology (e.g., DNA sequences, genes, proteins)
    - embryology
    - comparative anatomy (e.g., homologous structures, vestigial structures)*
    - fossil record*

**Note: previously taught in 8th grade science*

Boundary Statement:
- Students are expected to conceptually explain the evidence for biological evolution.
- Students are *not* expected to recall lines of evidence for specific species.

Dimension 1: Science and Engineering Practice (SEP): *Construct an Explanation*
NAEP (2028 Framework)
- S12.18: Construct or revise an explanation that uses a chain of cause and effect or evidence-based associations between factors to account for the qualitative or quantitative relationships between variables in a phenomenon.

NSTA Progression
- Construct and revise an explanation based on valid and reliable evidence obtained from a variety of sources (including students' own investigations, models, theories, simulations, peer review) and the assumption that theories and laws that describe the natural world operate today as they did in the past and will continue to do so in the future.
- Apply scientific ideas, principles, and/or evidence to provide an explanation of phenomena and solve design problems, taking into account possible unanticipated effects.

Dimension 2: Crosscutting Concepts (CCC):
Crosscutting concepts are conceptual tools used along with the SEP and DCI to help students explain and predict phenomena. They support students in making connections between disciplines and provide a context for sense-making. Teachers should encourage students to frame their thinking around the terminology of the CCC through questions* and classroom discussions. The most relevant Crosscutting Concepts may vary in light of the specific learning objectives and how you structure the topic. Choose the one(s) that best support(s) your instructional goals and help(s) students make connections across different aspects of the content.
Suggested Crosscutting Concept: (A Framework for K-12 Science Education)
- **Patterns**

**STEM Teaching Tool #41: Prompts for Integrating Crosscutting Concepts Into Assessment and Instruction*

Dimension 3: Disciplinary Core Ideas (DCI):
A Framework for K-12 Science Education
- LS4.A: Genetic information provides evidence of evolution. DNA sequences vary among species, but there are many overlaps; in fact, the ongoing branching that produces multiple lines of descent can be inferred by comparing the DNA sequences of different organisms. Such information is also derivable from the similarities and differences in amino acid sequences and from anatomical and embryological evidence.

Benchmarks for Science Literacy

- 5A/H2*: The degree of relatedness between organisms or species can be estimated from the similarity of their DNA sequences, which often closely match their classification based on anatomical similarities.
- 5AH3**(SFAA): Similar patterns of development and internal anatomy suggest relatedness among organisms.
- 5F/H7*: Modern ideas about evolution and heredity provide a scientific explanation from the history of life on Earth as depicted in the fossil record and in the similarities evident within the diversity of existing organisms.
- 5F/H2: Molecular evidence substantiates the anatomical evidence for evolution and provides additional detail about the sequence in which various lines of descent branched off from one another.

NAEP (2028 Framework)

- L12.17: Genetic information provides evidence of evolution. DNA sequences vary among species, but there are many overlaps. Such information is also derivable from the similarities and differences in amino acid sequences and from anatomical and embryological evidence.

What does it look like to demonstrate proficiency?

***Revised Bloom's Taxonomy*: Illustrate-** Finding a specific example or illustration of a concept or principle

Constructing Explanations

Students construct an explanation that includes:

- The relatedness of species, as evidenced in similarities in DNA and other biomolecules, embryonic development, the fossil record, and anatomical structures, is the result of common ancestry.

Evidence

Students identify and describe* the evidence to construct the explanation, including:

- Similarities in DNA sequences and amino acid sequences can be used to illustrate common ancestry.
- Sharing the same anatomical structures suggests common ancestry.
    - Vestigial structures exist in organisms, but are an artifact of common ancestry.
    - Embryos of different species can have similarities that are not visible when the organisms are fully formed. Many of these similarities are homologous structures. These provide evidence that the species are related through common ancestry.
- Patterns in the fossil record (e.g., presence, location, and inferences possible in lines of evolutionary descent for multiple specimens) suggest relatedness.

Reasoning

Students use reasoning to connect evidence and construct an explanation about the relatedness among organisms. Students describe* the following chain of reasoning in their explanation:

- connections between each line of evidence and the claim of common ancestry and biological evolution.
- communicate that observed patterns (e.g., DNA sequences, embryological development, fossil records) provide evidence for causal relationships relating to biological evolution and common ancestry.

Revising the explanation

Given new data or information, students revise their explanation and justify the revision.

- When presented with a range of evidence obtained from a variety of sources (e.g., empirical investigations, models, theories, simulations), describe how the evidence can be used to support common ancestry and biological evolution.

**Note: When "describe" is referenced, any of the following descriptions could be used: written, oral, pictorial, and kinesthetic.*

Academic Language

Question/Sentence Stems that utilize academic language:

- Based on the evidence, which organisms are more closely related? How do you know?
- I/We can observe (notice) the pattern of _____ presented in the data collected.
- I/We can observe (notice) the pattern of _____in the data presented.
- The pattern seen in the collected data allows me/us to conclude (know) that _____.
- The observed pattern supports the conclusion that _____ is caused by _____ because _____.
- The pattern of _____ is changing over time.
- The following predictions can be made about _____ when using the pattern of _____ found in the data.

Words to support student discourse: evolution, DNA sequences, amino acid sequences, anatomical structures, fossil record, embryological development, common ancestry, comparative anatomy, species, homologous structures, vestigial structures

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LS.Bio.9.3 Use models to illustrate the conditions required for natural selection, including the overproduction of offspring, inherited variation, and the struggle to survive.

Clarification Statement:

- Models should demonstrate how factors can influence survival and reproduction within a population or species.
  - Factors may include: overproduction of offspring, inherited variation, limited resources, and struggle to survive.

Boundary Statement:

- Students are *not* expected to recall examples of specific species.
- Adaptations are covered in LS.Bio.9.4.

Dimension 1: Science and Engineering Practice (SEP): *Develop and Use Models*
NAEP (2028 Framework)

- S12.16: Develop, use, and/or revise a model that includes mathematical relationships (including both visible and invisible quantities) to describe, explain, and/or predict phenomena or to test a proposed design solution.

NSTA Progression

- Develop a complex model that allows for manipulation and testing of a proposed process or system.
- Develop, revise, and/or use a model based on evidence to illustrate and/or predict the relationships between systems or between components of a system.

Dimension 2: Crosscutting Concepts (CCC):
Crosscutting concepts are conceptual tools used along with the SEP and DCI to help students explain and predict phenomena. They support students in making connections between disciplines and provide a context for sense-making. Teachers should encourage students to frame their thinking around the terminology of the CCC through questions* and classroom discussions. The most relevant Crosscutting Concepts may vary in light of the specific learning objectives and how you structure the topic. Choose the one(s) that best support(s) your instructional goals and help(s) students make connections across different aspects of the content.
Suggested Crosscutting Concept(s): (A Framework for K-12 Science Education)

- **Patterns**
- **Cause and Effect**

**STEM Teaching Tool #41: Prompts for Integrating Crosscutting Concepts Into Assessment and Instruction*

Dimension 3: Disciplinary Core Ideas (DCI):
A Framework for K-12 Science Education

- LS4.B: Natural selection occurs only if there is both (1) variation in the genetic information between organisms in a population and (2) variation in the expression of that genetic information- that is, trait variation- that leads to differences in performance among individuals. The traits that positively affect survival are more likely to be reproduced and thus are more common in the population.
- LS4.C: Natural selection is the result of four factors: (1) the potential for a species to increase in number, (2) the genetic variation of individuals in a species due to mutation and sexual reproduction, (3) competition for an environment's limited supply of the resources that individuals need in order to survive and reproduce, and (4) the ensuing proliferation of those organisms that are better able to survive and reproduce in that environment.

Benchmarks for Science Education

- 5F/H3*: Natural selection provides the following mechanism for evolution: Some variation in heritable characteristics exists within every species; some of these characteristics give individuals an advantage over others in surviving and reproducing;

and the advantaged offspring, in turn, are more likely than others to survive and reproduce. As a result, the proportion of individuals that have advantageous characteristics will increase.

- 5F/H4: Heritable characteristics influence how likely an organism is to survive and reproduce.
- 5F/H6a: Natural selection leads to organisms that are well-suited for survival in particular environments.
- 5F/H6b: Chance alone can result in the persistence of some heritable characteristics having no survival or reproductive advantage or disadvantage for the organism.

5F/H10**(SFAA): The continuing operation of natural selection on new characteristics and in diverse changing environments, over and over again for millions of years, has produced a succession of diverse new species.

NAEP (2028 Framework)

- L12.18: Evolution by natural selection results from the interaction of four factors: (a) the potential for a species to increase in number, (b) the genetic variation of individuals in a species due to mutation and sexual reproduction, (c) competition for an environment's limited supply of the resources that individuals need in order to survive and reproduce, and (d) the ensuing proliferation of those organisms that are better able to survive and reproduce in that environment, passing on those traits to offspring. Fitness, as measured by survival and reproduction rates, may be altered if changes in the physical environment, whether naturally occurring or human induced, take place.

What does it look like to demonstrate proficiency?

***Revised Bloom's Taxonomy*: Illustrate-** Finding a specific example or illustration of a concept or principle

Components of the model

From the given model, students identify and describe* the components of the model including:

- Environments have limited resources.
- Individuals in a species have genetic variation (through mutations and sexual reproduction) that is passed on to their offspring.
    - Species produce more offspring than environments can support.
    - As a species grows in number, competition for limited resources can arise.
    - Individuals can have specific traits that give them a competitive advantage over other individuals in the species.
    - Evidence of variation can be seen in survival and reproduction rates.
- Specific biotic and abiotic differences in ecosystems (e.g., ranges of seasonal temperature, long-term climate change, acidity, light, geographic barriers, evolution of other organisms) can lead to change in survival rates of individuals of a population.

Relationships

Students identify the following relationship between components of the given model:

- Overproduction of offspring can create conditions in which organisms must compete for limited resources.
- Inherited variation in an organism can provide an advantage (or disadvantage) that impacts the organism's ability to compete for limited resources, survive, and reproduce.
- Organisms with more favorable traits for the given conditions are more likely to survive, reproduce, and pass these favorable traits to offspring.

Connections

Students use the given model to:

- *Describe the factors that create a struggle for survival (e.g., limited resources: food, water, shelter, healthy mates; large populations compete for similar resources).
- Recognize that the ability of an organism to survive and reproduce is dependent upon the environment in which they live. (e.g., When in a snowy environment, an organism that can camouflage in the snow has an advantage over an organism that cannot).
- Use a model to make predictions about changes in populations (e.g., if there is a change in the environment, organisms with favorable traits have an advantage for survival and reproduction).

**Note: When "describe" is referenced, any of the following descriptions could be used: written, oral, pictorial, and kinesthetic.*

Academic Language

Questions/Sentence Stems that utilize academic language:

- What would you predict in [present new situation involving same mechanism] would happen? How is the situation similar to or different from [the presented scenario]?
- I/We can observe (notice) the pattern of _____ in the data presented.
- The pattern observed in the data allows me/us to conclude (know) that _____.
- What caused the patterns you observed?
- How do _____ and _____ affect _____?

Words to support student discourse: natural selection, reproduction, overpopulation, competition, resources, trait, advantage, disadvantage, offspring, 'fitness', environmental conditions, variation, mutation, inherited

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LS.Bio.9.4 Construct an explanation to explain how natural selection leads to adaptations within populations.

Clarification Statement:

- Adaptations can include an organism's behaviors, morphology, and/or physiology.
- Similar environments may select for similar traits/adaptations, among more distantly related groups of organisms.

Boundary Statement:

- Students are expected to be familiar with reviewing changes in proportion (more/less) of traits in a population over time.
    - Students are *not* expected to calculate allele frequencies.
- Students are *not* expected to identify types of selection (disruptive selection, stabilizing selection, directional selection).
- Students are *not* expected to recall specific examples of adaptations or classify types of adaptations.
- Students are *not* expected to explain the process of convergent evolution, but should be able recognize examples of analogous structures.

Dimension 1: Science and Engineering Practice (SEP): *Construct an Explanation*

NAEP (2028 Framework)

- S12.18: Construct or revise an explanation that uses a chain of cause and effect or evidence-based associations between factors to account for the qualitative or quantitative relationships between variables in a phenomenon.

NSTA Progression

- Construct and revise an explanation based on valid and reliable evidence obtained from a variety of sources (including students' own investigations, models, theories, simulations, peer review) and the assumption that theories and laws that describe the natural world operate today as they did in the past and will continue to do so in the future.
- Apply scientific ideas, principles, and/or evidence to provide an explanation of phenomena and solve design problems, taking into account possible unanticipated effects.

Dimension 2: Crosscutting Concepts (CCC):

Crosscutting concepts are conceptual tools used along with the SEP and DCI to help students explain and predict phenomena. They support students in making connections between disciplines and provide a context for sense-making. Teachers should encourage students to frame their thinking around the terminology of the CCC through questions* and classroom discussions. The most relevant Crosscutting Concepts may vary in light of the specific learning objectives and how you structure the topic. Choose the one(s) that best support(s) your instructional goals and help(s) students make connections across different aspects of the content.

Suggested Crosscutting Concept: (A Framework for K-12 Science Education)

- **Cause and Effect: Mechanism and Explanation**

**STEM Teaching Tool #41: Prompts for Integrating Crosscutting Concepts Into Assessment and Instruction*

Dimension 3: Disciplinary Core Ideas (DCI):
A Framework for K-12 Science Education

- LS4.C: Natural selection is the result of four factors: (1) the potential for a species to increase in number, (2) the genetic variation of individuals in a species due to mutation and sexual reproduction, (3) competition for an environment's limited supply of the resources that individuals need in order to survive and reproduce, and (4) the ensuing proliferation of those organisms that are better able to survive and reproduce in that environment. Natural selection leads to adaptation- that is, to a population dominated by organisms that are anatomically, behaviorally, and physiologically well suited to survive and reproduce in a specific environment. That is, the differential survival and reproduction of organisms in a population that have an advantageous heritable trait leads to an increase in the proportion of individuals in future generations that have that trait and to a decrease in the proportion of individuals that do not. Adaptation also means that the distribution of traits in a population can change when conditions change.

Benchmarks for Science Literacy

- 5F/H6a: Natural selection leads to organisms that are well-suited for survival in particular environments.
- 5F/H6b: Chance alone can result in the persistence of some heritable characteristics having no survival or reproductive advantage or disadvantage for the organism.
  5F/H10**(SFAA): The continuing operation of natural selection on new characteristics and in diverse changing environments, over and over again for millions of years, has produced a succession of diverse new species.

NAEP (2028 Framework)

- L12.18: Evolution by natural selection results from the interaction of four factors: (a) the potential for a species to increase in number, (b) the genetic variation of individuals in a species due to mutation and sexual reproduction, (c) competition for an environment's limited supply of the resources that individuals need in order to survive and reproduce, and (d) the ensuing proliferation of those organisms that are better able to survive and reproduce in that environment, passing on those traits to offspring. Fitness, as measured by survival and reproduction rates, may be altered if changes in the physical environment, whether naturally occurring or human induced, take place.

What does it look like to demonstrate proficiency?

***Revised Bloom's Taxonomy*:** **Explain-** Constructing a cause-and-effect model of a system

Constructing Explanations
Students construct an explanation that identifies the cause-and-effect relationship between natural selection and adaptations, including:

- How natural selection provides a mechanism for species to adapt to changes in their environment.
- Use of evidence to describe the relationship between genetic variation, the selection of traits that provide advantages, and the evolution of populations that express the traits.

- Describe how traits present within a species can change over time as new factors are introduced to the environment.

Evidence
Students identify and describe* the evidence to construct the explanation, including:

- Individuals in a species have genetic variation (through mutations and sexual reproduction) that is passed on to their offspring.
- Organisms with different traits have different relative survival rates in specific environments.
- Changes in a population with environmental changes (refer to L.S.Bio.9.3).
- Traits that give organisms an advantage in a population, which may include:
    - Examples of behavioral adaptations: suckling, taxes/taxis, migration, estivation, hibernation, habituation, imprinting, classical conditioning, and trial and error learning
    - Examples of reproductive adaptations: sexual vs asexual reproduction, eggs, seeds, spores, placental, types of fertilization
    - Examples of structural adaptations: movement, camouflage, transport and excretion mechanisms, respiration, nutrition

Reasoning
Students use reasoning to connect evidence and construct an explanation about adaptation as a product of natural selection. Students describe* the following chain of reasoning in their explanation:

- Genetic variation can lead to variation of expressed traits in individuals in a population.
- Individuals with traits that give advantages can survive and reproduce at higher rates than individuals without the traits.
- Individuals that survive and reproduce at a higher rate will provide their specific genetic variations to a greater proportion of individuals in the next generation.

**Note: When "describe" is referenced, any of the following descriptions could be used: written, oral, pictorial, and kinesthetic.*

Academic Language
Questions/Sentence Stems that utilize academic language:

- What traits seem to be beneficial based on the data presented in the [table, chart, graph, model, simulation output]?
- What evidence presented in the scenario supports the claim that environmental conditions cause species to change?
- When time is a variable: How is _____ changing over time?
- By looking at patterns in the data, I/we determined that _____ caused _____.
- If _____ happens, I/we predict that _____ will occur.
- In order to conclude that _____ caused _____, the following evidence is needed _____.

Words to support student discourse: natural selection, evolution, species, speciation, heritable, genetic variation, mutation, sexual reproduction, competition, limited resources, adaptation, beneficial/favorable, selective pressure, environment, generation, analogous structures

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LS.Bio.10 Analyze evolutionary relationships among organisms.

LS.Bio.10.1 Construct an explanation to illustrate how varying environmental conditions may result in: changes in the number of individuals of a species; the emergence of new species over time, or the extinction of other species.

Clarification Statement:

- Emphasis is on examining how changes to the environment (e.g., deforestation, overfishing, application of fertilizers, drought, flood, and the rate of change of the environment) affects populations and species.
- Natural selection acts at the level of populations. Populations are impacted by the local environment, and may change in size, experience speciation, or extinction.
- Change in environmental conditions can select for adaptations that may result in the evolution of a new species or extinction.

Boundary Statement:

- Students are *not* expected to calculate gene frequency.
- Students are *not* expected to explain changes in species in terms of punctuated equilibrium, adaptive radiation, convergent evolution, and divergent evolution.

Dimension 1: Science and Engineering Practice (SEP): *Construct an Explanation*
NAEP (2028 Framework)

- S12.18: Construct or revise an explanation that uses a chain of cause and effect or evidence-based associations between factors to account for the qualitative or quantitative relationships between variables in a phenomenon.

NSTA Progression

- Construct and revise an explanation based on valid and reliable evidence obtained from a variety of sources (including students' own investigations, models, theories, simulations, peer review) and the assumption that theories and laws that describe the natural world operate today as they did in the past and will continue to do so in the future.
- Apply scientific ideas, principles, and/or evidence to provide an explanation of phenomena and solve design problems, taking into account possible unanticipated effects.

Dimension 2: Crosscutting Concepts (CCC):
Crosscutting concepts are conceptual tools used along with the SEP and DCI to help students explain and predict phenomena. They support students in making connections between disciplines and provide a context for sense-making. Teachers should encourage students to frame their thinking around the terminology of the CCC through questions* and classroom discussions. The most relevant Crosscutting Concepts may vary in light of the specific learning objectives and how you structure the topic. Choose the one(s) that best support(s) your instructional goals and help(s) students make connections across different aspects of the content.

Suggested Crosscutting Concept: (A Framework for K-12 Science Education)

- **Cause and Effect: Mechanism and Explanation**

**STEM Teaching Tool #41: Prompts for Integrating Crosscutting Concepts Into Assessment and Instruction*

Dimension 3: Disciplinary Core Ideas (DCI):
A Framework for K-12 Science Education

- LS4.C: Changes in the physical environment, whether naturally occurring or human induced, have thus contributed to the expansion of some species, the emergence of new distinct species as populations diverge under different conditions, and the decline– and sometimes the extinction– of some species. Species become extinct because they can no longer survive and reproduce in their altered environment. If members cannot adjust to change that is too fast or too drastic, the opportunity for the species' evolution is lost.

NAEP (2028 Framework)

- L12.18: Evolution by natural selection results from the interaction of four factors: (a) the potential for a species to increase in number, (b) the genetic variation of individuals in a species due to mutation and sexual reproduction, (c) competition for an environment's limited supply of the resources that individuals need in order to survive and reproduce, and (d) the ensuing proliferation of those organisms that are better able to survive and reproduce in that environment, passing on those traits to offspring. Fitness, as measured by survival and reproduction rates, may be altered if changes in the physical environment, whether naturally occurring or human induced, take place.

What does it look like to demonstrate proficiency?

Revised Bloom's Taxonomy: **Illustrate-** Finding a specific example or illustration of a concept or principle

Constructing explanations
Students construct an explanation that identifies the cause-and-effect relationship/or that illustrates:

- Changes in environmental conditions (selective pressures) may result in changes in the number of individuals of a species, emergence of new species, or extinction of species over time.

Evidence
Students identify and describe* the evidence to construct the explanation, including:

- Data indicating changes in species over time in:
  - The number of individuals in each species;
  - The number of species in an environment; and
  - Traits in species (e.g., beak length, bird songs, mating behaviors)
- Environmental factors that can determine the ability of individuals in a species to survive and reproduce.
  - Examples of environmental conditions may include forest fire, deforestation, application of fertilizers, drought, flood, natural disasters, rate of changes in climate conditions
- Example data and phenomenon may include:
  - The Kaibab squirrels inhabit the North Rim and the Abert squirrels inhabit the South Rim.
  - The shores of the Colorado River around Moab were filled with an Asian plant species called *tamarisk* which has many adaptations suited for this local environment. As the *tamarisk* grew, the native willows and cottonwoods decreased in numbers.
  - Diverse habitats of the Galapagos Islands support an array of closely related but distinct species of finch (Darwin's or Galapagos finches).

Reasoning
Students use reasoning to connect evidence and construct an explanation about changing population size, speciation, or extinction. Students describe* the following chain of reasoning in their explanation:

- Populations are genetically variable due to mutations and genetic recombination (LS.Bio.6.2).
- Over many generations, groups of individuals with particular traits that enable them to survive and reproduce in distinct environments using distinct resources can evolve into a different species.
- Changing environments select for adaptations which can result in the change in number of individuals of a species, emergence of a new species (speciation), or extinction of a species.
  - Geographic areas with varying environmental conditions and a variety of niches may result in speciation.
  - Geographic isolation may result in speciation.
  - When environmental change is too fast or drastic, species become extinct because they can no longer survive and reproduce in their altered environment.
- Genetically diverse populations are more resilient to changing environmental conditions.
- Examples with reasoning may include:
  - A rapidly changing climate is coupled with large-scale, decreasing population sizes and high rates of extinction.
    - Polar bears rely upon ice floes for hunting. With diminishing ice coverage in Arctic areas, wild polar bears are predicted to become extinct.

- The Kaibab squirrels inhabit the North Rim and the Abert squirrels inhabit the South Rim. The two species diverged due to geographic isolation.
- Diverse habitats of the Galapagos Islands support an array of closely related but distinct species of finch (Darwin's or Galapagos finches). Each species is uniquely adapted to its island environment and food sources, as illustrated by differences in beak size and shape.
- The shores of the Colorado River around Moab were filled with an Asian plant species called *tamarisk* which has many adaptations suited for this local environment. As the tamarisk grew, the native willows and cottonwoods were not able to compete and decreased in numbers.

**Note: When "describe" is referenced, any of the following descriptions could be used: written, oral, pictorial, and kinesthetic.*

Academic Language
Sentence stems that utilize academic language:

- How might different populations of organisms be affected by a sudden change in the environment?
- Why might many species become extinct at the same time?
- Explain how changing environmental conditions impacts different populations.
- By looking at patterns in the data, I determined that _____ caused _____.
- If _____ happens, I predict that _____ will occur.
- The evidence _____ presented in the scenario supports the claim that _____ causes _____.
- What evidence do we need to support a claim about changes in population size?

Words to support student discourse: emergence, environmental change, stability, disturbance, extinction, speciation, adaptation, evolution, frequency, gene, advantageous, detrimental, population size, genetic variation, selective pressure, niche, invasive species

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LS.Bio.10.2 Use models (including dichotomous keys, scientific nomenclature, cladograms, phylogenetic trees) to identify organisms and exemplify relationships.

Clarification Statement:

- The changing nature of classification is based on new discoveries and research (i.e., DNA technology).
- Levels of classification provide evidence of evolutionary relationships (e.g., organisms with more levels of classification in common are more closely related).
- Emphasis is on classifying organisms using a dichotomous key.
- Emphasis is on comparing organisms on a cladogram and phylogenetic tree in terms of relatedness and time of

appearance in geologic history.

Boundary Statement:

- Students are expected to be able to use a dichotomous key to identify a species.
- Students are expected to infer relationships between organisms using phylogenetic trees and cladograms.
- Students are *not* expected to construct dichotomous keys, phylogenetic trees, or cladograms.
- Students are *not* expected to be familiar with specific historical classification systems (e.g., systems developed by Aristotle, Linneaus, Haeckel).
- Students are *not* expected to recall specific characteristics of each level of classification: kingdom, phylum, class, order, family, genus, species.

Dimension 1: Science and Engineering Practice (SEP): *Develop and Use Models*
NAEP (2028 Framework)

- S12.16: Develop, use, and/or revise a model that includes mathematical relationships (including both visible and invisible quantities) to describe, explain, and/or predict phenomena or to test a proposed design solution.

NSTA Progression

- Develop a complex model that allows for manipulation and testing of a proposed process or system.
- Develop, revise, and/or use a model based on evidence to illustrate and/or predict the relationships between systems or between components of a system.

Dimension 2: Crosscutting Concepts (CCC):
Crosscutting concepts are conceptual tools used along with the SEP and DCI to help students explain and predict phenomena. They support students in making connections between disciplines and provide a context for sense-making. Teachers should encourage students to frame their thinking around the terminology of the CCC through questions* and classroom discussions. The most relevant Crosscutting Concepts may vary in light of the specific learning objectives and how you structure the topic. Choose the one(s) that best support(s) your instructional goals and help(s) students make connections across different aspects of the content.
Suggested Crosscutting Concept: (A Framework for K-12 Science Education)

- **Patterns**

**STEM Teaching Tool #41: Prompts for Integrating Crosscutting Concepts Into Assessment and Instruction*

Dimension 3: Disciplinary Core Ideas (DCI):
A Framework for K-12 Science Education

- LS4.A: Genetic information provides evidence of evolution. DNA sequences vary among species, but there are many overlaps; in fact, the ongoing branching that produces multiple lines of descent can be inferred by comparing the DNA sequences of different organisms. Such information is also derivable from the similarities and differences in amino acid sequences and from anatomical and embryological evidence.

Benchmarks for Science Literacy

- 5A/H5**(SFAA): A classification system is a framework created by scientists for describing the vast diversity of organisms, indicating the degree of relatedness between organisms, and framing research questions.

NAEP (2028 Framework)

- L12.17: Genetic information provides evidence of evolution. DNA sequences vary among species, but there are many overlaps. Such information is also derivable from the similarities and differences in amino acid sequences and from anatomical and embryological evidence.

What does it look like to demonstrate proficiency?

***Revised Bloom's Taxonomy*: Exemplify-** Finding a specific example or illustration of a concept or principle

Components of the model

From the given model, students identify and describe* the components of the model in order to:

- Illustrate evolutionary relationships between organisms, including:
  - The scientific name of an organism is Genus (capitalized) and species (lowercase), in italics (e.g., *Homo sapiens or H. sapiens*).
  - Characteristics can be shared among species, or unique to specific species.
  - Branch lengths on a phylogenetic tree may represent the amount of time since organisms shared a common ancestor.
  - A dichotomous key shows characteristics that are present or absent within a species.
  - Cladograms are organized by shared physical traits or genetic information.

Relationships

Students identify the following relationship between components of the given model:

- Organisms at the ends of the lines (tips of phylogenetic tree) represent descendent groups or species.
- Nodes or connection points with the phylogenetic tree or cladogram represent common ancestors.
- Cladograms and phylogenetic trees are functionally similar.
  - Cladograms do not indicate time or the amount of difference between groups.
  - Phylogenetic trees often indicate time spans between branching points.
- The organism at the base of the phylogenetic tree or cladogram is the most distantly related.

- Unique characteristics distinguish among species in a dichotomous key.

Connections

Students use the given model to illustrate:

- The more closely related two species are, the more traits they share.
- In phylogenetic trees and cladograms, organisms that share the most nodes are more closely related than organisms that share fewer nodes.
- Different characteristics or traits may be used to construct phylogenetic trees and cladograms.
- Molecular evidence (e.g., DNA sequences) may result in different representations of relationships between organisms.
- Multiple lines of evidence provide more robust support of evolutionary relationships.

**Note: When "describe" is referenced, any of the following descriptions could be used: written, oral, pictorial, and kinesthetic.*

Academic Language

Sentence stems that utilize academic language:

- What is one way you could classify or group these _____, to create groups that are similar to each other? Describe the attributes (characteristics) you are using to classify the _____.
- What patterns do you observe in the data presented in the phylogenetic tree or cladogram?
- What does the pattern of data you see allow you to conclude about relationships between organisms?
- Does the pattern in the data support the conclusion that _____ is related to _____? Why or why not?

Words to support student discourse: dichotomous key, scientific nomenclature, genus, species, cladogram, phylogenetic tree, relationship, trait, (common) ancestor, clade, node, molecular evidence, evidence, physical traits, DNA sequences, genes, proteins

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